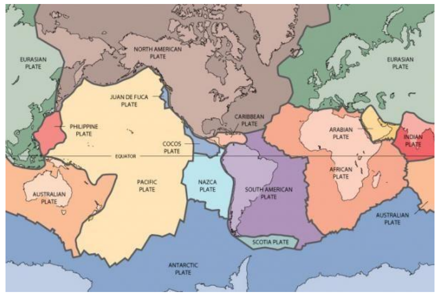
Chapter 8: Plate Tectonics and Geologic Time

Plate Tectonics and Geologic Time



https://en.wikipedia.org/wiki/Plate_tectonics

Guiding Question: When Alfred Wegener first proposed the hypothesis of continental drift other scientists of his time did not agree with his ideas. Look at the images and think about the possible evidence that he could have used to support his hypothesis.

Learning Outcomes

At the end of this chapter, the students will be able to:

1. Explain how continental drift helped form current continents
2. Support Wegener's theory of continental drift
3. Describe seafloor spreading
4. Explain how fossils help with radiometric dating
5. Explain the theory of superposition
6. Compare and contrast the types of boundaries and faults
7. Define uniformitarianism
8. Diagram the important events for each geologic time span

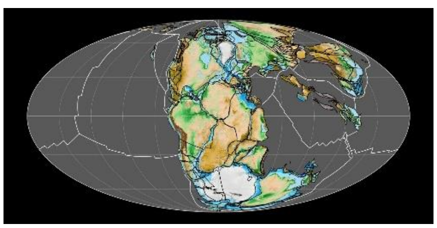
Essential Vocabulary

- Continental drift
- Lithosphere
- Seafloor spreading
- Asthenosphere
- Plate tectonics
- Divergent boundaries
- Convergent boundaries
- Transform boundaries
- Fossils
- Uniformitarianism
- Radiometric dating
- Geologic eras and epochs

Overview and Introduction to Plate Tectonics

What does the Earth look like under the oceans? How can we, as man, discover how the Earth's continents became the land forms we see today? Was there really a huge supercontinent or were the continents the same 4.6 billion years ago as they are now? We know what the land forms look like, but are those same features under the ocean? Those are the kinds of thoughts that challenged scientists in the 1800s and 1900s. It was a time of many unconventional scientific ideas. For example, Alfred Wegener proposed continental drift which lead to ideas about plate tectonics. It was a time of scientific learning that was coming almost faster than scientists could manage the knowledge. And much of the information was shaking scientific learning by its very foundations.

When, in 1912, Alfred Wegener proposed his theory about continental drift it was revolutionary. The theory described one way to explain how continents moved over time. However, his fellow scientists did not agree with Wegener and it took until the 1950s for his hypothesis to be accepted as the continental drift theory. This theory explained that the continents are slowly drifting around the Earth. His main evidence was the formation of the large continents and how the shapes seemed to fit together like puzzle pieces. As you can see from these pictures, Wegener's ideas were supported by hard evidence. Let's explore the idea of plate tectonics further.



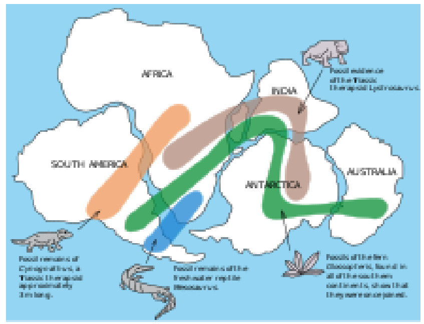
https://en.wikipedia.org/wiki/Pangaea#/media/File:Pangaea_200Ma.jpg

https://www.worldatlas.com/continents

That idea that the continents fit together was supported by the shapes of the different continents. When you look at the world map, it is easy to see how South America and Africa "fit together." He proposed the idea of Pangaea, a super continent. He also proposed that it broke up about 200 million years ago and the smaller continents started to move apart. However, scientists wanted more evidence in support of the idea of continental drift.

Continental Drift

If you read about the history of the Earth and how our continents developed, you will find that more than just volcanoes and erosion have changed the landscape of the Earth. Evidence from the examination of the different continents has demonstrated that the continental shelf from each continent actually seemed to fit together across the various continents. Not only did the land masses seem to fit together, evidence from fossil remains indicated that certain plant and animal fossils were found on land areas that were separated by large bodies of water. That evidence provided additional support to the idea that the land masses were once connected as a supercontinent. At some point, scientists identified the large landmass as Gondwana. This supercontinent was formed by the multiple collisions that occurred during the Paleozoic Era. It took another several number of years before Gondwana and Euramerica joined to form the larger area called Pangea. After a while, Pangea broke up into the continents we know today.



https://en.wikipedia.org/wiki/Alfred_Wegener

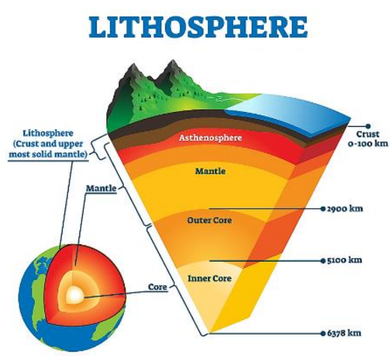
Today, South America, Africa, Antarctica, India and several other areas are the result of Gondwana breaking up. When it was discovered that the same fossils and rock strata formations were present on continents with significant distances between them, more of Wegener's colleagues began to support his theory.

Originally, scientists thought there were two supercontinents: Gondwana and Euramerica. These existed almost 200 million years ago. The two parts became Pangea which was the supercontinent proposed by Wegener. He also proposed that Pangea broke apart into current continents and those continents drifted apart until they reached their current locations. He called this continental drift. And, while Wegener was a well-respected scientist, he could not provide an adequate explanation of how these huge continents were moved. In other words, he provided no mechanism for the movement that could be readily accepted by his colleagues. As a result, his ideas were largely ignored. It should be noted, however, that Wegener worked hard to keep these ideas in the forefront of scientific discussions until his death. It was not until technological advances allowed the United States Navy to study the ocean floor that strong evidence was provided to support Wegener's theory. They found the ocean floor topography is composed of many land features that are similar to the continental topography. In other words, the ocean floor has mountains, plains, valleys and other features that exist on our continents. Using this new information, another scientist, Harry Hess, reexamined Wegener's theory and provided the mechanism for continental drift. Hess showed how the seafloor was always changing and that there must be some molten material that allowed the tectonic plates to float and move. This softer layer is the asthenosphere and allows the rigid plates to move on the Earth's surface. This is plate tectonics.

Some historical context might be good here. Scientists did not give credence to Hess and Wegener's theories and did not really consider the topography of the Earth's crust under the oceans. World War II changed that. During the war, using submarines made is essential for all countries to keep track of the locations of submarines. While doing that, it was discovered that the ocean floor had many topographical features. After the war, the United State Office of Naval Research continued ocean floor mapping using Sonar technology. Sonar (Sound Navigation and Ranging) uses sound waves to calculate the depth of the ocean floor. That technology allowed scientists to identify the features on the ocean bottom, including mountain ranges, seamounts, and abyssal plains. Today scientists use multibeam sonar systems to map the seafloor. This newer technology allows scientists to have a more detailed understanding of the ocean floor. Even today only about 25% of the ocean floor has been mapped. The goal is to have the entire seafloor mapped by 2030.

So, what does it mean by plate tectonics? These discoveries by Wegener and Hess helped to develop the theory of plate tectonics. If you study the Earth's crust, you will find that it is not very thick (between 50 to 280 km) but it is rigid. It is, however, broken into several plates that range in size from small to large. As a group, this is called the lithosphere. The lithosphere is hard and rocky and, on Earth, is made up of the crust and a small part of the upper mantle. The lithosphere "floats" on a somewhat molten substance known as the asthenosphere. And, you probably recall that the crust (or lithosphere) is composed of metamorphic, igneous and sedimentary rock. The asthenosphere, softer than the plates and more viscous, allows the plates to move across the Earth's surface. Augustus Edward Hough Love (1911) suggested the existence of the plates and he, and his colleagues, are now credited with developing the theory of plate tectonics.

