

## **Handout for GLY 137 – The Dinosaurs**

### **The Geologic Time Scale and a Brief History of Life on Earth**

The Geologic Time Scale is divided into four major units: Eons, Eras, Periods and Epochs. An Eon is the longest division of geologic time, so long in fact that there have only been four Eons. Collectively the first three eons are called the Precambrian, that stretch of geological time from the formation of the Earth itself to the start of the Cambrian period. This immensely long stretch of time - some four billion years or more - saw the formation of the Earth as a planetary body, including geosphere, atmosphere, and hydrosphere, as well as the appearance of life.

#### **Divisions of the Precambrian**

The Precambrian is divided into the Hadean, which refers to the conditions on the still forming Earth, the Archean (“first” or “primary”) and the more recent Proterozoic (“age of first life”). The first two eons are not typically divided into smaller units (other than “early”, “middle” and “late”) because there is no basis for division.

Hadean time (4.6 Bya – 3.9 Bya) is not a geological period as such, because no rocks on the Earth are this old - except for meteorites. During Hadean time, the Solar System was forming, probably within a large cloud of gas and dust around the sun, called an accretion disc. The sun formed within such a cloud of gas and dust, shrinking in on itself by gravitational compaction until it began to undergo nuclear fusion and give off light and heat. Surrounding particles began to coalesce by gravity into larger lumps, or planetesimals, which continued to aggregate into planets. "Left-over" material formed asteroids and comets.

Because collisions between large planetesimals release a lot of heat, the Earth and other planets would have been molten at the beginning of their histories. Solidification of the molten material into rocks happened as the Earth cooled. The oldest meteorites and lunar rocks are about 4.5 billion years old, but the oldest Earth rocks currently known are 3.8 billion years old. Sometime during the first 800 million or so years of its history, the surface of the Earth changed from liquid to solid. Once solid rock formed on the Earth, its geological history began. This most likely happened prior to 3.8 billion years, but hard evidence for this is lacking. Erosion and plate tectonics has probably destroyed all of the solid rocks that were older than 3.8 billion years. The beginning of the rock record that is currently present on the Earth is the inception of a time known as the Archean.

It was early in the Archaean Eon (3.9 – 2.5 Bya) that life first appeared on Earth. Our oldest fossils date to roughly 3.5 billion years ago, and consist of bacteria microfossils. In fact, all life during the more than one billion years of the Archaean was single-celled bacteria, for example stromatolites - colonies of photosynthetic bacteria which have been found as fossils in Early Archaean rocks of South Africa and Western Australia. The atmosphere was very different from what we breathe today; at that time, it was likely a reducing atmosphere of methane, ammonia, and other gases which would be toxic to most life on our planet today. Also during this time, the Earth's crust cooled enough that rocks and crustal plates began to form. Although simple, cyanobacteria was ultimately responsible for one of the most important "global changes" that the Earth has undergone. Being photosynthetic, cyanobacteria produce oxygen as a by-product. Photosynthesis is the only major source of free oxygen gas in the atmosphere. As stromatolites became more common 2.5 billion years ago, they gradually changed the Earth's atmosphere from a carbon dioxide-rich mixture to the present-day oxygen-rich atmosphere. This major change paved the way for the next evolutionary step, the appearance of life based on the eukaryotic cell.

The period of Earth's history that began 2.5 billion years ago and ended 544 million years ago is known as the Proterozoic. Many of the most exciting events in the history of the Earth and of life occurred during the Proterozoic -- stable continents first appeared and began to accrete, a long process taking about a billion years. Also coming from this time are the first abundant fossils of living organisms, mostly bacteria and archaeans, but by about 1.8 billion years ago eukaryotic cells appear as fossils too.

With the beginning of the Middle Proterozoic comes the first evidence of oxygen build-up in the atmosphere. This global catastrophe spelled doom for many bacterial groups, but made possible the explosion of eukaryotic forms. These include multicellular algae, and toward the end of the Proterozoic, the first animals. In the latest Proterozoic - a time period now called the Vendian, or the Ediacaran, and lasting from about 650 to 540 million years ago the Vendian biota, multi-celled animals, appear including sponges. The continents had merged into a single supercontinent called Rodinia and macroscopic fossils of soft-bodied Vedian organisms can be found in a few localities around the world.

