HS Earth's History

Dana Desonie

flexbook
next generation textbooks

To access a customizable version of this book, as well as other interactive content, visit www.ck12.org

AUTHOR
Dana Desonie

CONTRIBUTOR
Mary Lusk

CK-12 Foundation is a non-profit organization with a mission to reduce the cost of textbook materials for the K-12 market both in the U.S. and worldwide. Using an open-content, web-based collaborative model termed the **FlexBook®**, CK-12 intends to pioneer the generation and distribution of high-quality educational content that will serve both as core text as well as provide an adaptive environment for learning, powered through the **FlexBook Platform®**.

Printed: December 25, 2012

flexbook
next generation textbooks

CHAPTER 1 HS Earth's History

CHAPTER OUTLINE

Earth looks very different today than it did when it first formed more than 4.5 billion years ago. Rare parts of the planet may retain a bit of the feel of the ancient environment, such as the Grand Prismatic Spring in Yellowstone National Park. Earth's internal heat creates hot springs that are home to extremophiles, organisms that thrive in extreme environments. The orange, spongy materials in this photo are mats of thermophilic bacteria, organisms that thrive in extremely hot environments. Since the Earth's environment was undoubtedly more extreme in the early days, it seems likely that the most ancient life forms were forms of extremophiles.

Life on Earth has changed tremendously since those early days. Creatures have become multicellular; they have gained the ability to make their own food energy by photosynthesis; they have adapted to living in water, on land and in the air; and they've even evolved intelligence. The geology of the planet has also changed. The Earth's crust has hardened, mountains have risen, oceans have grown, and erosion has reduced features to flat plains. All of this has happened over an extremely long period of time, and humans have been around for only a tiny part.

1.1 Early Earth

Lesson Objectives

- Describe how the Earth formed with other parts of the solar system about 4.6 billion years ago.
- Recount the Moon's birth story.
- Explain how Earth's atmosphere has changed over time.
- Explain the conditions that allowed the first forms of life to develop on Earth.

Vocabulary

- differentiation
- outgassing
- paleontologist

Introduction

Historical geologists study Earth's past to understand what happened and when it happened. **Paleontologists** do the same thing, but with an emphasis on the history of life, especially as it is understood from fossils. Despite having very little material from those days, scientists have many ways of learning about the early Earth.

Formation of Earth

Earth came together (accreted) from the cloud of dust and gas known as the solar nebula nearly 4.6 billion years ago, the same time the Sun and the rest of the solar system formed. Gravity caused small bodies of rock and metal orbiting the proto-Sun to smash together to create larger bodies. Over time, the planetoids got larger and larger until they became planets. More information about planet formation is in the chapter about the solar system.

There is little hard evidence for scientists to study from Earth's earliest days. Much of what scientists know about the early Earth come from three sources: (1) zircon crystals, the oldest materials found on Earth, which show that the age of the earliest crust formed at least 4.4 billion years ago; (2) meteorites that date from the beginning of the solar system, to nearly 4.6 billion years ago (**Figure** 1.1); and (3) lunar rocks, which represent the early days of the Earth-Moon system as far back as 4.5 billion years ago.

Molten Earth

When Earth first came together it was really hot, hot enough to melt the metal elements that it contained. Why was the early Earth so hot?

- Gravitational contraction: As small bodies of rock and metal accreted, the planet grew larger and more massive. Gravity within such an enormous body squeezes the material in its interior so hard that the pressure swells. As Earth's internal pressure grew, its temperature also rose.
- Radioactive decay: Radioactive decay releases heat, and early in the planet's history there were many radioactive elements with short half lives. These elements long ago decayed into stable materials, but they were responsible for the release of enormous amounts of heat in the beginning.

FIGURE 1.1
The Allende Meteorite is a carbonaceous chondrite that struck Earth in 1969. The calcium-aluminum-rich inclusions are fragments of the earliest solar system.

- Bombardment: Ancient impact craters found on the Moon and inner planets indicate that asteroid impacts were common in the early solar system. Earth was struck so much in its first 500 million years that the heat was intense. Very few large objects have struck the planet in the past many hundreds of millions of year.

Differentiation

When Earth was entirely molten, gravity drew denser elements to the center and lighter elements rose to the surface. The separation of Earth into layers based on density is known as **differentiation**. The densest material moved to the center to create the planet's dense metallic core. Materials that are intermediate in density became part of the mantle (**Figure** 1.2).

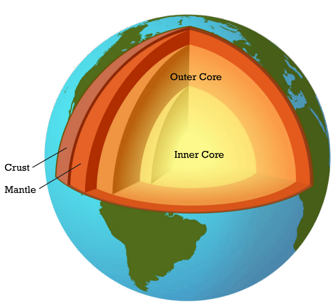


FIGURE 1.2
Earth

Lighter materials accumulated at the surface of the mantle to become the earliest crust. The first crust was probably basaltic, like the oceanic crust is today. Intense heat from the early core drove rapid and vigorous mantle convection so that crust quickly recycled into the mantle. The recycling of basaltic crust was so effective that no remnants of it are found today.