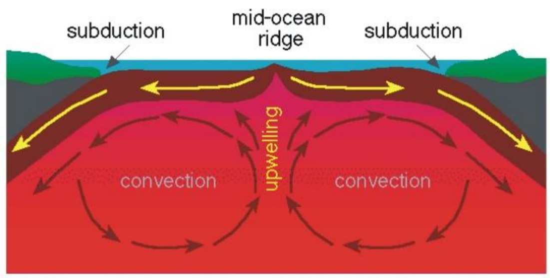
The theory of plate tectonics states that the uppermost crust, along with the uppermost mantle, behaves like a strong, rigid layer known as the lithosphere. This lithosphere is broken into a series of plates which are thinnest under the ocean and thickest on the continents. The lithosphere "floats" on a less rigid layer called the asthenosphere. Since the asthenosphere is less rigid that the lithospheric plates, it allows the plates to move across the globe. The movement of the asthenosphere results from gravitational heat convection, keeping it a semi fluid. There are seven large lithospheric plates and many smaller ones. The largest is the Pacific plate.



https://www.worldatlas.com/geography/what-is-the-lithosphere.html

Given that the lithosphere ranges in depth, it is easy to realize that the thinnest part of the lithosphere is under the ocean, while the thickest part makes up the continents that we live on. This allows us to classify the lithosphere as oceanic or continental. The oceanic lithosphere is under the ocean and commonly called the sea floor. Because the sea floor is always being renewed, the oceanic lithosphere is generally younger than the continental lithosphere. The oldest oceanic lithosphere is about 170 million years old.

The continental lithosphere ranges from 40 km to 280 km. It makes up about 30% of the Earth's surface (the ocean covers about 70%) and is made up of features like mountains, valleys, plans, and other surface features. The continental lithosphere is critical to Earth's survival as the plants that supply food and oxygen are supported on the land area. You should also think about the lithosphere as covering the entire Earth's surface, including under the oceans. When you consider the lithosphere being under the oceans, it then makes sense that there are features on the ocean floor that are similar to the feature on the continents. One difference between the continental crust and oceanic crust is that the seafloor is continuously being recycled in a process called seafloor spreading.

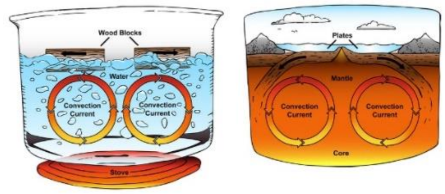


https://publish.illinois.edu/platetectonics/a-shift-to-plate-tectonics/

Seafloor spreading is a process that occurs under the ocean and new crust is formed. Generally, this occurs at the mid-ocean ridges. To fully understand seafloor spreading, you will need to remember that the Earth's crust is only one layer of the Earth's composition. The crust sits on the mantle, and, technically the crust and asthenosphere meet the uppermost part of the mantle. The mantle convection causes the hot rocks to expand, become less dense, and rise, allowing cooler and heavier rocks to sink. Those mantle convection currents result in plate tectonic movement, including producing earthquakes and volcanoes.

In seafloor spreading, the warm rock from the mantle wells up at sites like the mid-ocean ridge. The force makes the seafloor spread to let the warm rock seep through the opening. The new molten material them spreads out and cools, producing new seafloor. Seafloor spreading can be summarized into four easy steps. First a long crack forms at the mid-ocean ridge in the ocean's crust. Then the molten materials from the mantle rises and comes up through the crack, Third, the older rock moves outward from the crack in the ridge. Finally, the molten material cools and forms a strip of solid rock in the center of the ridge, sealing up the crack. Of course, you have concluded the rock nearest the ridge is "younger" than the rock farthest away from the ridge, which provides evidence for the theory. Just in case you were wondering, Hess and Wegener provided the original hypotheses about seafloor spreading. The old crust is melted back and recycled into magma and the process continues.

Scientists have studied the movement of mantle convection and believe the tectonic plates move because of the convection currents that circulate in the mantle. Think of boiling water with the two blocks sitting in the pot. As the water gets warmer and begins to boil, those blocks will move as a result of the hot water motion. That is exactly what happens to the tectonic plates as the currents in the mantle move under them.

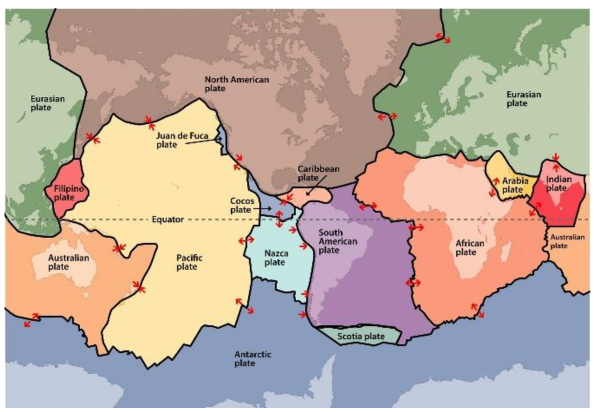


http://science8sc.weebly.com/convection-currents.html

The boundary between the crust and the mantle is called the Mohorovicic discontinuity (Moho for short). It separates the crust from the underlying mantle. It marks the lower limit of the Earth's crust and marks the area where seismic waves change velocities. At the Moho, seismic waves accelerate.

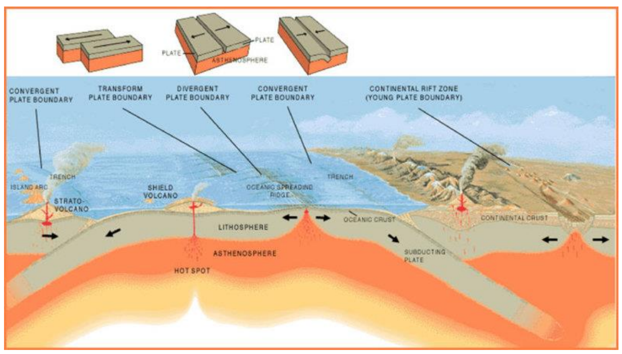
The plate tectonic theory implies that the plates move in relation to each other. In other words, locations on the same plate will stay about the same distance apart as the plates move. It is interesting to note that scientists think plates move about 5 centimeters a year! When the plates move, they can grind part each other or even bump into each other. The force of these movements along the edges of the plates can end up producing earthquakes, volcanoes, or even mountains. These areas are called plate boundaries.

As previously stated, there are seven large lithospheric plates. These are the North American, South American, Pacific, African, Eurasian, Australian-Indian and Antarctic. Just in case you did not notice, these are the main continents. These plates generally contain the continent and these allow the continents to move along the plate boundaries. The theory of plate tectonics proposed that the continents are located on the larger plates that move and result tin Earth's seismic activity along the plate boundaries.



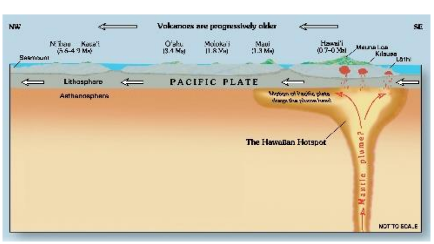
https://ugc.berkeley.edu/background-content/plate-tectonics/

There are four major types pf boundaries: divergent, convergent, transform, and hotspot. Let's examine each of these boundaries. First, *divergent boundaries* occur when two tectonic plates move apart (diverge). As these boundaries move, it is common for earthquakes to occur. It is also along these divergent boundaries that magma rises from the Earth's mantle to the surface, cooling and becoming solid as new oceanic crust is formed. In many cases, this occurs under the ocean and accounts for seafloor spreading and build up. The fact that little sea floor has been found to be over 180 million years old supports this theory. This accounts for the recycling of crust and the young seafloor. An example is, as mentioned before, the Mid-Atlantic Ridge. While divergent boundaries do not often occur on the continents, an example is the East African rift valleys. There are scientists who believe the African continent may be splitting and its northern portion moving towards Europe and into the Mediterranean Sea. The result might be a new ocean basin on the African continent. As indicated, divergent boundaries move apart, while *convergent boundaries* move together. Convergent plates are not always made of the same materials. If one plate is denser than the other, the heavier plate may slide under the lighter, less dense plate. This is called subduction. Subduction of the oceanic plates can result in deep ocean trenches. Sometimes two plates, one continental and one oceanic come together and subduction occurs, the impact can cause the edges of one or both plates to buckle up and mountains result from that impact. This occurred along South America and resulted in the Andes mountain range. If the two converging plates are the same density, such as the Eurasia and Indian plates, come together. This happened about 60 million years ago and resulted in the Himalayas. Volcanos and earthquakes are common along convergent boundaries. The Pacific Ring of Fire is a great example of a convergent boundary. The third type of boundary results when two plates slide past each other. These are called transform fault boundaries. The transform fault areas are always moving, although usually very slowly. The irregularities in the rock face along the fault prevent the rocks from moving rapidly. However, eventually the rocks either give way or are worn away and the transform boundary moves abruptly. The plates move past each other quickly and abruptly. The result is an earthquake. An example is the San Andrea's fault. Faults move past each other, but can also move up or down. When they move up or down, it appears as cliff like areas. Examine the three major type of faults in this illustration:

