How Old is Old?

When did the earth form? When did life begin? When did humans and the other primates first appear? Reasonably accurate scientific answers to these questions did not develop until the 1960's and 1970's when new radiometric dating techniques were invented that could date samples that are billions of years old. However, before the 1960's, scholars in many cultures tried to estimate the age of the earth and of life.

In the past, estimates often were based on counts of generations of people in sacred texts. **Manetho**, an ancient Egyptian historian, listed all of the dynasties of pharaohs and gods that reigned down to his time (3rd century B.C.). This made the earth about 38,000 years old (from our time). In the early 17th century A.D., Archbishop **James Ussher** of Armagh, Ireland accepted the Judeo-Christian Old Testament as being literally true and subsequently determined the age of the earth by counting biblical generations and adding their time to modern recorded history. With this method, he calculated that the creation was in 4004 B.C. on October 23 (about 6,000 years ago).

James Ussher
1581-1656

Edmond Halley F.R.S.
1656-1742

With the rapid growth of European scientific knowledge, largely beginning in the late 17th century A.D., it became increasingly clear that the earth must be much more than a few thousand years old. Some scientists abandoned the theological approach and began to devise methods for determining the age by measuring natural phenomena. In 1691, the British astronomer and mathematician **Edmond Halley** proposed that if the original oceans were fresh water, one could calculate the minimum age of the earth by dividing the total amount of salt now present in the oceans by the amount added each year from the world's rivers and streams. While he actually did not have the full necessary data available, Halley used this approach to conclude that the earth is minimally 100,000,000 years old.

In 1785, the Scottish geologist **James Hutton** proposed that different layers of rock came from specific periods of geologic time. Further, he observed that the layers that were deeper down were older. In 1799, the English canal and mine engineer **William "Strata" Smith** expanded on this idea of geologic time by dividing sedimentary rock layers into 6 main divisions based, in part, on the fossil evidence of life that they contained:

William Smith
1769-1839

Geologic Era	Fossil Forms Present
Cenozoic	recent life forms (age of mammals)
Mesozoic	middle life forms (age of reptiles)
Paleozoic	ancient life forms
Proterozoic	early life forms
Archaeozoic	beginning life forms
Azoic	no life forms

These main divisions, or eras, proposed by William Smith became the basic framework for the geologic time scale of the earth that we still use today. Smith also created the first detailed geologic map of England. Since this was the first map of its kind, he is now thought of as the father of geology.

Charles Lyell
1797-1875

By the mid 19th century, some geologists were estimating the amount of time for the successive changes in animal species found as fossils in the sedimentary rock layers identified by William Smith. The English geologist **Charles Lyell** used this approach in 1867 to estimate that life had been on earth for about 240,000,000 years. This estimate was made 8 years after **Charles Darwin** published his book *On the Origin of Species*, which described how natural selection can result in the evolution of new species.

Charles Darwin
1809-1882

Despite their revolutionary implications, these and other early scientific estimates for the age of the earth and of life were, in fact, far too small. We now know that the earth is approximately 4.54 billion years old and that there have been living things on our planet for at least 3.5 billion years.

Modern Methods of Dating the Earth

Modern methods of dating the earth and the major events in the evolution of life depend on understanding radioactive decay processes. Certain radioactive isotopes in rocks are the driving mechanisms for reliable "atomic clocks." For instance, uranium-238 decays through several steps into lead-206. The rate at which this occurs is fixed by the uranium-238 half-life of approximately 4.5 billion years. In 1905, the American chemist **Bertram Boltwood** realized that the age of an ancient rock could be determined by carefully measuring the relative amount of these two isotopes in a sample. By 1907, he had dated the oldest rocks that he could find with this method. Based on this work, he concluded that the earth must be at least 2 billion years old.

By the early 1960's, the decay rates of many other elements had been discovered and were beginning to be used for radiometric dating. Geologists began looking seriously for the earliest piece of the earth's crust. We now know that rocks dating to 3.5 billion years are relatively

common and are found on all continents. The oldest still intact rock found so far is from the eastern shore of Canada's Hudson Bay. It dates to 4.28 billion years but is not part of the earth's primordial crust. Rather, it is a piece of greenstone that probably formed by precipitation in a deep sea hydrothermal vent. Still older are zircon crystals found in sedimentary rock from Western Australia. These date to 4.36 billion years. They are not intact original crust material either. The rock from which they originated eroded, and the individual particles became part of the later sedimentary rock that was sampled. It is unlikely that we will ever find an intact piece of the original earth. Erosion and other geological processes long ago recycled the first crust. In any case, our planet is almost certainly somewhat older than that solid crust because the surface of the early earth was molten rock.