The final Eon is the Phanerozoic, which means "revealed or visible Life" and goes from 540 Mya through to today. The Phanerozoic represents a relatively brief period of time (brief that is relative to the age of the Earth and the universe) that constitutes the age of multicellular animal life on Earth. During this time micro- and multicellular organisms left a detailed fossil record,

and built up complex and diverse ecosystems, and life has evolved through countless transformations and millions upon millions of species. The Phanerozoic is broken into three Eras: Paleozoic, Mesozoic and Cenozoic.

Of the three main eras that make up the Phanerozoic, the Paleozoic is the longest and most diverse, spanning the period from very early multicellular life that only inhabited the oceans to quite advanced amphibians and reptiles and extensive forests on land. The Paleozoic Era is bracketed by two of the most important events in the history of animal life. At its beginning, multicelled animals underwent a dramatic "explosion" in diversity called the Cambrian Explosion (named for the first period of the Paleozoic), and almost all living animal phyla appeared within a few millions of years. At the other end of the Paleozoic, the largest mass extinction in history wiped out approximately 90% of all marine animal species. The causes of both these events are still not fully understood and the subject of much research and controversy. Roughly halfway in between, animals, fungi, and plants alike colonized the land, and the insects took to the air.

The Paleozoic Era ("ancient life") takes up over half of the Phanerozoic, approximately 300 million years. During the Paleozoic there were six major continental land masses; each of these consisted of different parts of the modern continents. For instance, at the beginning of the Paleozoic, today's western coast of North America ran east-west along the equator, while Africa was at the South Pole. These Paleozoic continents experienced tremendous mountain building along their margins, and numerous incursions and retreats of shallow seas across their interiors.

The Paleozoic is divided into seven (or six if you are European) periods based on the dominant forms of life. The earliest period is the Cambrian Period lasting from 540 to 500 mya. The Cambrian Explosion of life occurs; all existent phyla develop. Many marine invertebrates (marine animals with mineralized shells: shell-fish, echinoderms, trilobites, brachiopods, mollusks, primitive graptolites). First vertebrates. Earliest primitive fish. Mild climate. The supercontinent Rodinia began to break into smaller continents (no correspondence to modern-day land masses). Mass extinction of trilobites and nautiloids at end of Cambrian (50% of all animal families went extinct), probably due to glaciation.

Next is the Ordovician Period, 505 to 438 mya, when primitive plants appear on land. First corals. Primitive fishes, seaweed and fungi. Graptolites, bryozoans, gastropods, bivalves, and echinoids. High sea levels at first, global cooling and glaciation, and much volcanism. North America under shallow seas. Ends in huge extinction, due to glaciation. At this time, the area north of the tropics was almost entirely ocean, and most of the world's land was collected into

the southern super-continent Gondwana. Throughout the Ordovician, Gondwana shifted towards the South Pole and much of it was submerged underwater. The Ordovician is best known for the presence of its diverse marine invertebrates, including graptolites, trilobites, brachiopods, and the conodonts (early vertebrates). A typical marine community consisted of these animals, plus red and green algae, primitive fish, cephalopods, corals, crinoids, and gastropods. More recently, there has been found evidence of tetrahedral spores that are similar to those of primitive land plants, suggesting that plants invaded the land at this time. From the Early to Middle Ordovician, the earth experienced a milder climate in which the weather was warm and the atmosphere contained a lot of moisture. However, when Gondwana finally settled on the South Pole during the Late Ordovician, massive glaciers formed causing shallow seas to drain and sea levels to drop. This likely caused the mass extinctions that characterize the end of the Ordovician, in which 60% of all marine invertebrate genera and 25% of all families went extinct.