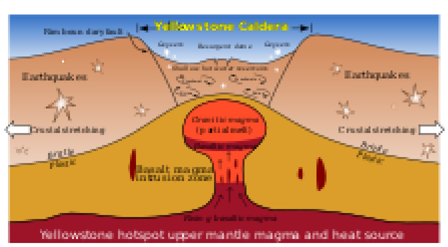


https://oceanexplorer.noaa.gov/facts/plate-boundaries.html

The final type of fault is classified as a hot spot. This is an area under the crust where the magma is hotter than the surrounding magma. This causes the crust to melt and become thinner. This is called a mantle plume and results in significant volcanic activity. Hot spots occur far from plate boundaries which is what makes them so interesting. The volcanos that form at hot spots do not form chains, but do have volcanic activity. A perfect example of a hit spot are the volcanos that form the Hawaiian Islands. Hot spots can occur in the oceans as well as on the continents. Yellowstone is a continental hot spot.



https://en.wikipedia.org/wiki/Hotspot_%28geology%29



https://en.wikipedia.org/wiki/Yellowstone_hotspot

While scientists continue to tell us the Earth's plates are moving, they move so slowly that few of us think about the motion. After all. Unless an item has moved significantly, few people notice the change in position. Scientists inferred the motion and predicted the changes were occurring. Advances in technology have finally supported these inferences. Satellite technology has allowed scientists to measure the changes in the locations of the plates and have calculated continental movements. Imagine if Wegener and Hess could come back to see how their insights have shaped the scientific community!

Overview and Introduction to Geologic Time

There is no more fascinating study than that of our history and geological past. Each time you put gasoline in your gas tank, you are using plants from long ago eras. You wear jewelry that may have been the remains of dinosaurs. Go to any museum of natural history and you can imagine those huge animals walking around the Earth, eating plants larger than the buildings that house their remains. It was a time of many unconventional scientific ideas. For example, Charles Darwin proposed natural selection and Alfred Wegener proposed continental drift. It was a time of scientific learning that was coming almost faster than scientists could manage the knowledge. And much of the information was shaking scientific learning by its very foundations.

And the learning continues to amaze scientists! The television program 60 Minutes reported a recent discovery of a young boy's remains in central Africa. Who did that discovery? It was a young boy about the same age as the boy whose bones were found near an area that may once have been a well. What else was found inside that well? The remains of a female that may have been the child's mother. Can you imagine the story that went along with those bones and artifacts? And, how old were those ones?

First, let's review the types of fossils that can provide evidence of living organisms. Of course, we know there are the original remains of the organism. We might even be able to dig in our yard and find the bones of different organisms. Great examples of original remain fossils can be seen here:



https://i.pinimg.com/originals/96/ca/33/96ca332134a3d0d8f054915c239dc197.jpg
https://m.media-amazon.com/images/I/61c9aEPBWrL._AC_SL1202_.jpg
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These organisms were trapped in amber so they look a great deal like the living ones of today. However, most original remains are the hard parts of the organism, like shark teeth and bones. Other types of fossils are called replacement fossils. This type of fossil occurs when the hardest parts of the buried organism are replaced by different kinds of minerals. That produces a copy of the original organism. I am sure you have seen imprints of feet or leaves in cement. This might be called a mold fossil because it leaves a depression. Examine the fossils here:

http://photos.demandstudios.com/getty/article/3/70/180354634.jpg

https://images.wisegeek.com/fish-fossil-in-rock.jpg

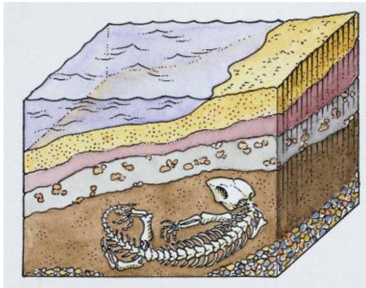
Besides molds, there are cast fossils. These fossils occur when a new mineral fills in the mold and a cast of the original organism forms.

https://www.reddit.com/media?url=https%3A%2F%2Fi.redd.it%2F52lv3oe85ej31.jpg

The last type of fossil is a trace fossil. This is exactly what it sounds like – there trace evidence of the organism's existence. These include tracks, or borings in wood. There is often evidence in old furniture of organisms that once lived in the furniture many years ago. They could be tracks or trails:

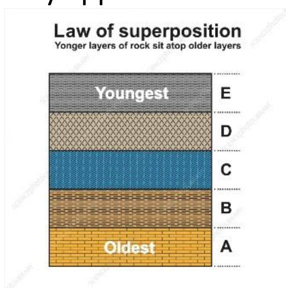
https://image3.slideserve.com/5508489/slide11-l.jpg

Earth's history began when Earth was formed, but the evidence of fossils is the only way scientists can develop a record of how climate and environmental conditions changed over its long evolution. The fossil record also helps scientists try to understand how life began on Earth. While generally not found in igneous or metamorphic rock, almost all fossils are more often found in the layers of sedimentary rock. Recall from the previous chapter that sedimentary rock is laid down in layers. Those layers pile up on top of each other, with the youngest layer on the uppermost level.



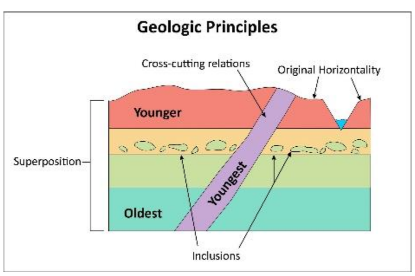
https://socratic.org/questions/why-are-sedimentary-rocks-the-only-rock-type-to-contain-fossils

This idea was translated into a geological law by Nicolas Steno in 1669. It was later discussed again by William "Strat" Smith and is also known as the first of Smith's' laws. The Law of Superposition states that sedimentary rock layers are stacked up in order of age. Each layer is older that the layer above it but younger than the layer under it and in horizontal layers. You can observe this phenomenon when you drive from Albany to Atlanta and see the layers of sedimentary rock. This law is one of the strategies used to determine the relative age of the rock layers as well as any fossils that may appear within those layers.



https://www.sciencephoto.com/media/1311110/view/law-of-superposition-illustration

To supplement the Law of Superposition, scientists theorized that the layers are deposited from above and laid horizontally. That became another geologic law. The Law of Horizontality states that layers of rocks are deposited horizontally but , on occasion, can later be compressed or deformed. That deformation can sometimes lead to the wrong conclusions regarding age of a fossil or layer. Some of the sources of error when dating fossils are shown in the illustration. Positions of fossils can change due to compressing of the rock layers and making it appear different ages. On other occasions, parts of the layers are eroded away and fossils appear to be younger or older than the original age. Finally, cross cutting is any feature that cuts across a layer of sediment or rock that is actually younger than the rock/layer that it cuts through.

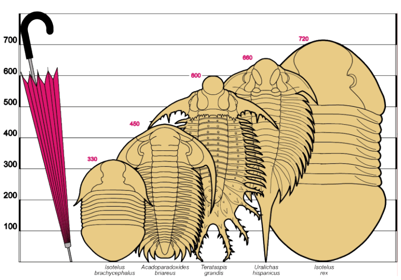


https://silurian-reef.fieldmuseum.org/narrative/411

These irregularities in the horizontal layers impacts how scientists determine the age of fossils. However, scientists determined that these irregularities, like erosion, weathering and deposition, have been happening for millions of years. The result was another idea called the principle of uniformitarianism. All these ideas support the idea that scientists can determine the age of fossils. And, why is this important? The preserved remains of formerly living organisms tell the historical record of Earth's geologic history and can help scientists understand how evolutionary development occurs in Earth processes as well as in living organisms. Dating fossils helps scientists collect evidence to when it existed and helps build that evolutionary history of the Earth. There are two main types of dating we will examine: relative dating and radiometric dating.