Most astronomers believe that the numerous asteroids and smaller rock objects orbiting our sun primarily between Mars and Jupiter were created at about the same time as the earth. Since these bodies lack molten cores and are too small to have atmospheres, it is probable that they are still more or less as they were when they were formed. Periodically, some of them are pulled out of orbit by comets and crash into the Sun. On rare occasions, the earth gets in the way, and these rock bodies strike our planet. Remnants of such meteors that have been dated with multiple radiometric methods range in time from 4.29 to 4.58 billion years, with most of them near the older end of this range. Based on these dates, the U.S. Geological Survey has estimated that the earth is most likely about 4.54 ± .02 billion years old. Supporting this estimate are the radiometric dates for rocks brought back from the moon by the Apollo missions of NASA in the early 1970's. The oldest moon rocks are 4.29 to 4.56 billion years old. Most astronomers believe that the moon coalesced out of debris from the earth that was thrown into space by the impact of a massive asteroid or small planet that struck the early earth.

Evolution of Life

The earth experienced heavy bombardments of asteroids and possibly comets around 3.9 billion years ago. These devastating impacts of thousands of large space objects very likely went on for 20-200 million years and probably contributed to the development of an early atmosphere that included water vapor. It has been suggested that these events could have resulted in the necessary conditions for the appearance of life.

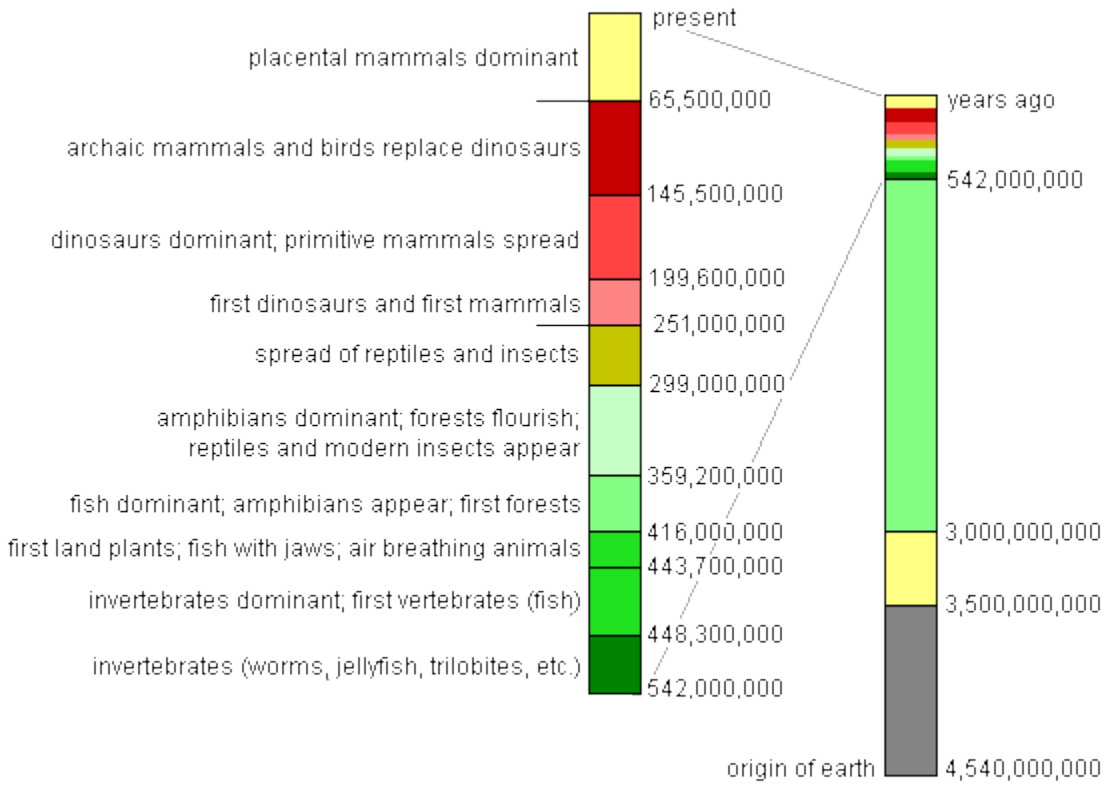
The earliest signs of life on earth consist of organic chemicals that were presumably produced by single-celled microscopic organisms. These chemicals have been found in rock from western Greenland dating to 3.7-3.9 billion years ago. However, this evidence is not convincing to some researchers because it consists of the chemical markers of life rather than actual cells. Much more credible have been the discovery of fossil colonies of single-celled microscopic organisms dating to 3.5 billion years ago in Australia and South Africa.