How the Moon Formed

One of the most unique features of planet Earth is its large Moon. Unlike the only other natural satellites orbiting an inner planet, those of Mars, the Moon is not a captured asteroid. Understanding the Moon's birth and early history reveals a great deal about Earth's early days.

To determine how the Moon formed, scientists had to account for several lines of evidence:

- The Moon is large; not much smaller than the smallest planet, Mercury.
- Earth and Moon are very similar in composition.
- Moon's surface is 4.5 billion years old, about the same as the age of the solar system.
- For a body its size and distance from the Sun, the Moon has very little core; Earth has a fairly large core.
- The oxygen isotope ratios of Earth and Moon indicate that they originated in the same part of the solar system.
- Earth has a faster spin than it should have for a planet of its size and distance from the Sun.

Can you devise a "birth story" for the Moon that takes all of these bits of data into account?

Astronomers have carried out computer simulations that are consistent with these facts and have detailed a birth story for the Moon. A little more than 4.5 billion years ago, roughly 70 million years after Earth formed, planetary bodies were being pummeled by asteroids and planetoids of all kinds. Earth was struck by a Mars-sized asteroid (**Figure** 1.3).

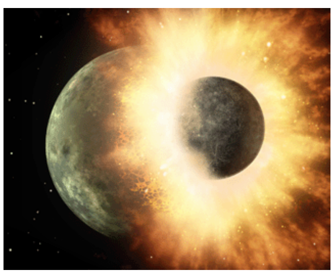


FIGURE 1.3
An artist

The tremendous energy from the impact melted both bodies. The molten material mixed up. The dense metals remained on Earth but some of the molten, rocky material was flung into an orbit around Earth. It eventually accreted into a single body, the Moon. Since both planetary bodies were molten, material could differentiate out of the magma ocean into core, mantle, and crust as they cooled. Earth's fast spin is from energy imparted to it by the impact.

Lunar rocks reveal an enormous amount about Earth's early days. The Genesis Rock, with a date of 4.5 billion years, is only about 100 million years younger than the solar system (**Figure** 1.4). The rock is a piece of the Moon's anorthosite crust, which was the original crust. Why do you think Moon rocks contain information that is not available from Earth's own materials?

More information about the Genesis Rock from NASA is found here: http://www.nasa.gov/mission_pages/LRO/news/image_release042310.html.

Can you find how all of the evidence presented in the bullet points above is present in the Moon's birth story?

Earth's Early Atmosphere and Oceans

At first, Earth did not have an atmosphere or free water since the planet was too hot for gases and water to collect. The atmosphere and oceans that we see today evolved over time.

FIGURE 1.4
The Genesis Rock was brought back to Earth by the Apollo 15 astronauts.

Earth's First Atmosphere

Earth's first atmosphere was made of hydrogen and helium, the gases that were common in this region of the solar system as it was forming. Most of these gases were drawn into the center of the solar nebula to form the Sun. When Earth was new and very small, the solar wind blew off atmospheric gases that collected. If gases did collect, they were vaporized by impacts, especially from the impact that brought about the formation of the Moon.

Eventually things started to settle down and gases began to collect. High heat in Earth's early days meant that there were constant volcanic eruptions, which released gases from the mantle into the atmosphere (**Figure** 1.5). Just as today, volcanic **outgassing** was a source of water vapor, carbon dioxide, small amounts of nitrogen, and other gases.

Scientists have calculated that the amount of gas that collected to form the early atmosphere could not have come entirely from volcanic eruptions. Frequent impacts by asteroids and comets brought in gases and ices, including water, carbon dioxide, methane, ammonia, nitrogen, and other volatiles from elsewhere in the solar system (**Figure** 1.6).

Calculations also show that asteroids and comets cannot be responsible for all of the gases of the early atmosphere, so both impacts and outgassing were needed.

Earth's Second Atmosphere

The second atmosphere, which was the first to stay with the planet, formed from volcanic outgassing and comet ices. This atmosphere had lots of water vapor, carbon dioxide, nitrogen, and methane but almost no oxygen. Why was there so little oxygen? Plants produce oxygen when they photosynthesize but life had not yet begun or had not yet developed photosynthesis. In the early atmosphere, oxygen only appeared when sunlight split water molecules into hydrogen and oxygen and the oxygen accumulated in the atmosphere.