Relative dating was developed during the early days when geology first emerged as a natural science. The laws and principles discussed above lead scientists to determine that fossils that were found in the same layers were approximately the same age. Relative dating of a rock compared the rock It did not consider any of the irregularities like cross cutting. Relative dating assumes the age of the fossils could be compared to the age of another nearby fossil. Scientists could determine the relative ages of rock layers in different locations by using what is called an index fossil. Index fossils are from organisms that lived during a short period of defined time and are found over a large area. In other words, the fossilized remains of specific plants or animals that lived during a particular limited geologic time and found over large distances and areas. The most commonly known index fossil is a trilobite. Trilobites are a group of marine arthropods that existed from 521 million years ago until about 250 million years ago. While they appear to have disappeared, new evidence about how and when they lived is still being discovered. As you can see from the illustration below, they were not small and evidence indicates they were carnivores.

https://www.rockngem.com/what-are-trilobite-fossils/



https://dinopedia.fandom.com/wiki/Trilobita

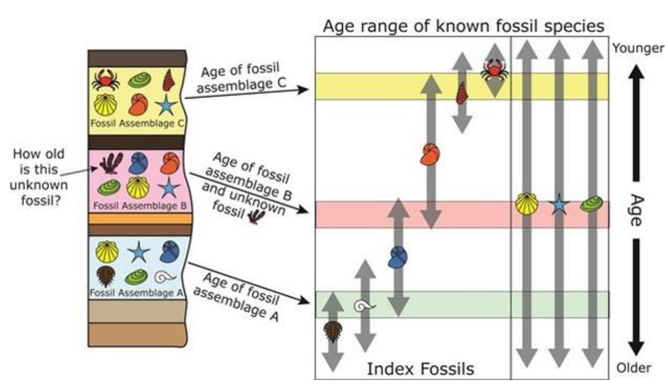
While index fossils provide a way to determine relative age, to be accurate, the Earth processes must stay uniform and the sedimentary layers need to remain stationary. However, rock processes are not uniform. Sometimes forces within the Earth cause older layers of rock to lift up into younger layers. Other times, young layers are eroded away and older layers appear to be the uppermost layer. The areas where an old eroded surface is in contact with a newer or younger rock layer is called an unconformity Unconformities can represent a gap in the relative ages of fossils. Faults, cracks in the Earth's crust which allows movement to occur at the site of the fault, can also impact the use of relative dating. There are also times when magma can be forced upward into the existing rock layers and harden. This is called an intrusion. Intrusions are younger and can impact relative dating. Magma that forms lava and hardens at the Earth's surface is called an extrusion. It soon became evident to scientists, that events that impact sedimentary layers also impact the relative dating of fossils. They needed a more accurate method.

While scientists could get a general idea of a fossil's age, a more exact age would benefit the study of evolutionary development. As a result, scientists wanted to determine the absolute age of fossils and rock layers. An absolute age gives the number of years since an event occurred or an organism lived. Scientists turned to radioactive elements to help provide this information.

Radioactive substances are unstable and decay. The unstable element decays into a more stable element (radioactive decay). The original radioactive material is called the parent element and the more stable element is called the daughter element. While the rate of decay is different for every radioactive element, the rate is measurable. The rate of decay is called the half life of the element. The half-life of an element is the time it takes for one-half of the radioactive element to decay to the more stable element. In other words, half of the parent element (radioactive) becomes the daughter element (stable element). That process of decay is what helps scientists tell us how old fossils are through radiometric dating. It provides a closer estimate to the absolute age of the remains of the living organisms. Scientists can determine the absolute age by calculating the amount of radioactive element remaining in the fossil or rock. Most of the time, scientists are trying to date fossils. Since fossils were once living organisms, and all living organisms contain Carbon-14, scientists can use that element to date the fossil. When a living organism dies, the Carbon-14 begins to decay. Since the half life of Carbon-14 is relatively short (5730 years), scientists can calculate how much has decayed and give a relative accurate age of the fossil. Scientists use Carbon-14 to find the age of fossils like Lucy and other ice age creatures.

While radiometric dating has been fairly accurate in finding how old fossils are, the newest technologies have made the process even more accurate. Scientists now use mass spectrometers to date fossils to get even more accurate predictions of age.

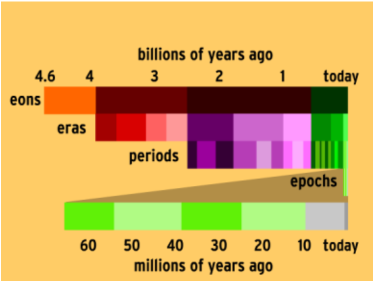
The following picture shows how all these laws and principles work together to help scientists predict the age of different fossils:



https://www.nature.com/scitable/knowledge/library/dating-rocks-and-fossils-using-geologic-methods-107924044/

Examine how the layers are shown horizontally. Then review the idea of superposition to determine which fossils are older. Finally, look at the fossil samples and identify the index fossils that could help age the samples. Think about how these fossils tell us about the events that characterize the different geologic time spans.

Geologic time is defined as the time we can define from the geologic evidence on Earth. For example, it can be defined as the Earth's history as recorded in the rock strata. It is like a calendar of the events that have formed Earth as we know it today. The ages of the Earth is so large, that the time spans are divided into smaller lengths called eons, eras, periods, epochs and ages. One type of evidence used to determine these time spans is evidence of living organisms.



https://www.brainpop.com/science/earthsystem/geologictime/

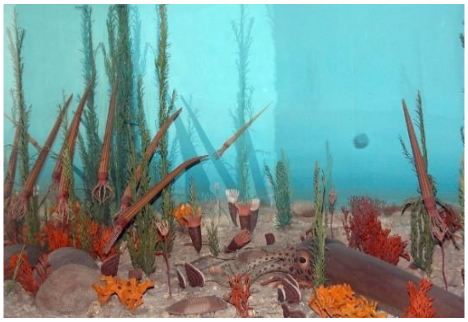
While geologic time started many billions of years ago, it may be difficult to identify specific times and events. To make this easier, geologists break the larger time into smaller components. The largest block are the eons. Eons are broken into eras, periods and epochs. Eras are the second longest unit after eons. Eras are subdivided into periods which is, again, a small unit of time. Epochs are the smaller, and subdivided into ages. Each time frame has important events that characterize that segment. For example, in the Mesozoic era there is a Jurassic Period. We all know that period from the movie: Jurassic Park. Now, let's find out a little more about each of these time frames.

Since the Earth is 4.6 billion years old, we can assume the geologic time started long ago. Let's start with Precambrian time. The time frame covers almost 90% of Earth's history (lasting almost 4 billion years) and includes the Hadean, Archean, Proterozoic (these three are often called Precambrian time) and Phanerozoic Eons. Generally, little is known about the Hadean and Archean Eons because there is little evidence to study. However, geologists do say the first eon may be considered the Hadean Eon which is considered to start 4.6 billion years ago, with the Earth's formation. It progressed to the Archean Eon, from 4.0 billion to 2.5 billion years ago. There was little known life during the Proterozoic Eon as well and, rocks from the eon, were not particularly fossil rich. Most of this time was spent with no oxygen on Earth and such an extreme hot temperature that life could not even survive. If any life existed it was unicellular. The Precambrian gives way to the Phanerozoic Eon, compromised of the Paleozoic, Mesozoic and Cenozoic Eras. Then, during the Phanerozoic Eon, about 2.4 billion years ago, cyanobacteria evolved. This was a very important evolutionary event because these organisms were the first to perform photosynthesis, allowing oxygen to build up in the Earth's atmosphere. There has been additional evidence of life evolving in the Precambrian time. For example, there are fossils that seem to indicate algae, flagellates and a few different organisms existed. There is also some evidence that, in the late Precambrian, the first multicellular organisms evolved. Life responded to the development of the atmosphere and oceans in this time period. As indicated, the fossil evidence indicated these organisms were doing photosynthesis, adding oxygen to the atmosphere. The oceans have been more stable during this time period and seems to have maintained that stability over time. The climate during the Precambrian was mostly influenced by the arrangement of the continents and the lack of volcanoes. Those external factors influenced the temperatures by impacting the temperatures of both oceans and atmospheric conditions. The Phanerozoic Eon had a significant impact on the evolution of the Earth and the beginning of life. And, it is evident in its name: Phanerozoic means "visible life," and the three eras are "old life [Paleozoic], middle life [Mesozoic], and new life [Cenozoic]." The majority of prehistoric knowledge about the Earth comes from these three eras due to the rapid evolutionary events that occurred. That is because there was some form of organic life, including both plants and animals. During the Paleozoic era, trilobites seemed to be common and plant life started. The Mesozoic era is called the age of dinosaurs and the Cenozoic is known as the age of mammals and the "youngest" of the times. The Quaternary Period is actually where we are today.