Assuming that the beginning of life on earth occurred about that time or a bit earlier, we must conclude that our planet was lifeless for its first billion or so years.

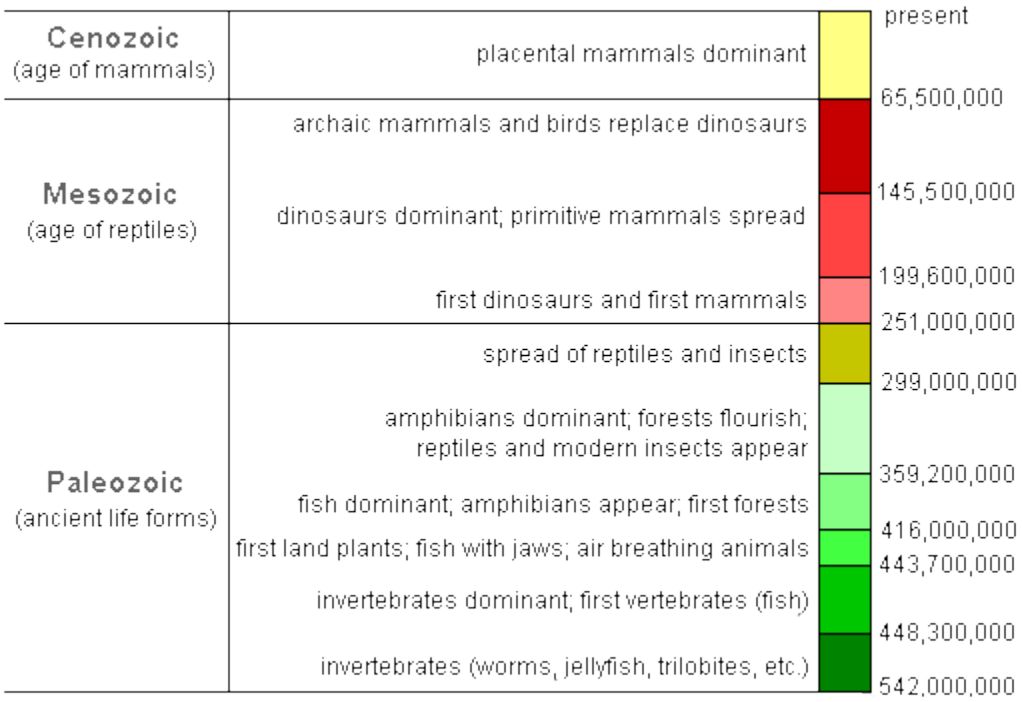
By 3-3.5 billion years ago, large colonies of algae were flourishing near the surface of oceans and seas. By 2.4 billion years ago, photosynthesizing blue-green algae apparently were producing enough oxygen to transform our planet's atmosphere to one suitable for the oxygen breathing creatures that would later evolve. In addition, more complex single-celled organisms with nuclei were now common. The most advanced creatures were sponges, which are essentially intermediate between single and multi-celled organisms. Research done by S. Blair Hedges of Pennsylvania State University suggests that the evolution of life accelerated with the appearance of mitochondria around 1.8 billion years ago. Hedges estimates that the split between what eventually would become the plant and animal lines of evolution occurred about 1.6 billion years ago. By 1.5 billion years ago, there were simple creatures with up to 10 different kinds of eukaryotic cells. By 1 billion years ago, their descendents had up to 50 different kinds of cells.

Complex multicellular forms of life are surprisingly recent on our planet. They have existed only for about 600,000,000 years or slightly more. When these creatures began to appear, 87% of the earth's existence had already gone by, and 83% of the total time life has existed had already passed as well.