**Silurian Period 438 to 408 mya** The first jawed fishes and uniramians (like insects, and centipedes and millipedes) appeared during the Silurian (over 400 million years ago). First vascular plants (plants with water-conducting tissue as compared with non-vascular plants like mosses) appear on land (*Cooksonia* is the first known). High seas worldwide. Brachiopods, crinoids, corals. The Silurian was a time when the Earth underwent considerable changes that had important repercussions for the environment and life within it. The Silurian witnessed a relative stabilization of the earth's general climate, ending the previous pattern of erratic climatic fluctuations. One result of these changes was the melting of large glacial formations. This contributed to a substantial rise in the levels of the major seas. Coral reefs made their first appearance during this time, and the Silurian was also a remarkable time in the evolution of fishes. Not only does this time period mark the wide and rapid spread of jawless fish, but also the highly significant appearances of both the first known freshwater fish as well as the first fish with jaws. It is also at this time that our first good evidence of life on land is preserved, including relatives of spiders and centipedes, and also the earliest fossils of vascular plants.

**Devonian Period "The Age of Fishes" 408 to 360 mya** Fish and land plants become abundant and diverse. First tetrapods appear toward the end of the period. First amphibians appear. First sharks, bony fish, and ammonoids. Many coral reefs, brachiopods, crinoids. New insects, like springtails, appeared. Mass extinction (345 mya) wiped out 30% of all animal families) probably due to glaciation or meteorite impact. The vegetation of the early Devonian consisted primarily of small plants, the tallest being only a meter tall. By the end of the Devonian, ferns, horsetails and seed plants had also appeared, producing the first trees and the first forests. Also during the Devonian, two major animal groups colonized the land. The first tetrapods, or land-living vertebrates, appeared during the Devonian, as did the first terrestrial

arthropods, including wingless insects and the earliest arachnids. In the oceans, brachiopods flourished. Crinoids and other echinoderms, tabulate and rugose corals, and ammonites were also common. Many new kinds of fish appeared. During the Devonian, there were three major continental masses: North America and Europe sat together near the equator, much of their current land underneath seas. To the north lay a portion of modern Siberia. A composite continent of South America, Africa, Antarctica, India, and Australia dominated the southern hemisphere.

Next is the Carboniferous Period which occurred from about 360 to 286 million years ago. This was a time of wide-spread coal swamps, foraminiferans, corals, bryozoans, brachiopods, blastoids, seed ferns, lycopsids, and other plants. Amphibians become more common. The term "Carboniferous" or "carbon-bearing" comes from England, in reference to the rich deposits of coal that occur there. These deposits of coal occur throughout northern Europe, Asia, and midwestern and eastern North America. The term "Carboniferous" is used throughout the world to describe this period, although this period has been separated into the Mississippian Period 360 to 325 mya (Lower Carboniferous) and the Pennsylvanian Period 325 to 280 mya (Upper Carboniferous) in the United States. This system was adopted to distinguish the coal-bearing layers of the Pennsylvanian from the mostly limestone Mississippian, and is a result of differing stratigraphy on the different continents. In addition to having the ideal conditions for the beginnings of coal, several major biological, geological, and climatic events occurred during this time.

One of the greatest evolutionary innovations of the Carboniferous was the amniote egg, which allowed for the further exploitation of the land by certain tetrapods. The amniote egg allowed the ancestors of birds, mammals, and reptiles to reproduce on land by preventing the desiccation of the embryo inside. There was also a trend towards mild temperatures during the Carboniferous, as evidenced by the decrease in lycopods and large insects and an increase in the number of tree ferns. The first winged insects, the first reptiles, first mayflies and cockroaches appear. Geologically, the Late Carboniferous collision of Laurussia (present-day Europe and North America) into Gondwanaland (present-day Africa and South America) produced the Appalachian mountain belt of eastern North America and the Hercynian Mountains in the United Kingdom. A further collision of Siberia and eastern Europe created the Ural Mountains.