The Paleozoic Era, which lasted from 538 mya to 252 mya (million years ago), is composed of the following periods: Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and Permian. The continents during the Cambrian period were mostly located along the south pole. Glaciers existed and there was a period of rapid growth of multicellular organisms in the oceans. During the Cambrian explosion, arthropods and Mollusks appeared. Some of the ocean organisms ventured onto land, generally as arthropods.

https://en.wikipedia.org/wiki/Cambrian#/media/File:510_Ma_paleoglobe.png

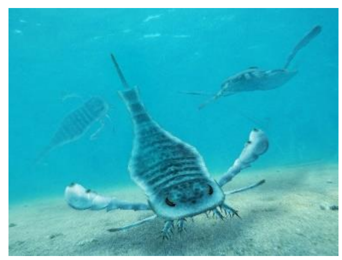
It is during the Cambrian period that organisms became more complex and multicellular and left fossils for scientists to study. While algae were present, the most abundant organisms were trilobites. For that reason, scientists began to learn more about these past eras and periods. Gondwana, the supercontinent, was formed. During the second period, the Ordovician period, life flourished. At the beginning of the period, trilobites, snails and shellfish were common and some may have gone onto land. There was heavy tectonic movement and multiple active volcanoes. Seafloor spreading was rapid and resulted in great flooding. The early climate was hot, but eventually became temperate. At the end of the period, glaciers appeared. Several organisms, including trilobites, die out. Most plant life was algal and in the oceans. Fauna (animal life) was diverse, including a number of different predators (see long tubular organisms below). The time was known for diverse ecosystems that included branchiopods, mollusks, and echinoderms (first sea stars). Land plants first appeared. However, by the end of the period, there were mass-extinction events and there was a significant glaciation event.


https://en.wikipedia.org/wiki/Ordovician#/media/File:Nmnh_fg09.jpg


https://commons.wikimedia.org/w/index.php?curid=68849540

While the Silurian period may have been one of the shortest periods, one of the most important events was the emergence of terrestrial vascular plants. Arachnids and other arthropods also became terrestrial. In the oceans, first jawless then jawed fish appeared and diversified into cartilaginous fish and bony fish. This evolution of fish was a significant event. Land organisms appeared, including fungi, and early insects. There is evidence that temperatures were stable and warm, but there were high levels of carbon dioxide. Evidence of fossils showed that there were terrestrial animals as well. These are examples of some plants and animals from the period.

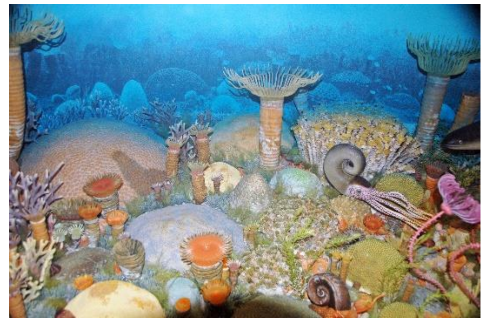

https://en.wikipedia.org/wiki/Silurian#/media/File:Cooksonia.png


https://en.wikipedia.org/wiki/Silurian#/media/File:Eurypterus_Paleoart.jpg

The Devonian period is commonly known as the age of fishes and lasted from 444 – 419 mya. During this time there appeared to be a great diversity of jawed fish. Sharks appeared (cartilaginous fish) and even fresh water fish appeared. Plants continued to diversify on land and even grew taller. Seeds appeared, producing new habitats which increased the diversity of the arthropods. Four-legged amphibians appeared. Oceans had less oxygen, causing some species to go extinct. Gondwanaland has changed positions of the land masses. The major land forms became located closer together.


https://en.wikipedia.org/wiki/Devonian#/media/File:370_Ma_paleoglobe.png

There was a relatively warm and dry climate, sea levels were high for most of the period. Marine life flourished and was very diverse (see below).

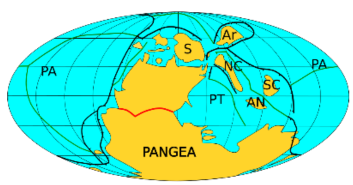


https://en.wikipedia.org/wiki/Devonian#/media/File:Gessetal2023_environment_reconstruction.png

https://en.wikipedia.org/wiki/Devonian#/media/File:Diorama_of_a_Devonian_seafloor__corals,_coiled_cephalopod,_gastropod,_crinoids_(44933262614).jpg

It was during the Devonian period that plants and animals began to have a strong existence on land. Most of the early plants were mosses and spore producing plants. By the end of the period, seed forming plants appeared. This explosion of plant life decreased the level of carbon dioxide on the Earth and produced cooler temperatures. Animal life included primitive arthropods on land. Other insects appeared as well. There was still significant diversity in ocean life. However, towards the end of the Devonian period, it became very cold. Some scientists believe it was caused by asteroid impacts but there is no clear evidence to support the idea. The result of several small events produced another extinction that greatly impacted on several marine organisms, especially the reef builders.

The coal and gas we use today is a result of the events that occurred during the Carboniferous period. The Carboniferous period lasted about 60 million years, from 359 0 299 million years ago (mya). During this period, Pangea, as we know it, was formed.



310 Ma

https://en.wikipedia.org/wiki/Carboniferous#/media/File:Pangea_assembly_310.png

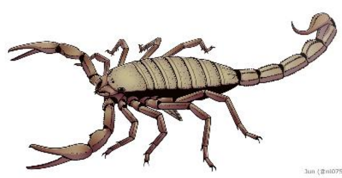
If you compare the movement of the land forms from the earlier illustrations, you can see the beginning of the continents being formed. Tectonic movements resulted in mountain ranges being formed. Our current continents were starting to form.

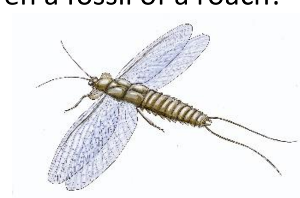
The warm temperatures produced tropical swamps, allowing plants to flourish. As plants dominated, oxygen levels increased and carbon dioxide levels decreased. Plants that we would normally see as small in size, like ferns, grew to great heights (see illustration below):

https://en.wikipedia.org/wiki/Paleozoic#/media/File:Devonianscene-green.jpg

New groups of plants appeared, including early gymnosperms. As these plants died, they built up large amounts of dead material which, eventually, became the coal deposits we use today. As the plants died, the materials built up in the swamps, allowing the material to stay wet. Peat was produced and compressed as it became buried under more and more dead plants. That pressure compressed the peat into coal. That is the coal we use today. It is considered a non-renewable resource because, while we have plants today, they decay at a faster rate (due to better decomposers) and do not last long enough to go through the coal producing process. In addition, the specific climatic conditions of the Carboniferous period may have allowed the coal deposits to build up. Scientists still debate regarding why the coal deposits were formed during this time, but most agree this resource is not renewable.

The abundance of plants allowed land organisms to diversify and become plentiful. Insects grew large, including a 2 foot 4 in scorpion relative. There are fossil remains that indicate an 8-foot millipede and dragonflies with over two feet wingspans. Fossil evidence indicates the presence of grasshoppers, crickets, and early scorpions. There is even a fossil of a roach!





https://en.wikipedia.org/wiki/Carboniferous#/media/File:20210116_Pulmonoscorpius_kirktonensis.png
https://en.wikipedia.org/wiki/Carboniferous#/media/File:Arthropleura_reconstruction.png
https://en.wikipedia.org/wiki/Carboniferous#/media/File:Mazothairos1.jpg

Marine and freshwater organisms flourished. Bivalves and gastropods increased, including the ancestor of today's Nautilus. Fish were plentiful. Fossil evidence indicates sharks were present and grew to great lengths. Many adapted to new niches and teeth evidence indicates different food sources. Some fish crushed hard shells while others had sharp rows of teeth.