FIGURE 1.5
Nearly constant volcanic eruptions supplied gases for Earth

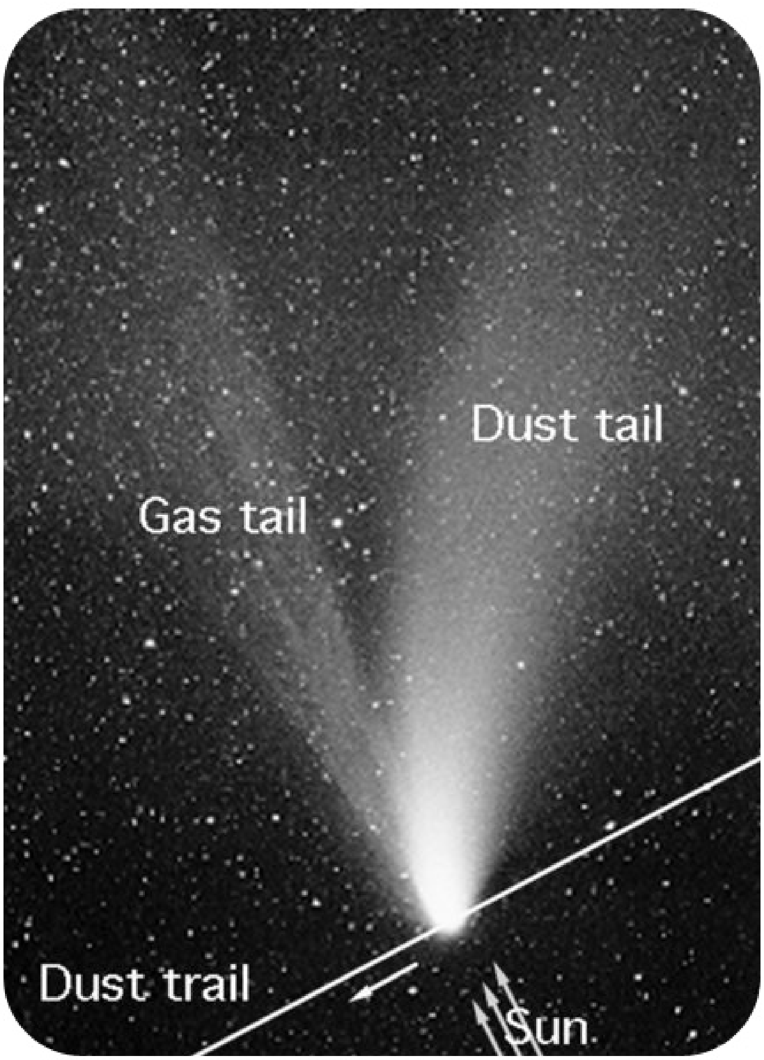


FIGURE 1.6
The gases that create a comet

Without oxygen, life was restricted to tiny simple organisms. Why is oxygen essential for most life on Earth?

1. Oxygen is needed to make ozone, a molecule made of three oxygen ions, O_3. Ozone collects in the atmospheric ozone layer and blocks harmful ultraviolet radiation from the Sun. Without an ozone layer, life in the early Earth was almost impossible.

2. Animals need oxygen to breathe. No animals would have been able to breathe in Earth's early atmosphere.

Early Oceans

The early atmosphere was rich in water vapor from volcanic eruptions and comets. When Earth was cool enough, water vapor condensed and rain began to fall. The water cycle began. Over millions of years enough precipitation collected that the first oceans could have formed as early as 4.2 to 4.4 billion years ago. Dissolved minerals carried by stream runoff made the early oceans salty. What geological evidence could there be for the presence of an early ocean? Marine sedimentary rocks can be dated back about 4 billion years. By the Archean, the planet was covered with oceans and the atmosphere was full of water vapor, carbon dioxide, nitrogen, and smaller amounts of other gases.

Lesson Summary

- Earth and the other planets in the solar system formed about 4.6 billion years ago.
- The early Earth was frequently hit with asteroids and comets. There were also frequent volcanic eruptions. Both were sources of water and gases for the atmosphere
- The early Earth had no ozone layer, no free oxygen, and was very hot.
- The oceans originally formed as water vapor released by volcanic outgassing and comet impacts cooled and condensed.
- Earth was struck by a giant impactor, which flung material out into orbit around the planet. This material accreted into Earth's only natural satellite, the Moon.

Review Questions

1. From what sources did water arrive in Earth's atmosphere?

2. Describe how the Earth's different layers vary by density. When did the layers undergo differentiation?

3. What are the two main reasons that an oxygen-rich atmosphere is important for life on Earth?

4. List three ways Earth is different today from when it was first formed.

5. If Earth had been much cooler when it first formed, how would the planet be different now from the way it is today?

Further Reading / Supplemental Links

Read about the oldest material yet found in the Solar System: http://news.nationalgeographic.com/news/2010/08/100823-oldest-solar-system-two-million-years-older-science/

Points to Consider

- What would you recognize from modern times if you traveled back to the early days of Earth?
- How do scientists know what happened in the early Earth?
- When was the planet ready for life to begin?

1.2 The Precambrian

Lesson Objectives

- Describe how the early continents came together.
- Understand what was needed for the first life and the various ways it may have come about.
- Discuss the early atmosphere and how and why free oxygen finally increased.
- Know the features and advantages of multicellular organisms.

Vocabulary

- amino acid
- craton
- cyanobacteria
- eukaryote
- extinct
- greenstone
- LUCA (last universal common ancestor)
- metabolism
- microbe
- microcontinent
- nucleic acid
- paleogeography
- photosynthesis
- platform
- prokaryote
- RNA world hypothesis
- shield
- stromatolites
- supercontinent
- symbiotic

Introduction

The longest span of time is the Precambrian Era, which includes the Proterozoic, Archean, and Pre-Archean (also called the Hadean). The Precambrian began when the Earth formed and ended at the beginning of the Cambrian period, 570 million years ago. The events recounted in the previous section were all part of the earliest Earth history, the Hadean. But there was still much more to come in the Precambrian Era. The geological principles explained in the earlier chapters of this book apply to understanding the geological history of these old times (**Figure** 1.7).