The last period of the Paleozoic is the Permian period which lasted from 286 to 245 million years ago. The distinction between the Paleozoic and the Mesozoic is made at the end of the Permian in recognition of the largest mass extinction recorded in the history of life on Earth. It affected many groups of organisms in many different environments, but it affected marine

communities the most by far, causing the extinction of most of the marine invertebrates of the time. Some groups survived the Permian mass extinction in greatly diminished numbers, but they never again reached the ecological dominance they once had, clearing the way for another group of sea life. On land, a relatively smaller extinction of diapsids and synapsids cleared the way for other forms to dominate, and led to what has been called the "Age of Dinosaurs". Also, the great forests of fern-like plants shifted to gymnosperms, plants with their offspring enclosed within seeds. Modern conifers, the most familiar gymnosperms of today, first appear in the fossil record of the Permian.

In all, the Permian was the last of the time for some organisms and a pivotal point for others, and life on earth was never the same again. The global geography of the Permian included massive areas of land and water. By the beginning of the Permian, the motion of the Earth's crustal plates had brought much of the total land together, fused in a supercontinent known as Pangea. Many of the continents of today in somewhat intact form met in Pangea (only Asia was broken up at the time), which stretched from the northern to the southern pole. Most of the rest of the surface area of the Earth was occupied by a corresponding single ocean, known as Panthalassa, with a smaller sea to the east of Pangea known as Tethys. Models indicate that the interior regions of this vast continent were probably dry, with great seasonal fluctuations, because of the lack of the moderating effect of nearby bodies of water, and that only portions received rainfall throughout the year. The ocean itself still has little known about it. There are indications that the climate of the Earth shifted at this time, and that glaciation decreased, as the interiors of continents became drier.

The Mesozoic Era is divided into three time periods: the Triassic (248-208 mya), the Jurassic (208-146 mya), and the Cretaceous (146-65 mya). Mesozoic means "middle life", and is the time during which the world fauna changed drastically from that which had been seen in the Paleozoic. Dinosaurs, which are perhaps the most popular organisms of the Mesozoic, evolved in the Triassic, but were not very diverse until the Jurassic. Except for birds, dinosaurs became extinct at the end of the Cretaceous. Some of the last dinosaurs to have lived are found in the late Cretaceous deposits of Montana in the United States. The Mesozoic was also a time of great change in the terrestrial vegetation. The early Mesozoic was dominated by ferns, cycads, ginkgophytes, bennettitaleans, and other unusual plants. Modern gymnosperms, such as conifers, first appeared in their current recognizable forms in the early Triassic. By the middle of the Cretaceous, the earliest angiosperms had appeared and began to diversify, largely taking over from the other plant groups. During the Mesozoic, the Earth was very different than it is now. The climate was warmer, the seasons were very mild, the sea level was higher, and there was no polar ice. Even the shape of the continents on Earth was different; the continents were jammed

together at the beginning of the Mesozoic Era, forming the supercontinent of Pangaea, but would start breaking apart toward the middle of the Mesozoic Era.

Roughly 248 million years ago (mya) (the boundary between the Paleozoic and the Mesozoic), the Permo-Triassic extinction occurred. This is the largest extinction known. About 95% of all species and about 60% of the genera died out, including many marine animals (like the trilobite). The cause of the Permian extinction might have been global cooling, volcanic eruptions, or a decrease in the continental shelf area during the formation of Pangaea. This catastrophic extinction and continental rearrangement opened the way for the rise of the dinosaurs and mammals. There were no dinosaurs at the beginning of the Triassic, but there were many amphibians and some reptiles and dicynodonts. During the early Triassic, corals appeared and ammonites recovered from the Permian extinction. Seed plants dominated the land; in the Northern hemisphere, conifers flourish. Glossopteris was the dominant southern hemisphere tree during the Early Triassic period.