The period became known as the age of amphibians. The early amphibians from the Devonian period now dominated the land and evolved into land vertebrates. They grew long, some almost 20 feet long. Others were about 6 inches long. Their survival depended on another huge event. The development of the first amniotic egg allowed amphibians to explore more land areas and adapt to the cooler and drier environments that evolved during the carboniferous period. When the period came to and end with the collapse of the carboniferous rain forest, amphibians decreased but reptiles survived due to two adaptations: hard shelled eggs and scales.

By the beginning of the Permian period, Pangea was a supercontinent and was mostly located at our equator. It was a dry continent with harsh weather. The interior of the land was desert-like and the carboniferous rainforests and swamps no longer existed. The desert-like environment was perfect for gymnosperms, including fern and other plants that had spore-like seeds. Conifers, ginkgos, and cycads appeared and their relatives are still in existence.

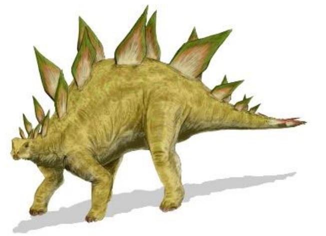
Marine life still favored mollusks, bivalves, and starfish type animals. Most plant and animal diversity was limited in the oceans, as well as on land. However, insects continued to diversify. The organisms that seemed to thrive were the vertebrates whose embryos are protected by the amnion while developing (called amniotes). These include reptiles, birds and mammals. The organisms that lived during this period were herbivores, carnivores and insectivores. Mostly, they looked like early dinosaurs:



https://en.wikipedia.org/wiki/Permian#/media/File:Weigeltisaurus_reconstruction.png
https://en.wikipedia.org/wiki/Permian#/media/File:Dimetr_eryopsDB.jpg
https://en.wikipedia.org/wiki/Permian#/media/File:Ocher_fauna_DB.jpg

The end of the Permian period was another mass extinction event. It was the largest one in history. About 90% of marine and over 70% of land organisms were wiped out! Believe this or not, it may be the only mass extinction of insects! It may have been magma, or ocean venting or some other factor but there was a mass extinction none the less.

If you ever saw Jurassic Park, then you have heard of the Mesozoic Era. It has three periods: Triassic, Jurassic, and Cretaceous Periods. This era starts with a mass extinction and, unfortunately, ends with one as well. This era was called the age of the reptiles. This is mostly because dinosaurs appeared in the middle of the Triassic period and lasted until their extinction during the Cretaceous period. Pangea was still mostly a desert and, remember, there was just a mass extinction, so there were not a great many diversified living organisms. Pangea did not break up until the middle of the Triassic and, now, the continents had been distributed across the Earth. At the same time, many marine organisms were recovering, new reptiles were evolving and growing, and insects were growing larger and larger. Dinosaurs evolved and crocodiles first appeared. Some time near the end of the Triassic, mammal like organisms began to appear. As the Jurassic period came about, the climate warmed and organisms had plenty of food so they thrived. The first true mammals evolved but were relatively small. Late in the Jurassic, birds evolved. Here are some examples:



https://en.wikipedia.org/wiki/Mesozoic#/media/File:Sericipterus_NT.jpg
https://en.wikipedia.org/wiki/Mesozoic#/media/File:Stegosaurus_BW.jpg

Again, Pangea has still separating and diversity increasing. Ocean patterns were impacting climate. In the final period of the Mesozoic Era, dinosaurs continued to dominate. The climate bean to regulate with the poles getting colder and the equator being the warmest area. The warm climates supported plant life. Gymnosperms dominated, with a small appearance by flowering plants during the late Cretaceous period. The climate was warm and humid, making it a perfect time for plants to thrive. Some scientists believe the appearance of flowering plants was related to the number of insects, while others do not. Regardless, we know that plants continued to diversify and so did animals. It ended with another mass extinction, killing all the dinosaurs, and many other land and marine species.

Known as the age of mammals, the Cenozoic Era is happening right now. It has three periods: Paleogene (Paleocene, Eocene, Oligocene Epochs), Neogene (Miocene, Pliocene epochs), Quaternary Periods (Pleistocene and Holocene Epochs) that runs to our current day. After the great extinction, Earth had to recover. During the Paleocene period, continents took the shape we see today, there was a warming trend and plants flourished. Since the forests became so dense, animals stayed smaller. However, as the climates changed and the forests became less dense, the animals started to expand in size. Seasons returned and grasses evolved, producing wide savannas. As a result, elephants and other new species evolved. With the advent of the Neogene period, grasses spread and more seed plant species evolved. These abundant food supplies, along with the climate, allowed animals to become more complex. All types of mammals evolved, including flying ones. Apes appeared and, due to another ice age, animals could migrate from continent to continent. The first man, *Australopithecus,* appeared in Africa. Changes slowed down. Finally, the Quaternary period heralded in humans. We live in the Holocene epoch, which began about 11,700 years ago. One reason this epoch is so interesting is because mankind can study it. There are numerous artifacts (fossils) that tell the story of how mankind has evolved. There is also plant evidence that allows scientists to study how the climate during this epoch has changed. For example, studying specific kinds of pollen can tell us how vegetation in an area has evolved. Since the 1850s, with the start of the Industrial Age, the Earth has become warmer and warmer. Scientists continue to study how these climatic changes have impacted living organisms on Earth. Some scientists believe that these warming trends have contributed to the extinction of thousands of species and will continue to happen unless we begin to address climate change.

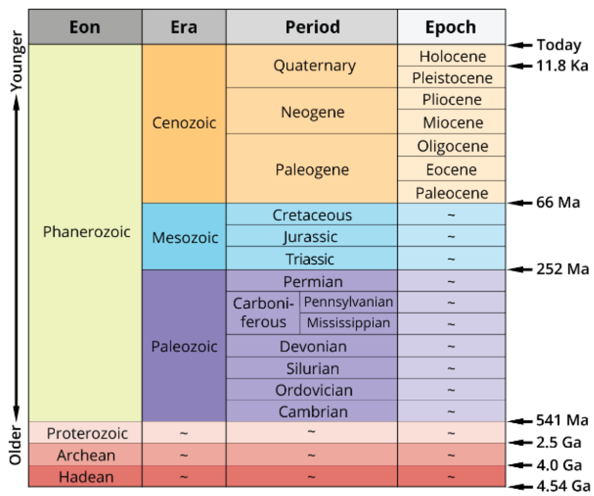
Summary

The age of the Earth is 4.6 billion years ago but man has been in existence for only about 2 million years. If this was a clock, and the age of the Earth was one hour, then man would have been here for one minute. All that adds up to the fact that Earth has been around a very long time and the evidence of life is only a very small part of the history of the Earth. Think about that next time you watch Jurassic Park!

Review

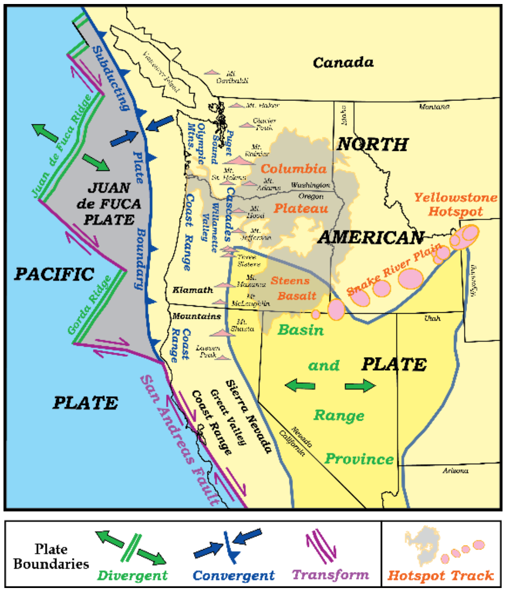
Questions

1. Explain how continental drift helped form the current continents.
2. Explain Wegener's theory of continental drift and provide the evidence to support it.
3. Describe seafloor spreading and explain its importance.
4. Describe radiometric dating and explain how fossils help with the process.
5. Explain the theory of superposition and provide evidence that scientists use to justify it.
6. Compare and contrast the types of boundaries and faults. What events occur at these sites?
7. Define uniformitarianism. Draw and label an example.
8. Using the diagram, describe the important events from each eon, era, period and epoch.



https://www.digitalatlasofancientlife.org/learn/geological-time/geological-time-scale/

9. Watch Jurassic Park and write a reflection about how the environment influenced the flora and fauna during that time period. Do you think scientists could actually bring back extinct creatures?
10. How did life on Earth change from one period of geologic time to the next? When did life first appear on Earth? What conditions were necessary on Earth for living things to survive?