Early Continents

The first crust was made of basaltic rock, like the current ocean crust. Partial melting of the lower portion of the basaltic crust began more than 4 billion years ago. This created the silica-rich crust that became the felsic continents.

EON	ERA	PERIOD	MILLIONS OF YEARS AGO
Phanerozoic	Cenozoic	Quaternary	1.6
		Tertiary	66
	Mesozoic	Cretaceous	138
		Jurassic	205
		Triassic	240
	Paleozoic	Permian	290
		Pennsylvanian	330
		Mississippian	360
		Devonian	410
		Silurian	435
		Ordovician	500
		Cambrian	570
Proterozoic	Late Proterozoic Middle Proterozoic Early Proterozoic		2500
Archean	Late Archean Middle Archean Early Archean		3800?
Pre-Archean			

FIGURE 1.7

The Geologic Time Scale.

Cratons and Shields

The earliest felsic continental crust is now found in the ancient cores of continents, called the **cratons**. Rapid plate motions meant that cratons experienced many continental collisions. Little is known about the **paleogeography**, or the ancient geography, of the early planet, although smaller continents could have come together and broken up.

Places the craton crops out at the surface is known as a **shield**. Cratons date from the Precambrian and are called Precambrian shields. Many Precambrian shields are about 570 million years old (**Figure** 1.8).

Geologists can learn many things about the Pre-Archean by studying the rocks of the cratons.

- Cratons also contain felsic igneous rocks, which are remnants of the first continents.
- Cratonic rocks contain rounded sedimentary grains. Of what importance is this fact? Rounded grains indicate that the minerals eroded from an earlier rock type and that rivers or seas also existed.
- One common rock type in the cratons is **greenstone**, a metamorphosed volcanic rock (**Figure** 1.9). Since greenstones are found today in oceanic trenches, what does the presence of greenstones mean? These ancient greenstones indicate the presence of subduction zones.

During the Pre-Archean and Archean, Earth's interior was warmer than today. Mantle convection was faster and plate tectonics processes were more vigorous. Since subduction zones were more common, the early crustal plates were relatively small.

In most places the cratons were covered by younger rocks, which together are called a **platform**. Sometimes the younger rocks eroded away to expose the Precambrian craton (**Figure** 1.10).

Since the time that it was completely molten, Earth has been cooling. Still, about half the internal heat that was generated when Earth formed remains in the planet and is the source of the heat in the core and mantle today.

FIGURE 1.8
The Canadian Shield is the ancient flat part of Canada that lies around Hudson Bay, the northern parts of Minnesota, Wisconsin and Michigan and much of Greenland.

FIGURE 1.9
Ice age glaciers scraped the Canadian Shield down to the 4.28 billion year old greenstone in Northwestern Quebec.

Precambrian Plate Tectonics

By the end of the Archean, about 2.5 billion years ago, plate tectonics processes were completely recognizable. Small Proterozoic continents known as **microcontinents** collided to create **supercontinents**, which resulted in the uplift of massive mountain ranges.

The history of the North American craton is an example of what generally happened to the cratons during the Precambrian. As the craton drifted, it collided with microcontinents and oceanic island arcs, which were added to the continents. Convergence was especially active between 1.5 and 1.0 billion years ago. These lands came together to create the continent of Laurentia.

About 1.1 billion years ago, Laurentia became part of the supercontinent Rodinia (**Figure** 1.11). Rodinia probably contained all of the landmass at the time, which was about 75% of the continental landmass present today.

Rodinia broke up about 750 million years ago. The geological evidence for this breakup includes large lava flows that are found where continental rifting took place. Seafloor spreading eventually started and created the oceans

FIGURE 1.10
The Precambrian craton is exposed in the Grand Canyon where the Colorado River has cut through the younger sedimentary rocks.

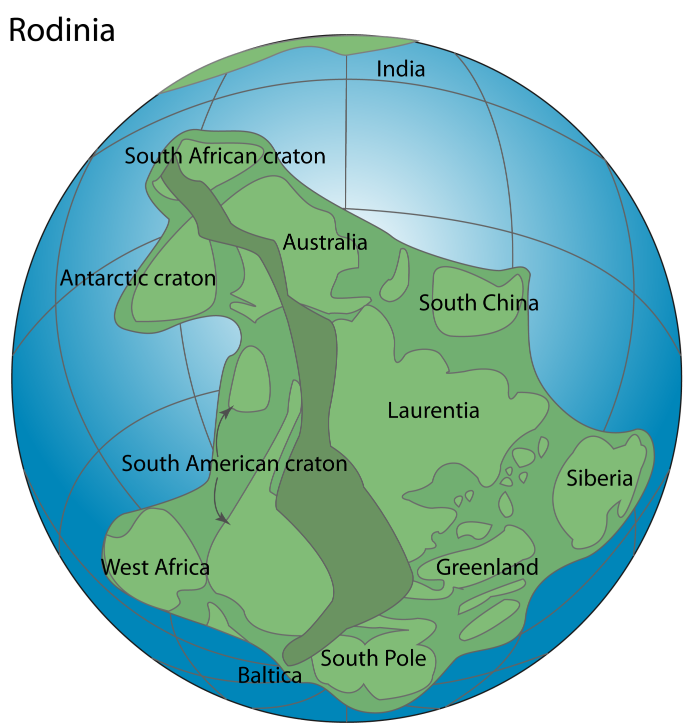
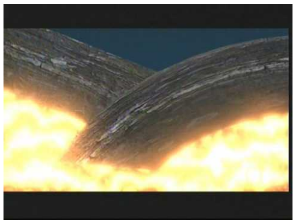


FIGURE 1.11
Rodinia as it came together about 1.1 billion years ago.

between the continents.

