Introduction

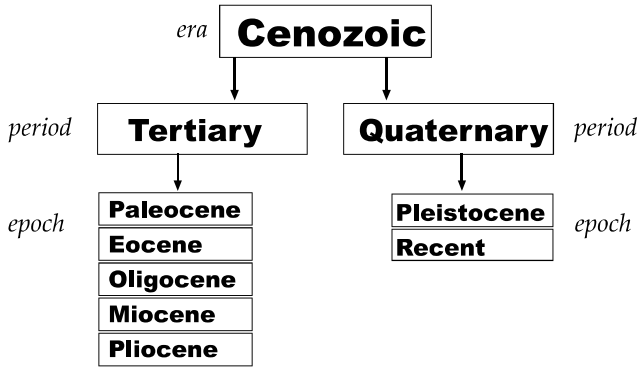
The sequence of Earth's history or geologic time covers such a large expanse of time that scientists have divided it into smaller units. **Eras**, **periods**, and **epochs**—the subdivisions of geologic time—are markers of the major changes in Earth's crust.

Changes in and on Earth's crust have caused many organisms to change or evolve over time. The study of the age of rocks, rock layers, and **fossils** is the scientists' way of solving the mystery of the earliest life form and the age of Earth.

Divisions of Geologic Time

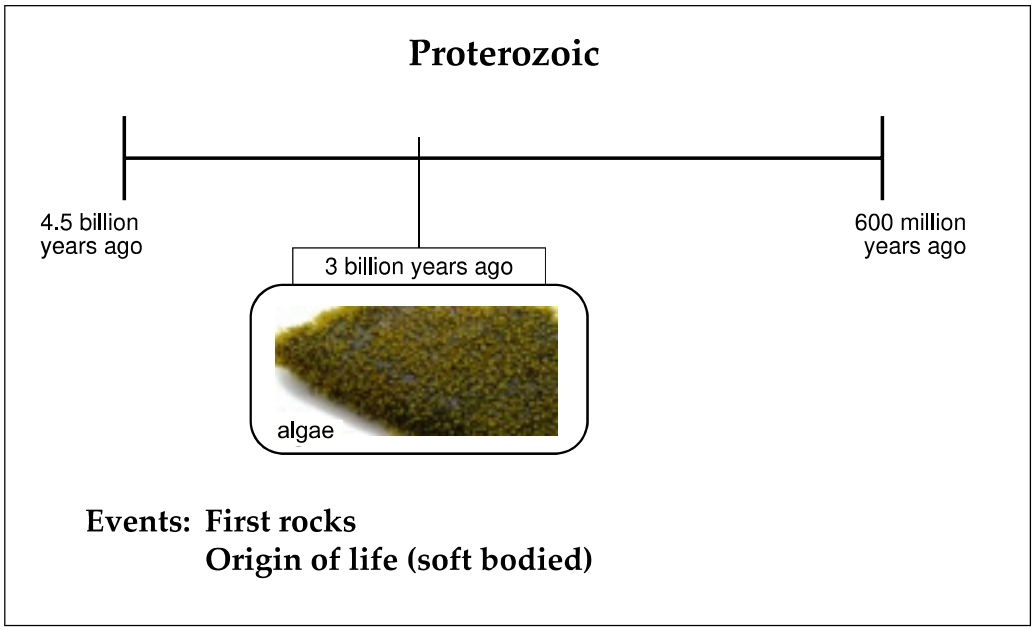
Geologists are scientists who study the origin, history, and structure of Earth, and the processes which change its surface. Geologists believe Earth to be about 4.5 billion years old. In order to study the events that happened on Earth more accurately, Earth is divided into periods of time, creating a **geologic time scale**. The largest divisions of geologic time are called *eras*. The length of an era is measured between major changes in Earth's crust called **revolutions**. Revolutions consist of violent volcanic activity and crustal movements causing major changes in Earth's surface. There are four major eras. From oldest to most recent, they are the **Proterozoic**, the **Paleozoic**, the **Mesozoic**, and the **Cenozoic**.