During the late Triassic, 220 million years ago, the first true mammals appeared. Some scientists believe that mammals evolved from a group of extinct mammal-like reptiles, Theriodontia, which were Therapsids. These primitive mammals were tiny and are thought to have been nocturnal. The earliest-known turtle, Proganochelys, appeared during the late Triassic. Turtles, frogs, salamanders, lizards (including snakes), and pterosaurs first appeared in the Triassic. Also in the Triassic was Pseudosuchia, possible ancestor of Archaeopteryx. Insects began to undergo complete metamorphosis from larva through pupa to adult. In the seas, ichthyosaurs, marine reptiles, appeared. Seed ferns like Glossopteris, ferns and early species of gymnosperms (seed plants, such as the evergreens, in which the seeds are not enclosed) dominate the Triassic terrain. Cycads, with tufts of tough, palm-like leaves and a woody trunk, appeared in the late Carboniferous and were abundant in the Triassic. Laurasia was dominated by conifers, other seed plants and ferns; Gondwanaland was dominated by Dicroidium. The Triassic's climate was generally hot and dry, with strong seasonality. The formation of the supercontinent of Pangaea at the beginning of the Triassic, 220 million years ago, decreased the amount of shoreline, formed mountains, and gave the interior of the supercontinent a dry, desert-like terrain. The polar regions were moist and temperate.

The Triassic period ended with a mass extinction accompanied by huge volcanic eruptions about 208-213 million years ago. The supercontinent Pangaea began to break apart. 35% of all animal families die out, including virtually all labyrinthodont amphibians, conodonts, and all marine reptiles except ichthyosaurs. Most synapsids, which had dominated the Permian and early Triassic, went extinct (except for the mammals). Most of the early, primitive dinosaurs

also went extinct, but other, more adaptive dinosaurs evolved in the Jurassic. No one is certain what caused this late Triassic extinction; possibilities include global cooling or an asteroid impact. A 210 million-year-old meteor crater surrounding Manicouagan Reservoir, Quebec, Canada, may be the remains of the culprit. This extinction allowed the dinosaurs to expand into many niches that were now unoccupied. Dinosaurs would become increasingly dominant, abundant and diverse, and remained that way for the next 150 million years.

At the beginning of the Jurassic (208-146 mya), the Earth's continents were still jammed together, forming the supercontinent Pangaea, but they were beginning to drift apart. There had been a minor extinction at the end of the Triassic period, which gave rise to an abundance of dinosaurs in the Jurassic. The climate was hot and dry and at the beginning of the Jurassic, strongly seasonal. The dinosaurs dominated the near-tropical Earth during the Jurassic, and many new groups appeared. The gigantic sauropod dinosaurs, like the *Diplodocus* and *Apatosaurus*, diversified. Carnivorous theropods, like *Allosaurus* and *Compsognathus*, were abundant. Bird-like dinosaurs also flourished. About 140 million years ago, during the late Jurassic period, the flowering plants (angiosperms) evolved, and would soon change the face of the Earth.

There was a minor mass extinction toward the end of the early Jurassic period (roughly 190-183 million years ago) in which more than 80% of marine bivalve species (like many clams) and many other shallow-water species died out. The cause of this extinction is unknown, but there is some speculation that it was triggered by the release of huge methane deposits from within the Earth (these deposits formed beneath the seabed as surface algae dies and sinks to the sea floor). Early mammals were developing and diversifying in the Jurassic. Some Jurassic period mammals included *Morganucodontids* (like *Morganucodon* and *Megazostrodon*), *Haramiyids* (like *Haramiya*), *Docodonts* (like *Docodon*), *multituberculates*, *symmetrodonts*, *pantotheres*, and a recently-found, mouse-sized Middle Jurassic mammal (a *tribosphenidan*) from Madagascar. Also, *Archaeopteryx*, the first, primitive, dinosaur-like bird appeared about 150 million years ago, toward the end of the Jurassic. There were also pterosaurs, flying reptiles which were the largest vertebrates ever known to fly. In the Jurassic seas, there were abundant coral reefs, fish, *ichthyosaurs* (fishlike reptiles), *plesiosaurs*, giant marine crocodiles, *ammonites*, squid, sharks and the first rays. Plant lines from the Triassic continued. There were many tufted, palm-like cycads, seed ferns, ginkgos, and conifers in the subtropical forests.