The breakup of Rodinia may have triggered Snowball Earth around 700 million years ago. Snowball Earth is the hypothesis that much of the planet was covered by ice at the end of the Precambrian. When the ice melted and the planet became habitable, live evolved rapidly. This explains the rapid evolution of life in the Ediacaran and Cambrian periods.

This video explores the origin of continents and early plate tectonics on the young Earth **(1c)**: http://www.youtube.c om/watch?v=QDqskltCixA (5:17).



MEDIA
Click image to the left for more content.

The presence of water on ancient Earth is revealed in a zircon crystal **(1c)**: http://www.youtube.com/watch?v=V21hFmZP5zM (3:13).

MEDIA
Click image to the left for more content.

The Origin of Life

No one knows how or when life first began on the turbulent early Earth. There is little hard evidence from so long ago. Scientists think that it is extremely likely that life began and was wiped out more than once; for example, by the impact that created the Moon.

To look for information regarding the origin of life, scientists:

- perform experiments to recreate the environmental conditions found at that time.
- study the living creatures that make their homes in the types of extreme environments that were typical in Earth's early days.
- seek traces of life left by ancient microorganisms, also called **microbes**, such as microscopic features or isotopic ratios indicative of life. Any traces of life from this time period are so ancient, it is difficult to be certain whether they originated by biological or non-biological means.

What does a molecule need to be and do to be considered alive? The molecule must:

- be organic. The organic molecules needed are amino acids, the building blocks of life.
- have a metabolism.
- be capable of replication (be able to reproduce).

Amino Acids

Amino acids are the building blocks of life because they create proteins. To form proteins, the amino acids are linked together by covalent bonds to form polymers called polypeptide chains (**Figure** 1.12).

These chains are arranged in a specific order to form each different type of protein. Proteins are the most abundant class of biological molecules. An important question facing scientists is where the first amino acids came from: Did they originate on Earth or did they fly in from outer space? No matter where they originated, the creation of amino acids requires the right starting materials and some energy.

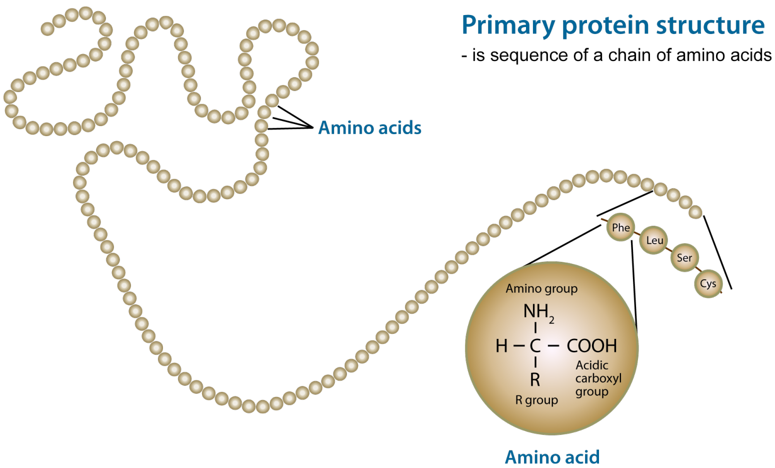


FIGURE 1.12
Amino acids form polypeptide chains.

To see if amino acids could originate in the environment thought to be present in the first years of Earth's existence, Stanley Miller and Harold Urey performed a famous experiment in 1953 (**Figure** 1.13). To simulate the early atmosphere they placed hydrogen, methane and ammonia in a flask of heated water that created water vapor, which they called the primordial soup. Sparks simulated lightning, which the scientists thought could have been the energy that drove the chemical reactions that created the amino acids. It worked! The gases combined to form water-soluble organic compounds including amino acids.