Time Table of the Evolution of Complex Life Forms on Earth



During the **Paleozoic Era** (ca. 542-251 million years ago), there was a comparatively rapid evolution of complex life forms including invertebrates, vertebrates, and plants. In addition, life moved onto the land for the first time. This dramatic explosion of biological diversity began around 542,000,000 years ago. During the **Mesozoic Era** that followed (ca. 251-65.5 million years ago), mammals first appeared, but large reptiles dominated the planet. This was the age of dinosaurs. With the end of the last dinosaurs by 65,500,000 years ago, the **Cenozoic Era** began and more advanced mammals rapidly evolved and became the dominant large animals. It was only in this last geologic era that primates evolved. Humans first appeared about 2.5 million years ago. By then, 99.9% of earth history had already occurred and most kinds of creatures had become extinct.



The evolution of life has not been a smooth process of ever increasing numbers of species. There have been major setbacks caused by global catastrophic events, such as ice ages, immense volcanic eruptions, asteroid impacts, and major fluctuations in the amount of oxygen in the atmosphere. The result has been at least six episodes of mass extinction and many minor ones.

Approximate Date Of Extinction Event	Approximate Duration (years)	Percent of Species That Became Extinct
65,500,000 (end of Mesozoic Era)	<1 million	76%
200,000,000 (end of Triassic Period)	3-4 million	80%
251,000,000 (end of Permian Period)	unknown	95-96%
360,000,000 (late Devonian Period)	<3 million	83%
444,000,000 (end of Ordovician Period)	10 million	85%
488,000,000 (end of Cambrian Period)	unknown	unknown

Source: Gibbs, W. Wayt (2001) "On the Termination of Species", *Scientific America* Vol. 285, No. 5.

As a result of each of these extinction episodes, there was an opening up of new opportunities for the relatively few surviving species. As older, often dominant creatures disappeared from the scene, others took advantage of the biological vacuum and rapidly diversified through adaptive radiation. For instance, the abrupt end of the last dinosaurs 65,500,000 years ago allowed the placental mammals to rapidly evolve into the numerous species lines of today and to become the dominant large animals. Beginning after that time, primates, rodents, dogs, cats, hoofed animals, and sea mammals all appeared and became major players in most environments around the globe.

There is reason to believe that we are now in the midst of a 7th major global extinction event. This one began 10-15,000 years ago as the last ice age was coming to an end. Several hundred large animal species have already become extinct, and many others are threatened. The explosion of our human population has played a major role in this.

Evolution of the Continents

The earth's **lithosphere** (the outer rock shell) consists of about a dozen enormous rigid plates and many smaller ones that are more or less constantly moving relative to each other at a rate of a few centimeters a year. Some are moving slower and others more rapidly. Most of the earth's volcanic and earthquake activity occurs where plates come together. These dynamic processes result in mountain building. Over tens of millions of years, this tectonic movement has also caused the continents to travel thousands of miles and to alter their shapes. It is now known that all of the continents came together and fused early in the time of the dinosaurs. This super-continent has been named **Pangaea** (Greek for "all of the earth"). It began forming about 285 million years ago. It was complete by about 210 million years ago and began drifting apart again 10 million years later.