Graded Assignments

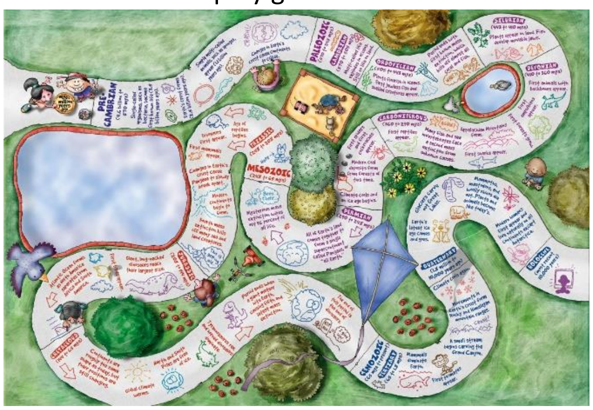
- You are asked to interpret the geologic history of Georgia. What might be five different pieces of data you would request to help you complete this task? Explain why each would be important.

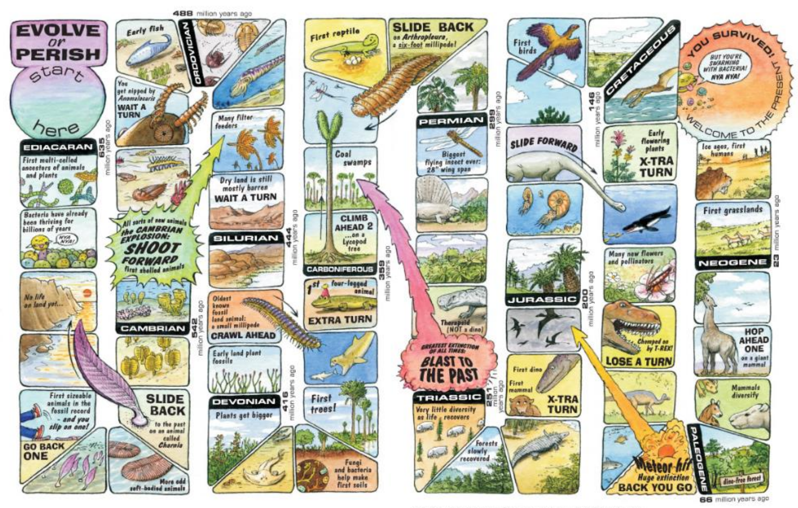
References

https://www.britannica.com/biography/Alfred-Wegener
https://cosmosmagazine.com/earth/earth-sciences/geologists-solve-the-mystery-of-what-tectonic-plates-float-on/
https://www.worldatlas.com/geography/what-is-the-lithosphere.html
https://oceanexplorer.noaa.gov/explainers/mapping.html#:~:text=Sonar%20technology%20was%20developed%20in%20the%201920s%20and,are%20made%20to%20when%20the%20echoes%20are%20heard
https://www.pmel.noaa.gov/eoi/nemo/explorer/concepts/spreading.html
https://education.nationalgeographic.org/resource/mantle/
https://science.howstuffworks.com/layers-earth.htm
https://www.worldatlas.com/articles/what-is-the-mohorovicic-discontinuity.html
https://oceanexplorer.noaa.gov/facts/plate-boundaries.html
https://www.nps.gov/subjects/geology/plate-tectonics-hotspots.htmhttps://en.wikipedia.org/wiki/Relative_dating
https://www.britannica.com/science/geologic-time
https://en.wikipedia.org/wiki/Cambrian
https://en.wikipedia.org/wiki/Devonian
https://en.wikipedia.org/wiki/Carboniferous
https://en.wikipedia.org/wiki/Mesozoic
https://www.britannica.com/story/a-journey-through-time-since-the-precambrian

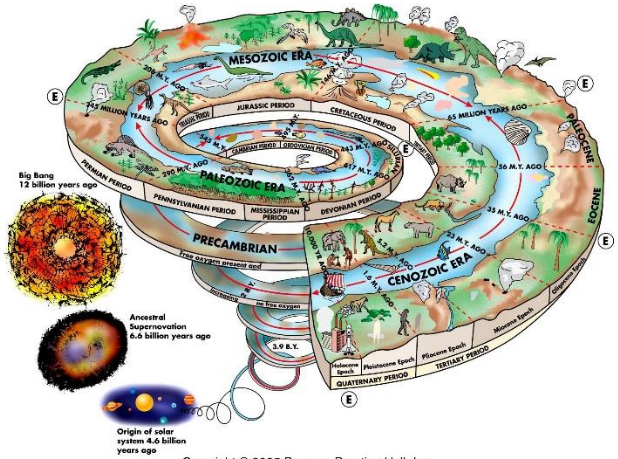
Instructional Suggestions

- problem based project
  - provide a problem and have the students develop potential solutions
    - e.g., global warming, mass extinction, extinction due to climatic changes
- e-book creation
  - use book creator to develop a story about one of the eras, periods, etc.
- game board activity
  - construct a monopoly game or other that addresses the geologic time spans