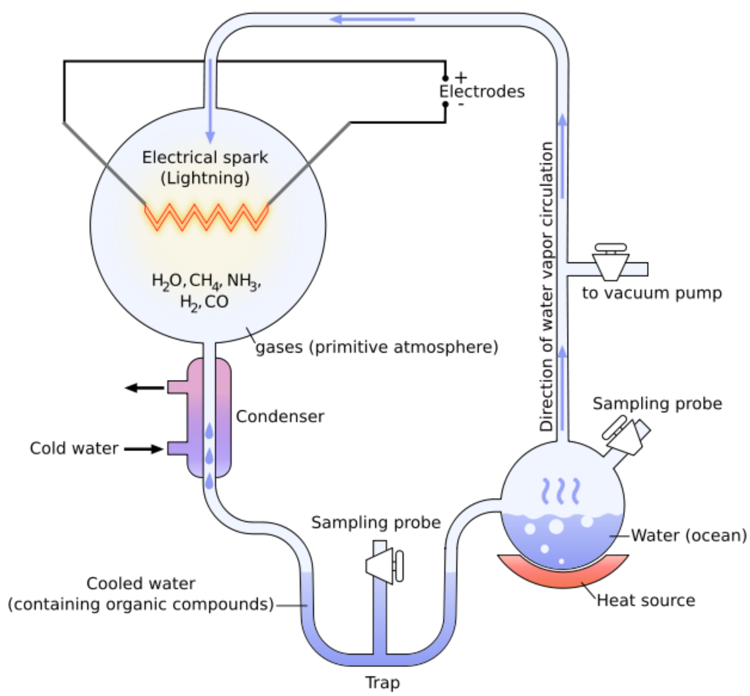


FIGURE 1.13
The Miller-Urey experiment was simple and elegant.

A dramatic reenactment of this experiment is performed on this video from the 1980 TV show Cosmos: http://www.youtube.com/watch?v=yet1xkAv_HY&feature=related. At the end you can learn about the possible role of RNA.

Amino acids might also have originated at hydrothermal vents or deep in the crust where Earth's internal heat is the energy source. Meteorites containing amino acids currently enter the Earth system and so meteorites could have delivered amino acids to the planet from elsewhere in the solar system (where they would have formed by processes similar to those outlined here).

Metabolism

Organic molecules must also carry out the chemical work of cells; that is, their **metabolism**. Chemical reactions in a living organism allow that organism to live in its environment, grow, and reproduce. Metabolism gets energy from other sources and creates structures needed in cells. The chemical reactions occur in a sequence of steps known as metabolic pathways. The metabolic pathways are very similar between unicellular bacteria that have been around for billions of years and the most complex life forms on Earth today. This means that they evolved very early in Earth history.

Replication

Living cells need organic molecules, known as **nucleic acids**, to store genetic information and pass it to the next generation. Deoxyribonucleic acid (DNA) is the nucleic acid that carries information for nearly all living cells today and did for most of Earth history. Ribonucleic acid (RNA) delivers genetic instructions to the location in a cell where protein is synthesized.

The famous double helix structure of DNA is seen in this animation: http://upload.wikimedia.org/wikipedia/commons/8/81/ADN_animation.gif

Many scientists think that RNA was the first replicator. Since RNA catalyzes protein synthesis, most scientists think that RNA came before proteins. RNA can also encode genetic instructions and carry it to daughter cells, such as DNA.

The idea that RNA is the most primitive organic molecule is called the **RNA world hypothesis**., referring to the possibility that the RNA is more ancient than DNA. RNA can pass along genetic instructions as DNA can, and some RNA can carry out chemical reactions like proteins can.

A video explaining the RNA world hypothesis is seen here: http://www.youtube.com/watch?v=sAkgb3yNgqg Pieces of many scenarios can be put together to come up with a plausible suggestion for how life began.

Simple Cells Evolve

Simple organic molecules such as proteins and nucleic acids eventually became complex organic substances. Scientists think that the organic molecules adhered to clay minerals, which provided the structure needed for these substances to organize. The clays, along with their metal cations, catalyzed the chemical reactions that caused the molecules to form polymers. The first RNA fragments could also have come together on ancient clays.

For an organic molecule to become a cell, it must be able to separate itself from its environment. To enclose the molecule, a lipid membrane grew around the organic material. Eventually the molecules could synthesize their own organic material and replicate themselves. These became the first cells.

The earliest cells were **prokaryotes** (**Figure** 1.14). Although prokaryotes have a cell membrane, they lack a cell nucleus and other organelles. Without a nucleus, RNA was loose within the cell. Over time the cells became more complex.

Evidence for bacteria, the first single-celled life forms, goes back 3.5 billion years (**Figure** 1.15).

Eventually life began to diversify from these extremely simple cells. The last life form that was the ancestor to all life that came afterward is called **LUCA**, which stands for the **Last Universal Common Ancestor**. LUCA was a prokaryote but differed from the first living cells because its genetic code was based on DNA. LUCA lived 3.5 to 3.8