There was no polar ice during the last two-thirds of the Jurassic. The climate was warm and moist and the sea levels high. There were vast flooded areas, temperate and subtropical forests, and coral reefs. The extensive water moderated the strong seasonality so that by the end



of the Jurassic there was less seasonality than we have now. In the Middle Jurassic, the supercontinent Pangaea started to drift apart. A north-south rift formed in mid-Jurassic, and by the late Jurassic, the separation of the continents of Laurasia and Gondwana was almost complete. Many giant sauropods lived during the late Jurassic period. Conifers dominated the landscape. There was a minor mass extinction toward the end of the Jurassic period. During this extinction, most of the stegosaurid and enormous sauropod dinosaurs died out, as did many genera of ammonoids, marine reptiles, and bivalves. No one knows what caused this extinction.

The Cretaceous (“chalk”) Period (146-65 mya) was the heyday of the dinosaurs. Forty percent of the known dinosaurs date from the last 15 million years of the Cretaceous period. Huge carnivores like *Tyrannosaurus rex* and *Giganotosaurus* appeared, as did *Triceratops* and many, many others. There was a tremendous diversity in dinosaur species. Mammals were flourishing, and flowering plants developed and radically changed the landscape. The breakup of the supercontinent Pangaea into separate continents was underway. The separation of Laurasia and Gondwana was complete. In the first half of the Cretaceous, temperatures were warm, seasonality was low, and global sea levels were high (no polar ice!). At the end of the Cretaceous, there were severe climate changes, lowered sea levels, and high volcanic activity.

The Cretaceous period ended 65 million years ago with the extinction of the dinosaurs and many, many other prehistoric life forms. This mass extinction was the second-most extensive in the history of the Earth. The first placental mammals appeared at the beginning of the Cretaceous. The Cretaceous saw the rise and extinction of the toothed birds, *Hesperornis* and *Ichthyornis*. The earliest fossils of birds resembling loons, grebes, cormorants, pelicans, flamingos, ibises, rails, and sandpipers were from the Cretaceous. During the Cretaceous, primitive flowering plants (anthophytes aka angiosperms) continued to develop (they evolved about 140 million years ago, during the late Jurassic period). Flowering plants (like magnolia, ficus, credneria, sassafras, viburnum) quickly outnumbered the other plants (mostly ferns, horsetails, trees (like conifers and ginkgos), and cycads), changing the environment tremendously. There was no polar ice during the mild warm, subtropical Cretaceous. The land was covered with forests surrounded by shallow seas. Seasonality was increasing. Most of the land mass was at or around sea level until the mid-Cretaceous, a time of high tectonic activity (continental plate movement) and accompanying volcanic activity. This is when many mountain ranges were formed, including California's Sierra Nevada and the European Alps. The sea levels rose during the mid-Cretaceous, covering about one-third of the land area. Toward the end of the Cretaceous, there was a drop in sea level, causing land exposure on all continents, more seasonality, and greater extremes between equatorial and polar temperatures. Also, the continents were taking on their modern-day forms.

The Cretaceous period ended with a bang! About 65 million years ago, a mass extinction wiped out the dinosaurs (except for the birds) and many other animals, including pterosaurs, ichthyosaurs, ammonites, mosasaurs, plesiosaurs, and half of all invertebrate marine organisms. The primary cause of the Cretaceous-Tertiary extinction is thought to be an asteroid impact, but there are a lot of other theories, including high volcanism, climate changes due to continental drift, the effects of disease, and/or competition from egg eating mammals. Although this extinction was huge, it was small when compared to the Permian-Triassic extinction (which preceded the existence of the dinosaurs). The Age of Reptiles came to an end. The Age of Mammals was about to begin.

The Cenozoic (“modern life”) Era is the most recent of the three major subdivisions of animal history. The Cenozoic spans only about 65 million years, from the end of the Cretaceous and the extinction of non-avian dinosaurs to the present. The Cenozoic is sometimes called the Age of Mammals. The Cenozoic is divided into two main sub-divisions: the Tertiary and the Quaternary. Most of the Cenozoic is the Tertiary, from 65 million years ago to 1.8 million years ago. The Quaternary includes only the last 1.8 million years.

The Tertiary period is divided into five epochs: Paleocene, Eocene, Oligocene, Miocene, and Pliocene. During this time mammals diversified quickly. Some examples are marsupials, insectivores, bears, hyenas, dogs, cats, seals, walruses, whales, dolphins, early mastodons, hoofed mammals, horses, rhinoceroses, hippopotamuses, oreodonts, rodents, rabbits, monkeys, lemurs, apes, and humans.