Enough is known about the three most recent eras to further break them down into smaller divisions called *periods*. The Paleozoic has seven, the Mesozoic has three, and the Cenozoic has two—thus far. Minor revolutions, such as climatic changes and the presence of fossils, mark the beginning and end of periods. Periods are usually named for the locations where these changes were discovered. For example, the Devonian Period was named after Devon, England.



Proterozoic Era

The first geologic era of Earth is called the Proterozoic. This era covers almost 90 percent of the age of Earth. It began with the formation of Earth and lasted until about 600 million years ago. Proterozoic time was marked by episodes of mountain building and the formation of the first rocks on Earth. The first living things developed during this era. They were simple, single-celled microorganisms such as protozoans and bacteria. Later, after the oceans formed, algae and simple invertebrates such as sponges and marine worms appeared. Since all of these life forms were soft bodied, they left very little fossil evidence.



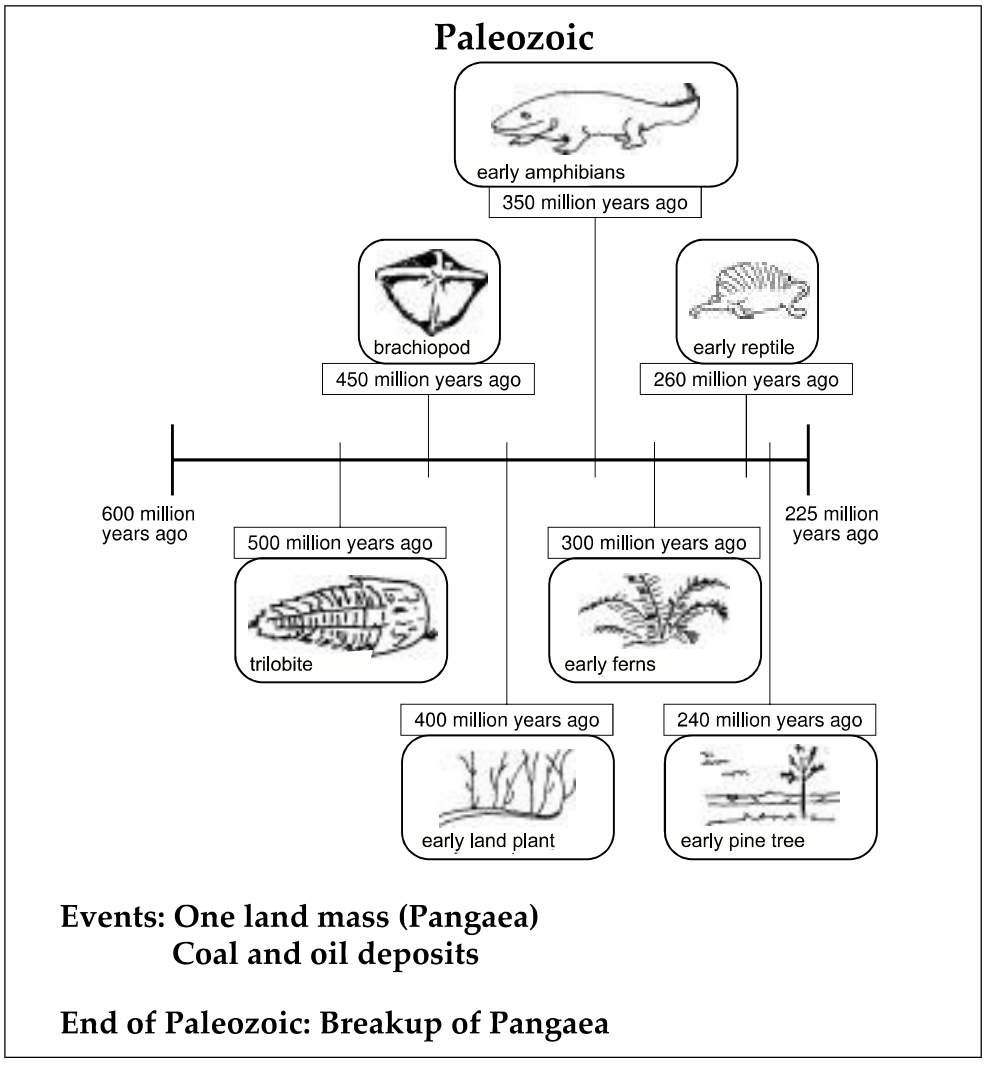
Paleozoic Era

An abundance of fossils marked the beginning of the Paleozoic era, which means *ancient life*. The Paleozoic Era began 600 million years ago and lasted until 225 million years ago. It is subdivided into six periods: the Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and the Permian.