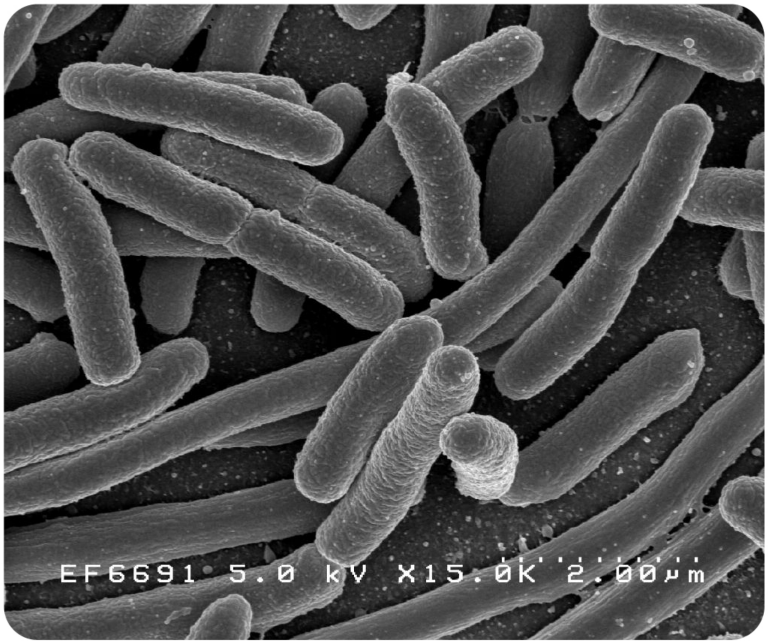


FIGURE 1.14

E. coli (Escherichia coli) is a primitive prokaryote that may resemble the earliest cells.

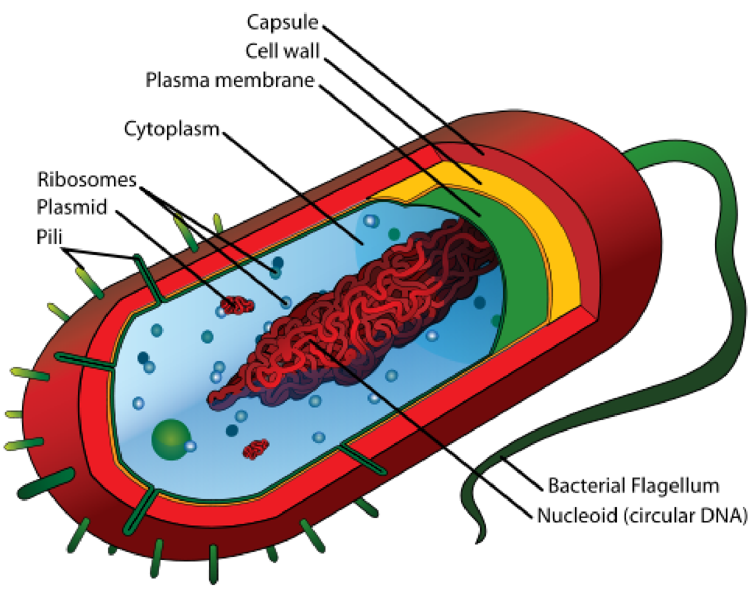


FIGURE 1.15

A diagram of a bacterium.

billion years ago. The oldest fossils are tiny microbe-like objects that are 3.5 billion years old.

Photosynthesis and the Changing Atmosphere

Without photosynthesis what did the earliest cells eat? Most likely they absorbed the nutrients that floated around in the organic soup that surrounded them. After hundreds of millions of years, these nutrients would have become less abundant.

Sometime around 3 billion years ago (about 1.5 billion years after Earth formed!), photosynthesis began. **Photosynthesis** allowed organisms to use sunlight and inorganic molecules, such as carbon dioxide and water, to create chemical energy that they could use for food. To photosynthesize, a cell needs chloroplasts (**Figure** 1.16).

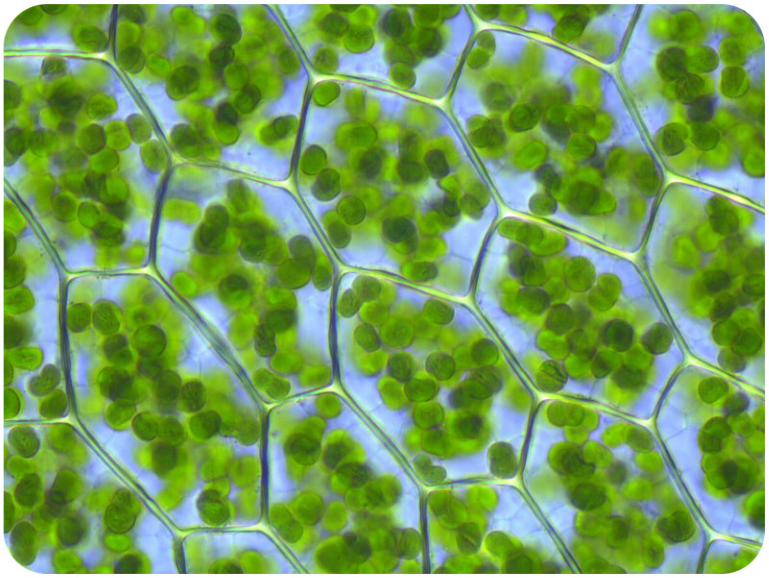


FIGURE 1.16
Chloroplasts are visible in these cells found within a moss.

In what two ways did photosynthesis make the planet much more favorable for life?

1. Photosynthesis allowed organisms to create food energy so that they did not need to rely on nutrients floating around in the environment. Photosynthesizing organisms could also become food for other organisms.

2. A byproduct of photosynthesis is oxygen. When photosynthesis evolved, all of a sudden oxygen was present in large amounts in the atmosphere. For organisms used to an anaerobic environment, the gas was toxic, and many organisms died out.

Earth's Third Atmosphere

The addition of oxygen is what created Earth's third atmosphere. This event, which occurred about 2.5 billion years ago, is sometimes called the oxygen catastrophe because so many organisms died. Although entire species died out and went **extinct**, this event is also called the Great Oxygenation Event because it was a great opportunity. The organisms that survived developed a use for oxygen through cellular respiration, the process by which cells can obtain energy from organic molecules.