225,000,000 years ago

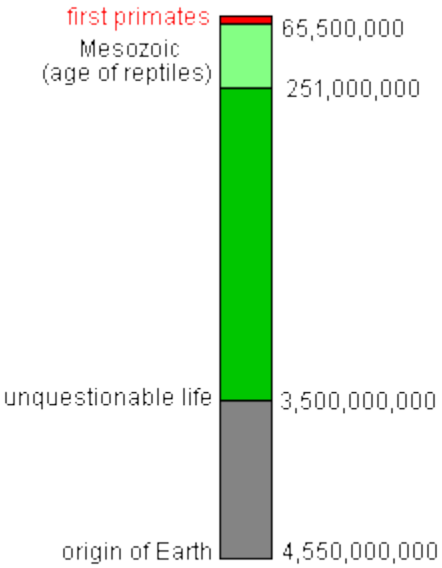
125,000,000 years ago

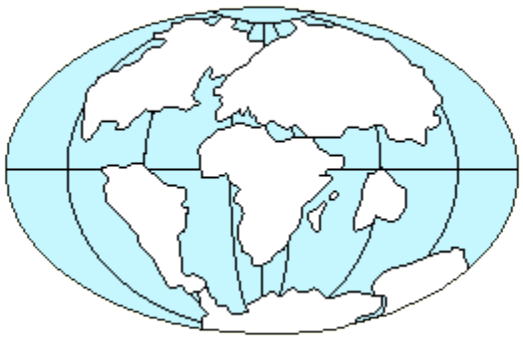
By 250 million years ago, Pangaea was massive enough to radically change the world's climates. The interior of this super-continent would have been far enough from oceans to have extreme seasonal swings in temperature much greater than today. Intense **tectonic movements** due to the squeezing together of the continental plates at that time may have triggered massive volcanic activity which would have blocked out the sun with fine ash for years. Some researchers believe that this would have cooled the earth's surface sufficiently to trigger a long, devastating ice age. Supporting this theory is the fact that there was at least a million cubic kilometers of lava that flowed over the surface of what is now Siberia about 250 million years ago. This period coincides with the most complete extinction episode known. Only about 4% of all plant and animal species survived. We almost lost life on our planet. It took about 10 million years for

biological diversity to recover following this genetic bottle-necking. The major animal beneficiaries were the dinosaurs and other reptiles. By 200 million years ago, the primitive mammals first appeared.

The First Primates

Primates are remarkably recent animals. Most animal species flourished and became extinct long before the first monkeys and their prosimian ancestors evolved. While the earth is about 4.54 billion years old and the first life dates to at least 3.5 billion years ago, the first primates did not appear until around 50-55 million years ago. That was after the dinosaurs had become extinct.





65,000,000 years ago

present

Transitional primate-like creatures were evolving by the end of the **Mesozoic Era** (ca. 65.5 million years ago). At that time, the world was very different from today. The continents were in other locations and they had somewhat different shapes. North America was still connected to Europe but not to South America. India was not yet part of Asia but heading towards it at a surprisingly rapid rate of nearly 8 inches (20 cm.) per year. Australia was close to Antarctica. Most land masses had warm tropical or subtropical climates.

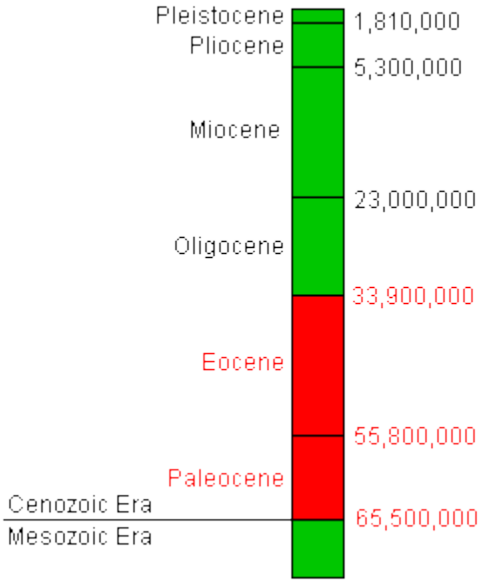
Small Insectivore from the end of the Mesozoic Era

The flora and fauna at the end of the Mesozoic Era would have seemed alien since most of the plants and animals that are familiar to us had not yet evolved. Large reptiles were beginning to be replaced by mammals as the dominant large land animals. Among the mammals, there were a few archaic egg-layers (monotremes) like the ancestors of the platypus and echidna. There were larger numbers of pouched opossum-like mammals (marsupials). The few placental mammals that existed at that time mainly consisted of the Insectivore ancestors of primates. The large grass-eating placental mammals, such as cattle and wildebeest, were absent as were the vast grasslands that

would later develop. Rodents and seed-eating birds were also absent. The great proliferation of flowering plants had not taken place yet. However, forests of broad-leafed trees were developing over much of the earth.

Primate-like Mammals

The first **primate-like mammals**, or **proto-primates**, evolved in the early **Paleocene Epoch**. They were roughly similar to squirrels and tree shrews in size and appearance. The existing, very fragmentary fossil evidence (mostly from North Africa and North America) suggests that they were adapted to an arboreal way of life in warm, moist climates. They probably were equipped with relatively good eyesight as well as hands and feet adapted for climbing in trees. These primate-like mammals (***Plesiadapiformes***) will remain rather shadowy creatures for us until more fossil data become available.