The Paleozoic Era began with the appearance of a large number of small marine invertebrates such as **trilobites**, believed to be ancestors of horseshoe crabs. There were also **brachiopods**, which were clam-like

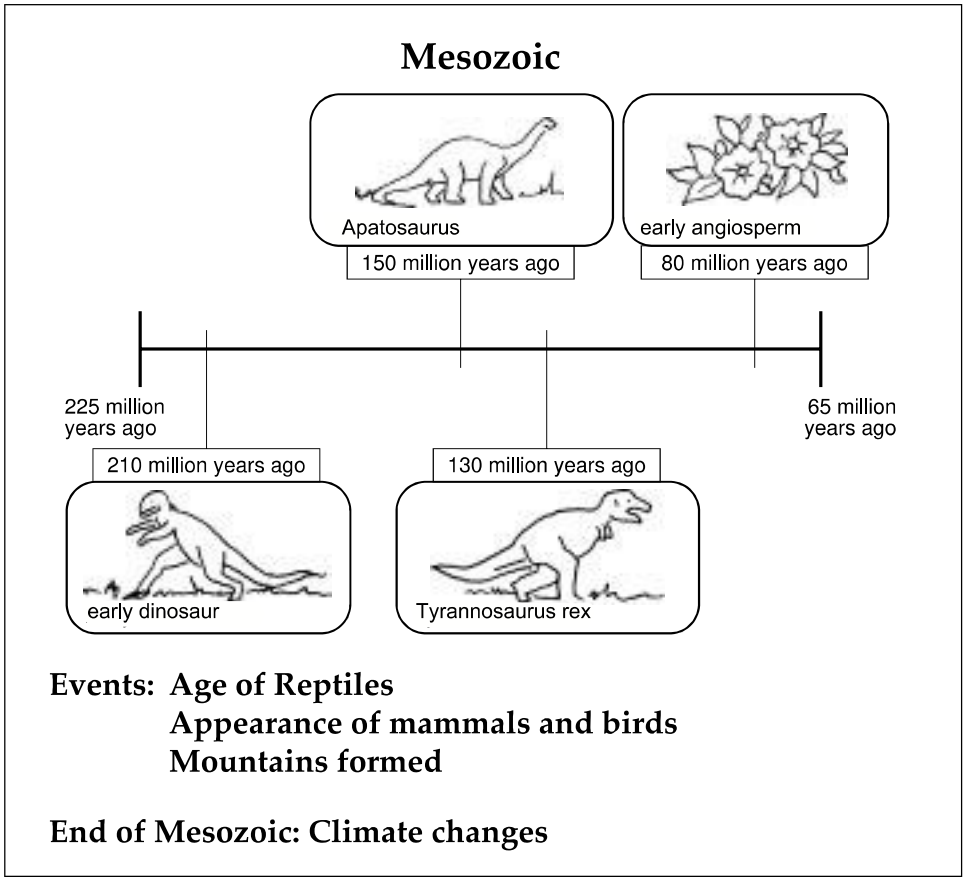
Pangaea

organisms. In later periods, land plants and animals developed. Vertebrate animals such as fish, amphibians, and reptiles appeared by the end of the Paleozoic Era. Thick forests of ferns and conifers (cone-bearing trees) appeared. During the second half of the Paleozoic Era, a variety of natural resources began forming. Fossil fuels, such as coal, oil, and natural gas, are found in rocks from the Paleozoic Era. During this period, geologists believe that the land portion of Earth was one huge continent now called *Pangaea*.