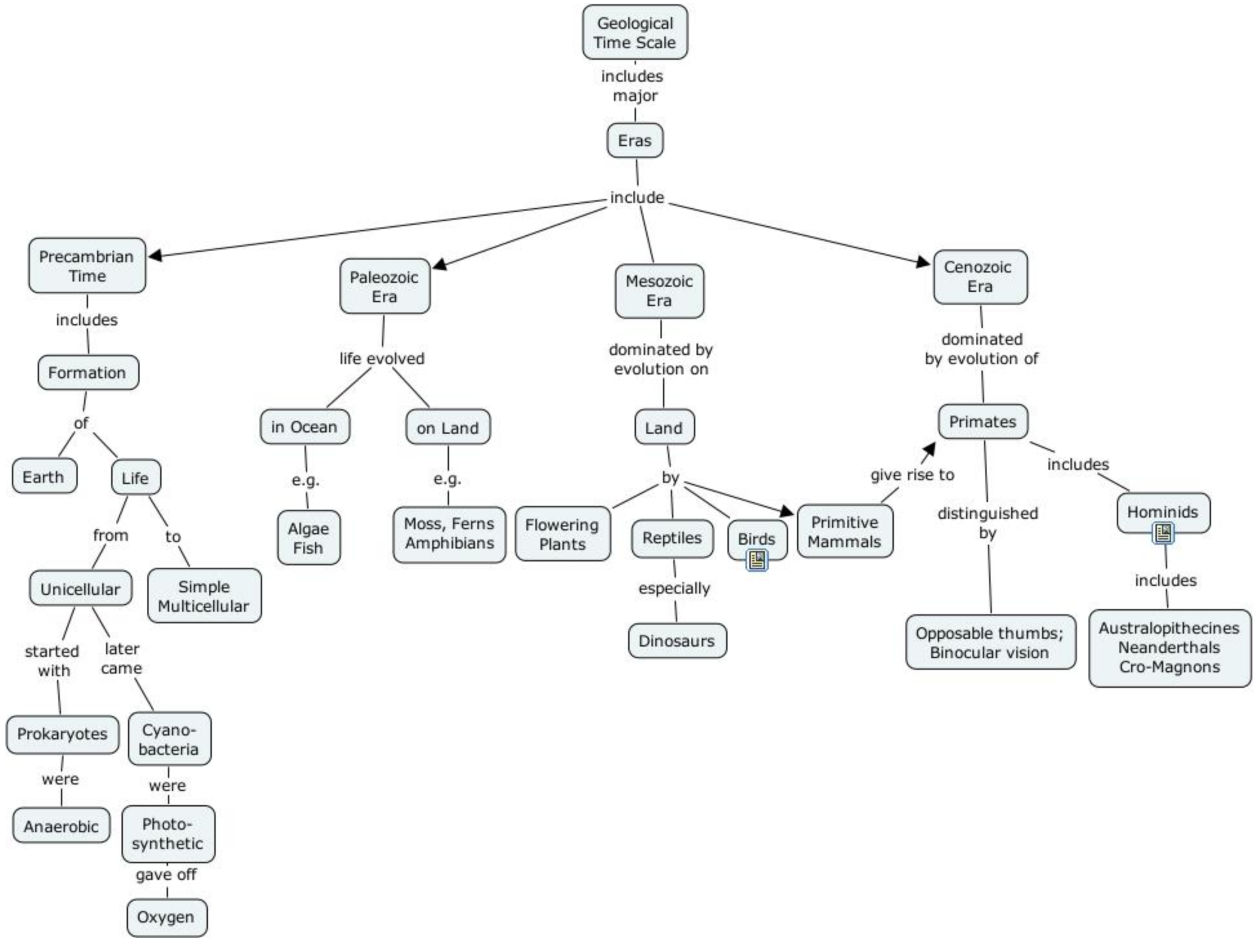




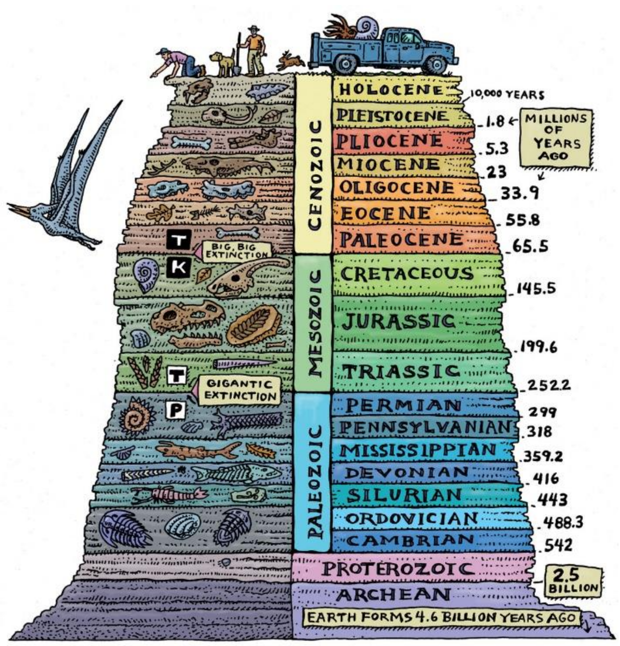
- educational pod cast
  - have the students develop a podcast about one of the time spans as if the student is living at the time
  - talk about the important events of the time
- gallery walk
  - hang poster paper around the room labeled with each geologic time span
  - have students work in small groups to write the important events they recall on each of the time spans
  - have them re-walk around the room and review the content that was posted
- choice board tic tac toe
  - provide the students with a 9-assignment choice board

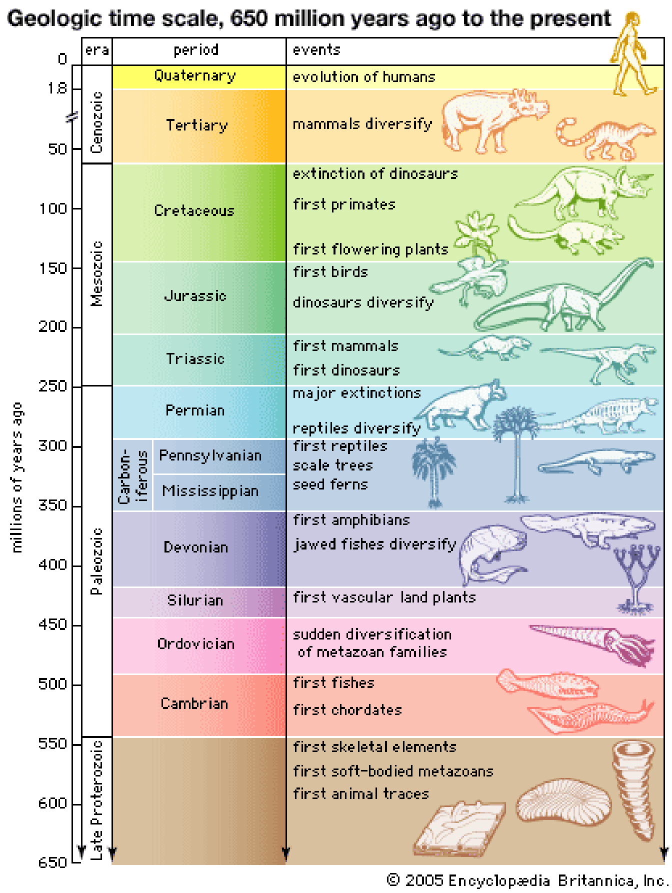
- after the student completes the three assignments, have each share their favorite
- include some of the pictures from the chapter and have student write reflection about what life might have been in that environment
- 

Worksheets



Have students create a similar time line




Geologic time scale, 650 million years ago to the present
era
period
events
millions of years ago
0
1.8
50
100
150
200
250
300
350
400
450
500
550
600
650
Cenozoic
Mesozoic
Paleozoic
Late Proterozoic
Quaternary
evolution of humans
Tertiary
mammals diversify
Cretaceous
extinction of dinosaurs
first primates
first flowering plants
Jurassic
first birds
dinosaurs diversify
Triassic
first mammals
first dinosaurs
Permian
major extinctions
reptiles diversify
Carbon-iferous
Pennsylvanian
Mississippian
first reptiles
scale trees
seed ferns
Devonian
first amphibians
jawed fishes diversify
Silurian
first vascular land plants
Ordovician
sudden diversification of metazoan families
Cambrian
first fishes
first chordates
first skeletal elements
first soft-bodied metazoans
first animal traces
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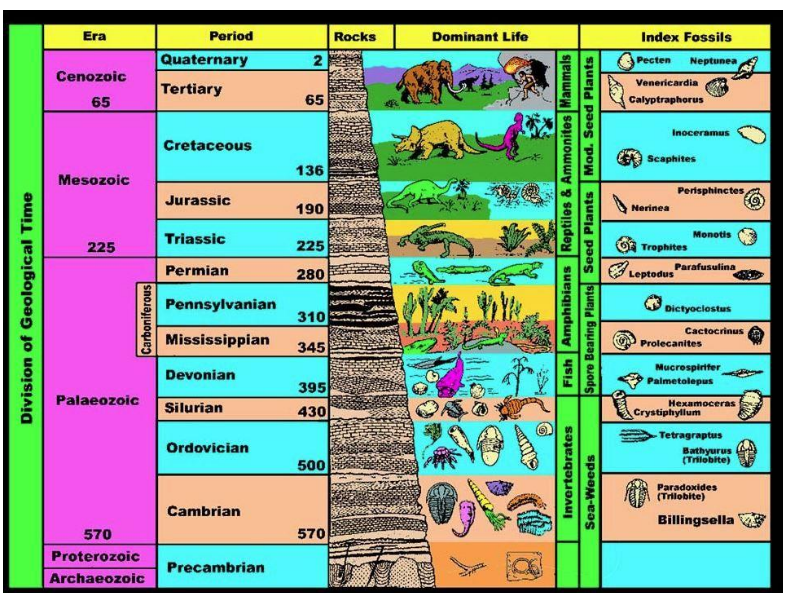
Division of Geological Time
Era
Period
Rocks
Dominant Life
Index Fossils
Cenozoic
65
Mesozoic
225
Palaeozoic
570
Proterozoic
Archaeozoic
Quaternary 2
Tertiary 65
Cretaceous 136
Jurassic 190
Triassic 225
Permian 280
Carboniferous
Pennsylvanian 310
Mississippian 345
Devonian 395
Silurian 430
Ordovician 500
Cambrian 570
Precambrian
Mammals
Reptiles & Ammonites
Amphibians
Fish
Invertebrates
Mod. Seed Plants
Seed Plants
Spore Bearing Plants
Sea-Weeds
Pecten
Neptunea
Venericardia
Calyptraphorus
Inoceramus
Scaphites
Perisphinctes
Nerinea
Monotis
Trophites
Parafusulina
Leptodus
Dictyoclostus
Cactocrinus
Prolecanites
Mucrospirifer
Palmetolepus
Hexamoceras
Crystiphyllum
Tetragraptus
Bathyurus (Trilobite)
Paradoxides (Trilobite)
Billingsella

Labs

- Lab: Half-life (M & M Half Life)
- Timeline lab activity (lab #39)