The primate-like mammals do not seem to have played an important role in the general transformation of terrestrial animal life immediately following the massive global extinctions of plants and animals that occurred about 65,500,000 years ago. The most dramatic changes were brought about by the emergence of large grazing and browsing mammals with tough hoofs, grinding teeth, and digestive tracts specialized for the processing of grass, leaves, and other fibrous plant materials. The evolution of these herbivorous mammals provided the opportunity for the evolution of the carnivorous mammals specialized to eat them. These new hunters and scavengers included the dogs, cats, and bears. Adaptive radiation was resulting in the rapid evolution of new species to fill expanding ecological niches, or food getting opportunities. Most of these new animals were placental mammals. With the exception of bats, none of them reached Australia and New Guinea. This explains why they did not exist there until people brought them in recent times. South America had also drifted away from Africa and was not connected to North America after 80,000,000 years ago. However, around 20,000,000 years ago, South America reconnected with North America and placental mammals streamed in for the first time, resulting in the extinction of most of the existing marsupials there.

Early Prosimians

The first true primates evolved by 55 million years ago or a bit earlier, near the beginning of the **Eocene Epoch**. Their fossils have been found in North America, Europe, and Asia. They looked different from the primates today. They were still somewhat squirrel-like in size and appearance, but apparently they had grasping hands and feet that were increasingly more efficient in

manipulating objects and climbing trees. The position of their eyes indicates that they were developing more effective stereoscopic vision as well.

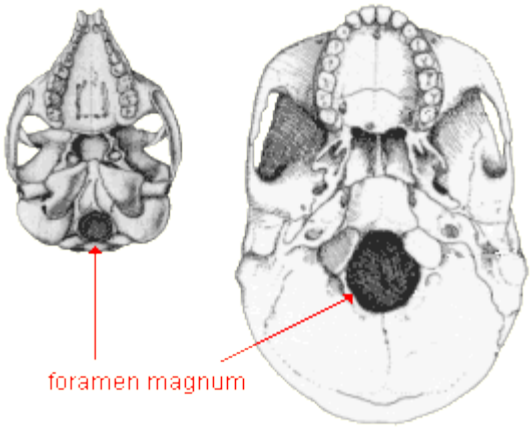
The beginning of the Eocene Epoch 55.8 million years ago coincides with the appearance of early forms of most of the placental mammal orders that are present today. In addition, placental mammals with larger bodies and bigger brains began to appear in the fossil record at this time. Paul Falkowski has suggested that this is due to the fact that the amount of oxygen in the earth's atmosphere more or less doubled around 50 million years ago. Larger mammals have relatively fewer capillaries for the distribution of oxygen to the cells of their bodies. Subsequently, they must breathe air that is more oxygenated. Brains have especially high oxygen requirements. In addition, pregnant placental mammals must transmit a substantial portion of the oxygen in their blood to their fetuses.

Coinciding with the increase in atmospheric oxygen at the beginning of the Eocene Epoch was a relatively abrupt global warming of 9-16° F. (5-9° C.) lasting at least 200,000 years. This also would have been a major factor in the rapid evolution of animals and plants at the time.

Smilodectes
(lemur-like family *Adapidae* from the Eocene Epoch)

Among the new Eocene mammals were primate species that somewhat resemble modern **prosimians** such as lemurs, lorises, and possibly tarsiers. This was the epoch of maximum prosimian adaptive radiation. There were at least 60 genera of them that were mostly in two families--the ***Adapidae*** (similar to lemurs and lorises) and the ***Omomyidae*** (possibly like galagos and tarsiers). This is nearly four times greater prosimian diversity than today. Eocene prosimians lived in North America, Europe, Africa, and Asia. It was during this epoch that they reached the island of Madagascar. The great diversity of Eocene prosimians was probably a consequence of the fact that they did not have competition from monkeys and apes since these latter more advanced primates had not yet evolved.