The Paleocene epoch, the first epoch of the Tertiary period, was marked by the continued uplift of the Rocky Mountains in western North America, which started at the end of the Mesozoic era continued throughout the Paleocene. The Cretaceous inland seas gradually withdrew from the Great Plains area and central and SW California. The Paleocene mammals were mostly small herbivores similar to their Mesozoic ancestors. By mid-Paleocene, the ungulates, or hoofed mammals of mostly five-toed forms, became abundant. Prosimian primates (tree shrews and tarsiers) also increased in number. Except for part of northern France, Europe was largely emergent (i.e., above water). During this epoch, the opening of the Norwegian Greenland Sea eventually resulted in a much more significant mixing of waters, creating the cold North Atlantic Deep waters. Greenland began separating from Europe as the northern mid-Atlantic Ridge formed. On the other side of the world, Antarctica and Australia had separated; India had completed its separation with Africa, resulting in an outpouring of basalts; and India,

Africa, and Australia were about to collide with Eurasia. By the end of Paleocene time, North America's last large sea retreated to the Gulf of Mexico.

The Eocene epoch is part of the Tertiary Period, and lasted from about 54 to 38 million years ago (mya). The oldest known fossils of most of the modern orders of mammals appear in a brief period during the Early Eocene and all were small, under 10 kg. Both groups of modern ungulates (Artiodactyla and Perissodactyla) became prevalent mammals at this time, due to a major radiation between Europe and North America.

From the Late Cretaceous to the Present rifts separated Africa from South America and the India, Australia, and Antarctica. North America rifted away from Europe. Then the rifted masses of old Gondwana, Africa, India, and Australia, moved northward towards Eurasia, closing the Tethys Ocean and forming the great Alpine-Himalayan mountains. As the process continues, a new super continent appears to be in the near geologic future, centered about the North Pole. As plate positions continue to adjust to the opening of the Atlantic, The Rocky Mountains grow and the Alps and Pyrenees are formed. The modern patterns of Planet Earth begin to appear.

The Oligocene epoch of the Tertiary Period lasted from about 38 to 23 million years ago (mya). The Oligocene is thus a relatively short span of time, though a number of major changes occurred during this time. These include the appearance of the first elephants with trunks, early horses, and the appearance of many grasses -- plants that would produce vast tracts of grasslands in the following epoch, the Miocene.

The Miocene was a time of warmer global climates than those in the preceding Oligocene, or the following Pliocene. It is particularly notable in that two major ecosystems first appeared at this time: kelp forests and grasslands. The expansion of grasslands is correlated to a drying of continental interiors as the global climate first warmed and then cooled. Global circulation patterns changed as Antarctica became isolated and the circum-polar ocean circulation became established. This reduced significantly the mixing of warmer tropical water and cold polar water, and permitted the buildup of the Antarctic polar cap. Likewise, the African-Arabian plate joined to Asia, closing the seaway which had previously separated Africa from Asia, and a number of migrations of animals brought these two faunas into contact.

The Pliocene was a time of global cooling after the warmer Miocene. The cooling and drying of the global environment may have contributed to the enormous spread of grasslands and savannas during this time. The change in vegetation undoubtedly was a major factor in the rise of

long-legged grazers who came to live in these areas. Additionally, the Panamanian land-bridge between North and South America appeared during the Pliocene, allowing migrations of plants and animals into new habitats. Of even greater impact was the accumulation of ice at the poles, which would lead to the extinction of most species living there, as well as the advance of glaciers and ice ages of the Late Pliocene and the following Pleistocene.

The Quaternary period is the younger of the two geologic periods of the Cenozoic era of geologic time, from 2 million years ago to the present. Comprising all geologic time from the end of the Tertiary period to the present, it is divided into the Pleistocene and Holocene, or Recent, epochs. During the early Quaternary, Europe and North America were covered by the glaciers of the Pleistocene epoch. Retreat of the glaciers led to isostatic rebound of the crust in the Holocene. In the Quaternary the climate and present physical features of the earth continued to develop. Significant changes in sea level within historic times are demonstrated by the submergence of the temple of Jupiter Serapis near Naples and by the rising of the shores of the Baltic. The life of the Quaternary has been marked by the rise and dominance of humans.