Mesozoic Era

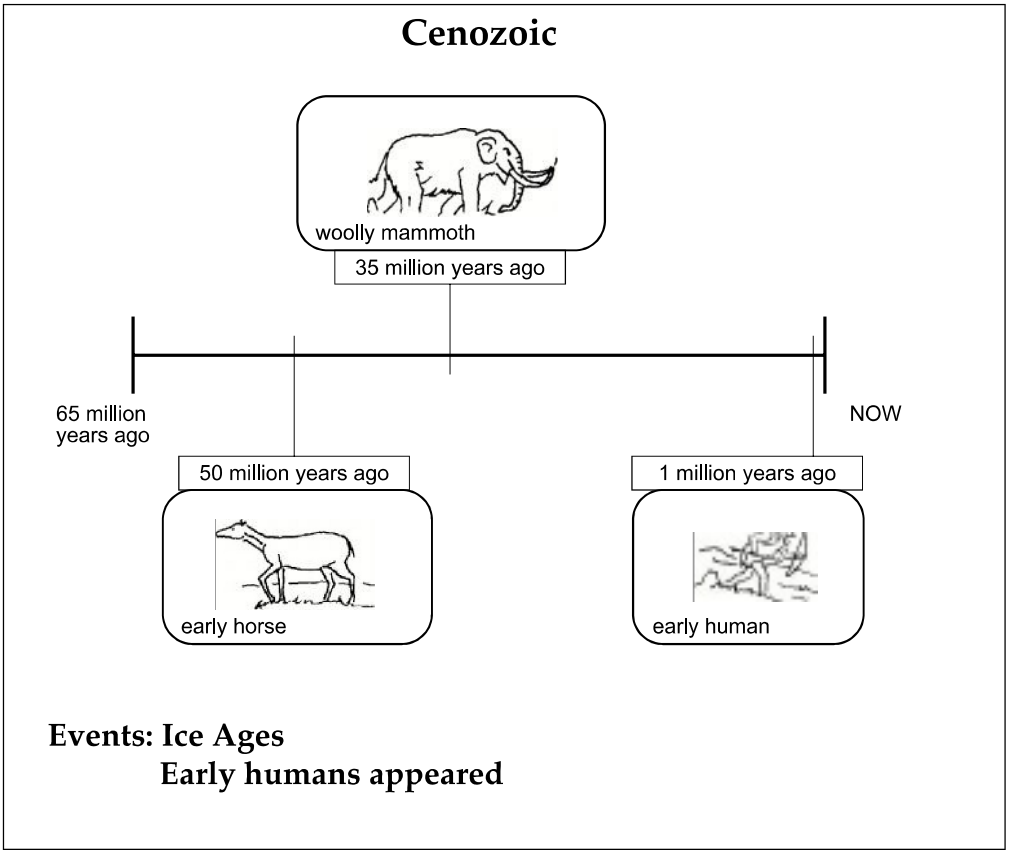
The breaking apart of Pangaea into separate continents marked the end of the Paleozoic and the beginning of the Mesozoic Era, which means *middle life*. This era began 225 million years ago and lasted until 65 million years ago. The Mesozoic Era is divided into three periods: the Triassic, Jurassic, and Cretaceous. The climate was mild during this era. Dinosaurs and other reptiles were the dominant form of life, which gave this era the name *Age of Reptiles*. Mammals and birds made their first appearance on Earth, as did flowering plants. Major geological changes occurred on Earth during this era. Most of our major mountain ranges were formed due to the movements of crustal plates. Towards the end of this era, the climate began to change as the warm tropical climate was replaced by colder temperatures. By the end of this era, the great dinosaurs had become **extinct**, or no longer living on Earth, possibly because of their inability to adapt to the climatic changes. Others have suggested that a large meteorite collided with Earth. This impact might have caused the climate changes and the extinction of the dinosaurs.