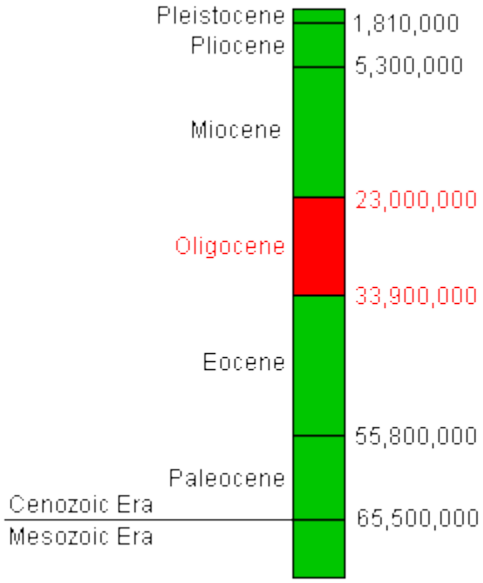
Major evolutionary changes were beginning in some of the Eocene prosimians that foreshadow species yet to come. Their brains and eyes were becoming larger, while their snouts were getting smaller. At the base of a skull, there is a hole through which the spinal cord passes. This opening is the **foramen magnum** (literally the "large hole or opening" in Latin). The position of the foramen magnum is a strong indicator of the angle of the spinal column to the head and subsequently whether the body is habitually horizontal (like a horse) or vertical (like a monkey). During the Eocene, the foramen magnum in some primate species was beginning to move from the back of the skull towards the center. This suggests that they were beginning to hold their bodies erect while hopping and sitting, like modern lemurs, galagos, and tarsiers.



Eocene Era primate and modern human skulls

By the end of the Eocene Epoch, many of the prosimian species had become extinct. This may be connected with cooler temperatures and the appearance of the first monkeys during the transition to the next geologic epoch, the Oligocene (about 34 million years ago).

Early Monkeys and Apes



The **Oligocene Epoch** was largely a gap in the primate fossil record in most parts of the world. This is especially true for prosimian fossils. Most of what we know about them came from the Fayum deposits in Western Egypt. While this area is a desert today, 36-31 million years ago it was a tropical rainforest. Other Oligocene deposits containing some fossil primate bones have been found in North and West Africa, the southern Arabian Peninsula, China, Southeast Asia, as well as North and South America.

Monkeys evolved from prosimians during the Oligocene or slightly earlier in the Eocene. They were the first species of our suborder--the ***Anthropoidea*** . Several genera of these early monkeys have been identified--***Apidium*** and ***Aegyptopithecus*** are the most well known. The former was about the size of a fat squirrel (2-3 pounds or .9-1.4 kg.), while the latter was the size of a large domestic cat (13-20 pounds or 5.9-9.1 kg.). Compared to the prosimians, they had fewer teeth, less fox-like snouts, larger brains, and increasingly more forward-looking eyes. These and other anatomical features suggest that the early monkeys were becoming mostly diurnal fruit and seed eating forest tree-dwellers.

New World monkeys appeared for the first time about 30 million years ago. It is generally thought that they began as isolated groups of Old World monkeys that somehow drifted to South America either from North America or Africa on large clumps of vegetation and soil. The evidence suggests

that Africa is the most likely continent of origin. Such "floating islands" produced as a result of powerful storms tearing at the land still occur in tropical regions of the world today.

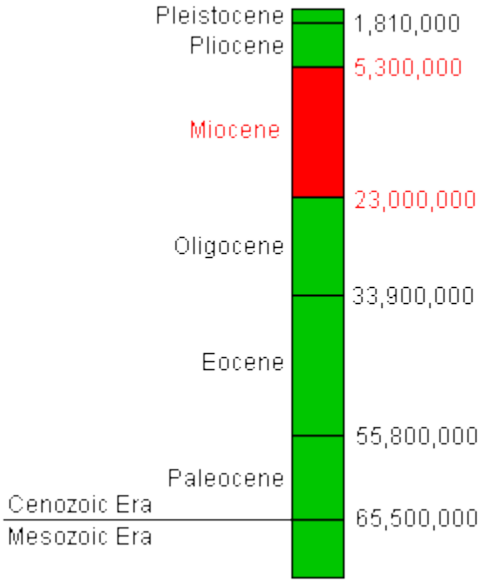
Due to the comparative scarcity of Oligocene Epoch prosimians in the fossil record, it is generally believed that the monkeys out-competed and replaced them in most environments at that time. Supporting this hypothesis is the fact that modern prosimians either live in locations where monkeys and apes are absent or they are normally active only at nighttime when most of the larger, more intelligent primates are sleeping.