Mammoths were one of the largest land mammals of the Pleistocene, the time period that spanned from 1.8 million to 11,000 years ago. Pleistocene biotas were extremely close to modern ones -- many genera and even species of Pleistocene conifers, mosses, flowering plants, insects, mollusks, birds, mammals, and others survive to this day. Yet the Pleistocene was also characterized by the presence of distinctive large land mammals and birds. Mammoths and their cousins the mastodons, longhorned bison, sabre-toothed cats, giant ground sloths, and many other large mammals characterized Pleistocene habitats in North America, Asia, and Europe. Native horses and camels galloped across the plains of North America. Great teratorn birds with 25-foot wingspans stalked prey. Around the end of the Pleistocene, all these creatures went extinct (the horses living in North America today are all descendants of animals brought from Europe in historic times). It was during the Pleistocene that the most recent episodes of global cooling, or ice ages, took place. Much of the world's temperate zones were alternately covered by glaciers during cool periods and uncovered during the warmer interglacial periods when the glaciers retreated. Did this cause the Pleistocene extinctions? It doesn't seem likely; the large mammals of the Pleistocene weathered several climate shifts. The Pleistocene also saw the evolution and expansion of our own species, *Homo sapiens*, and by the close of the Pleistocene, humans had spread through most of the world. According to a controversial theory, first proposed in the 1960s, human hunting around the close of the Pleistocene caused or contributed to the extinction of many of the Pleistocene large mammals. It is true that the extinction of large animals on different continents appears to correlate with the arrival of humans, but questions remain as to whether early human hunters were sufficiently numerous and technologically

advanced to wipe out whole species. It has also been hypothesized that some disease wiped out species after species in the Pleistocene. The issue remains unsolved; perhaps the real cause of the Pleistocene extinction was a combination of these factors.

Many paleontologists study Pleistocene fossils in order to understand the climates of the past. The Pleistocene was not only a time during which climates and temperatures shifted dramatically; Pleistocene fossils are often abundant, well-preserved, and can be dated very precisely. Some, such as diatoms, foraminifera, and plant pollen, are both abundant and highly informative about paleoclimates. Today, there is concern about future climate change (e.g. global warming) and how it will affect us. Paleontologists who work on Pleistocene fossils are providing a growing amount of data on the effect of climate change on the Earth's biota, making it possible to understand the effects of future climate change.

To observe a Holocene environment, simply look around you! The Holocene is the name given to the last 11,000 years of the Earth's history -- the time since the end of the last major glacial epoch, or "ice age." Since then, there have been small-scale climate shifts -- notably the "Little Ice Age" between about 1200 and 1700 A.D. -- but in general, the Holocene has been a relatively warm period in between ice ages. Another name for the Holocene that is sometimes used is the Anthropogene, the "Age of Man." This is somewhat misleading: humans of our own subspecies, *Homo sapiens sapiens*, had evolved and dispersed all over the world well before the start of the Holocene. Yet the Holocene has witnessed all of humanity's recorded history and the rise and fall of all its civilizations. Humanity has greatly influenced the Holocene environment; while all organisms influence their environments to some degree, few have ever changed the globe as much, or as fast, as our species is doing. The vast majority of scientists agree that human activity is responsible for "global warming," an observed increase in mean global temperatures that is still going on. Habitat destruction, pollution, and other factors are causing an ongoing mass extinction of plant and animal species; according to some projections, 20% of all plant and animal species on Earth will be extinct within the next 25 years.

Yet the Holocene has also seen the great development of human knowledge and technology, which can be used -- and are being used -- to understand the changes that we see, to predict their effects, and to stop or ameliorate the damage they may do to the Earth and to us. Paleontologists are part of this effort to understand global change. Since many fossils provide data on climates and environments of the past, paleontologists are contributing to our understanding of how future environmental change will affect the Earth's life.