Cenozoic Era

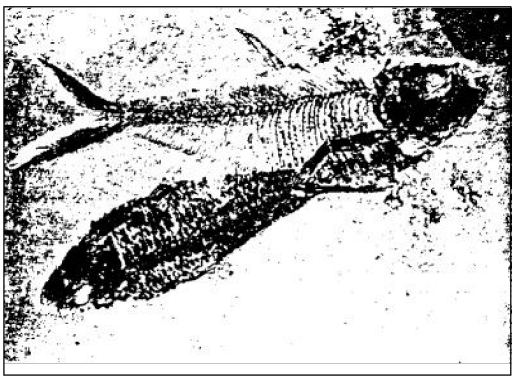
We are now in the last era, the Cenozoic Era, which began 65 million years ago. This era is commonly called the *Age of Mammals*. Because of excellent fossil records, more information is known about this era than any other era. Therefore, the Cenozoic Era's two periods, the Tertiary and Quaternary, are subdivided into smaller units called *epochs*. The Tertiary period has five epochs: the Paleocene, Eocene, Oligocene, Miocene, and Pliocene. The most recent period, the Quaternary Period, is divided into the Pleistocene and Recent Epochs. (See page 261.)

The climate late in the Cenozoic Era, in the Quaternary period, became much colder than during the Mesozoic Era. Several Ice Ages took place. Different types of large mammals that were adapted to the colder temperatures, such as the woolly mammoth, appeared. Angiosperms became the dominant plant forms because they could tolerate the colder climate. The landforms that we find today developed during this era. Humans appeared on Earth near the beginning of the last period of this era, which was between 500,000 and 1,000,000 years ago.



Fossil Formation

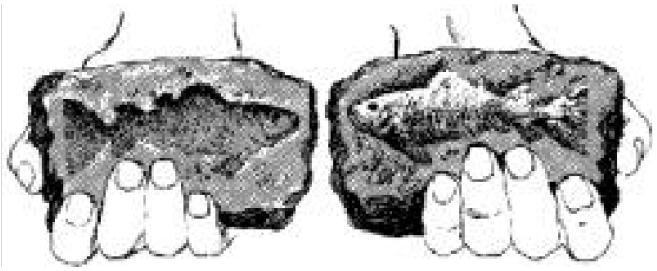
Fossils are the remains or traces of prehistoric plants and animals preserved in rock. Scientists who look for and study fossils to learn about Earth's history are called **paleontologists**. Because most dead organisms are eaten or *decay*, only about one percent of past life is left to become fossils. There are different types of fossils. Sometimes remains, or actual parts of the organism, will be found. Other times only evidence, such as a fossil footprint or imprint of the organism, will be discovered.



fish fossils

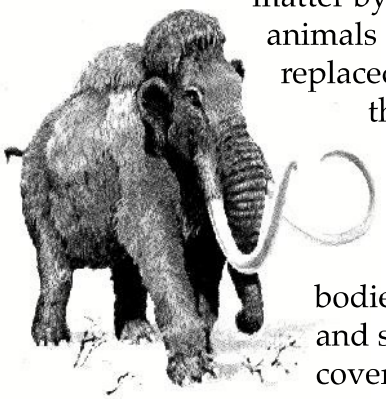
Most fossils are found in *sedimentary rock*. Organisms that lived near water were more often preserved than those that lived in drier regions. When the organism died, it must have been covered with sediment very quickly to prevent it from decaying or being eaten by other organisms. The *sediments* hardened, and the organism was preserved between the rock layers. Sometimes when an organism is buried in sedimentary rock, its soft parts decay, and the hard parts are dissolved, leaving only an impression. When this happens, a cavity called a **mold** forms in the rock in the exact shape of the organism that died. If this cavity becomes filled with sediments that harden, a **cast** of the original organism forms. This is a fossil.

Many ancient organisms left impressions in sediments that eventually hardened into rock and were preserved. Fossils formed in this way are called *imprints*. The activities of these animals left footprints, tracks, and burrows which formed fossil imprints called **trace fossils**. The trace fossils of dinosaurs and other animals that are *extinct* left important clues for scientists that led them to other discoveries about the animals.



imprint of a fossil

The remains of some ancient fossils have been preserved through **petrification**. Petrification is the gradual replacement of the organic matter by a stonelike substance. As ancient plants and animals decayed, the organic matter in their bodies was replaced by minerals. The minerals then hardened in the same shape or form of the organism that died.