Great Rift Valley system of East Africa (shown in brown)

The Oligocene was an epoch of major geological change with resulting regional climate shifts that likely affected the direction of evolution and altered fossil preservation conditions. By the beginning of the Oligocene, North America and Europe drifted apart and became distinct continents. The **Great Rift Valley** system of East Africa also was formed during the Oligocene along a 1200 mile long volcanically active fault zone between tectonic plates that are moving away from each other. This created an easy regional migration route for animals. By the early Eocene Epoch, about 55-54 million years ago, India finally crashed into Asia and began forcing up the Himalayan chain of mountains and the Tibetan Plateau beyond. During the Oligocene, the progressive growth of this immense barrier very likely altered continental weather patterns significantly by blocking the summer monsoonal rains. These and other major geological events during the Oligocene very likely triggered global climatic changes. The cooling and drying trend with associated expansion of grasslands that had begun in the late Eocene Epoch accelerated, especially in the northern hemisphere. A result was the general disappearance of primates from these northern areas. However, climates in most regions were still warmer than today.

India forcing up the Himalayas and the Tibetan Plateau

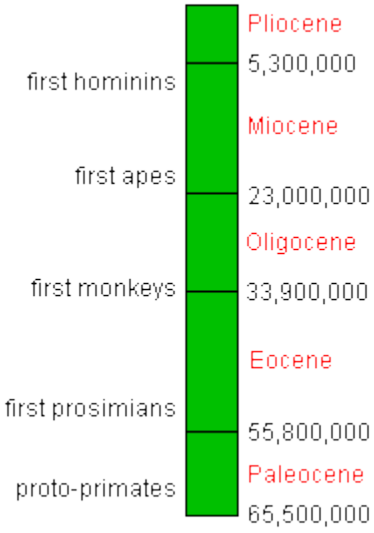
By the middle of the **Miocene Epoch**, the ongoing movement of tectonic plates created new mountain chains. These in turn altered local weather patterns. In addition, the progressive global cooling and drying trend continued. Growing polar ice caps reduced the amount of water in the oceans, causing sea levels to drop. This exposed previously submerged coastal lands. As a result of this and continental drift, a land connection was reestablished between Africa and Eurasia that provided a migration route for primates and other animals between these continents. Much of the East African and South Asian tropical forests began to be replaced by sparse woodlands and dry grasslands because of the climate changes. As a result, there were new selective pressures affecting primate evolution.



Proconsul

Primate fossils are common from the Miocene. However, not all primates are equally represented in the fossil record. Apes apparently evolved from monkeys early in this epoch. Fossil monkeys and prosimians are comparatively rare from most of the Miocene, but apes are common. It appears that apes at that time occupied some ecological niches that would later be filled by monkeys. One of the earliest of the monkey to ape transitional primates was **Proconsul**. It lived in Africa forests 21-14 million years ago.

Among the numerous Miocene primate species were the ancestors of all modern apes and humans. By 14 million years ago, the group of apes that included our ancestors was apparently in the process of adapting to life on the edges of the expanding savannas in Southern Europe. They were very likely members of the genus ***Dryopithecus***, which were generally similar in appearance to modern African apes. Toward the end of the Miocene, less hospitable cooler conditions in the northern hemisphere caused many primate species to become extinct while some survived by migrating south into Africa and South Asia. About 8-9 million years ago, the descendants of the **dryopithecines** in Africa diverged into two lines--one that led to gorillas and another to humans, chimpanzees, and bonobos. Around 5-6 million years ago, a further divergence occurred which separated the ancestors of modern chimpanzees and bonobos from the early **hominins** (human-like primates) that were our direct ancestors.

Summary

Primates are relative newcomers on our planet. The earliest ones are found in the fossil record dating to 50-55 million years ago. These first prosimians thrived during the Eocene Epoch. There were no monkeys or apes for them to compete with yet. By the time of the transition to the Oligocene Epoch, monkeys had begun to evolve from prosimians and became the dominant primates. Many of the prosimian species became extinct probably as a consequence. By the early Miocene Epoch, apes had evolved from monkeys and displaced them from many environments. In the late Miocene, the evolutionary line leading to hominins finally became distinct. This hominin line included our direct ancestors.