Ice, tar, or resin would sometimes preserve the entire plant or animal. Entire animal bodies were buried and frozen in large masses of ice and snow. When animals fell into tar pits, they were covered with tar and thus preserved. Many large animals, including the saber-toothed tiger and wooly mammoth, have been found in the La Brea Tar Pits in California. The sticky resin of pine trees preserved entire insects that became imbedded in the resin. After thousands of years, the resin was hardened, forming *amber*. The preservation of entire animals or plants in these ways gave scientists a great amount of information about these animals and their time periods.

Evidence of Earth's History from Fossils

The study of fossils is important to scientists because it gives them many clues as to how living things changed throughout geologic time. Divisions of geologic time are based on the appearance and disappearance of fossils.

Fossils used to divide geologic time into units are called **index fossils** or guide fossils. Index fossils identify the age of the rock in which they occur. These are fossils of plants and animals which only lived for a short period of time but were found in many areas of Earth. It can be determined that these fossils, although found in different areas, must have formed at the same time. Other fossils are the remains and imprints of species that lived over long periods of time, but only in certain areas. The disappearance of these fossils may indicate climatic or other changes which caused the extinction of the species.

By studying fossils, scientists have also learned how the surface of Earth has changed over time. For instance, fossils can help determine if and when an area was covered with water. If fossils of marine animals are found on land, scientists can assume that the land was once covered with water. Also, fossils found in layers of sedimentary rock, such as those found in the Grand Canyon, provide clues to the past climate of the area.

Fossils are also important tools for determining the age of sediments. Since fossils contain organic material, their age can be determined by the **half-life** of the **carbon-14** in them. Once the age of the fossil is determined, the age of the sediments will be approximately the same age as the fossil. However, if a fossil is found in a cave or canyon, it can only be assumed that the age of the rock is older than that of the fossil.

bee fossils

Ways to Determine the Age of Earth

Geologists have tried to measure geologic time using several methods. Since they are dealing with such a long period of time, it is very difficult to determine the exact dates when events occurred. Geologists use both relative and **absolute dates** when measuring geologic time. Absolute dates tell us how many years have passed since an event took place. **Relative dates** place events in historical order by comparing them with other happenings that took place, but they do not tell us how many years ago the events occurred. Several methods have been used to measure geologic time. They include 1) studying **rates of sedimentation**, 2) studying **rates of erosion**, 3) studying **radioactive decay**, and 4) studying evidence of fossils.

Methods for Measuring Geologic Time

- studying rates of sedimentation
- studying rates of erosion
- studying radioactive decay
- studying evidence of fossils

Scientists have studied the rate of sedimentation, or the amount of sediment deposited over time, to determine geologic time. Most sedimentary rocks are laid down in layers with the oldest layers on the bottom and younger layers near the top. This is called the **law of**

superposition. The sedimentary rock layers of the Grand Canyon are an excellent example of this law. Sedimentary rocks only give clues to relative ages of rocks rather than giving absolute dates.

At one time, scientists believed that geologic time could be measured by the *rate of erosion*. They assumed that the rate of erosion throughout time had always been the same. Their estimates were not accurate because the rate of erosion varies with the hardness and thickness of the rock and with the amount of precipitation that fell.

In the late 1800s, the work of Antoine Henri Becquerel and Marie and Pierre Curie led to the discovery of radioactive elements. They found that certain elements, such as uranium, were radioactive and gave off invisible energy waves. These radioactive elements would decay or break apart at a constant rate called a *half-life*, which is the time it takes one-half of the atoms of a sample of the material to decay. The half-life of radioactive elements varies for each element. By determining the half-life of radioactive elements found in rocks, scientists could accurately determine the age of the rocks. Radioactive carbon, called *carbon-14*, can be used to tell the age of materials that were once living.

All living things take in a certain amount of carbon-14 from the plants they eat. When they die, the carbon-14 that is already present in their bodies begins to decay. The age of bones, shells, wood, and other remains of plants and animals can be determined by measuring the amount of carbon-14 found.

Summary

Earth's history is outlined in the geologic time scale. The largest subdivisions are called eras. Each era is divided into periods and the periods into smaller units called epochs. You are living in the Recent Epoch of the Quaternary Period of the Cenozoic Era. Ways to measure geologic time include studying rates of sedimentation, rates of erosion, radioactive decay, and evidence of fossils.