What evidence do scientists have that large quantities of oxygen entered the atmosphere? The iron contained in the rocks combined with the oxygen to form reddish iron oxides. By the beginning of the Proterozoic, banded-iron formations (BIFs) were forming. The oldest BIFs are 3.7 billion years old, but they are very common during the Great Oxygenation Event 2.4 billion years ago (**Figure** 1.17). By 1.8 billion years ago, the amount of BIF declined. In recent times, the iron in these formations has been mined, and that explains the location of the auto industry in the upper Midwest.

With more oxygen in the atmosphere, ultraviolet radiation could create ozone. With the formation of an ozone layer to protect the surface of the Earth from UV radiation, more complex life forms could evolve.

FIGURE 1.17
Banded-iron formations display alternating bands of iron oxide and iron-poor chert that probably represent a seasonal cycle of an aerobic and an anaerobic environment.

Early Organisms

What were these organisms that completely changed the progression of life on Earth by changing the atmosphere from anaerobic to aerobic? The oldest known fossils that are from organisms known to photosynthesize are **cyanobacteria** (**Figure** 1.18). Cyanobacteria were present by 2.8 billion years ago, and some may have been around as far back as 3.5 billion years.

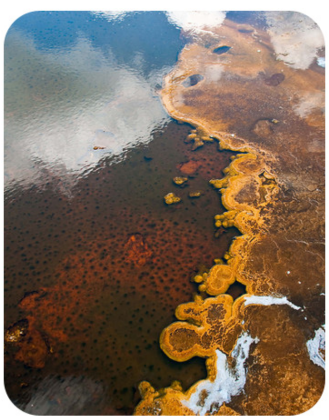


FIGURE 1.18
Thermophilic (heat-loving) bacteria in Yellowstone National park.

Modern cyanobacteria are also called blue-green algae. These organisms may consist of a single or many cells and they are found in many different environments (**Figure** 1.19). Even now cyanobacteria account for 20% to 30% of photosynthesis on Earth.

Cyanobacteria were the dominant life forms in the Archean. Why would such a primitive life-form have been dominant in the Precambrian? Many cyanobacteria lived in reef-like structures known as **stromatolites** (**Figure** below). Stromatolites continued on into the Cambrian but their numbers declined.

FIGURE 1.19
A large bloom of cyanobacteria is harmful to this lake.

FIGURE 1.20
These rocks in Glacier National Park, Montana may contain some of the oldest fossil microbes on Earth.

Eukaryotes

About 2 billion years ago, **eukaryotes** evolved. Eukaryotic cells have a nucleus that encloses their DNA and RNA. All complex cells and nearly all multi-celled animals are eukaryotic.

The evolution of eukaryotes from prokaryotes is an interesting subject in the study of early life. Scientists think that small prokaryotic cells began to live together in a **symbiotic** relationship; that is, different types of small cells were beneficial to each other and none harmed the other. The small cell types each took on a specialized function and became the organelles within a larger cell. Organelles supplied energy, broke down wastes, or did other jobs that were needed for cells to become more complex.

What is thought to be the oldest eukaryote fossil found so far is 2.1 billion years old. Eukaryotic cells were much better able to live and replicate themselves, so they continued to evolve and became the dominant life form over prokaryotic cells.

Multicellular Life

Prokaryotes and eukaryotes can both be multicellular. The first multi-celled organisms were probably prokaryotic cyanobacteria. Multicellularity may have evolved more than once in life history, likely at least once for plants and once for animals.

Early multicellular organisms were soft bodied and did not fossilize well, so little remains of their existence. Multicellular organism will be discussed in the lesson, History of Earth's Complex Life Forms.

Lesson Summary

- After partial melting of the original basaltic crust began, silca-rich rock formed the early continental crust.
- The oldest felsic continental crust is found in cratons. A craton found at the surface is a shield; a sediment covered craton is a platform.
- Precambrian rocks help scientists piece together the geology of that time.
- The continents formed as cratons collided with microcontinents and island arcs to form large continents.
- Rodinia was a supercontinent composed of Laurentia and other continents.
- Snowball Earth may have occurred during the late Precambrian and its end may have led to the explosion of life forms that developed during the Ediacaran and Cambrian.
- Amino acids were essential for the origin of life. They link together to form proteins.
- RNA may have been the first and only nucleic acid at the beginning of life.
- A cell needs a way to replicate itself, a metabolism, and a way to separate itself from its environment.
- An atmosphere that contains oxygen is important because of the ozone layer and cellular respiration.
- Multicellular organisms evolved long after prokaryotes evolved and they may have evolved more than once.

Review Questions

1. What is the difference between a craton, shield, and platform?
2. If a rock contains rounded grains of sediments, what can you tell about that rock?
3. What does a greenstone indicate about the plate tectonic environment in which it formed?
4. What happened to all of the heat Earth had when it formed?
5. What was Laurentia and what lands was it composed of? What happened to it?
6. How was Rodinia like Pangaea?
7. What were the possible sources of amino acids on the ancient Earth?
8. What was the significance of the Miller-Urey experiment?
9. What is the RNA world hypothesis and why is it called that?
10. What is the difference between prokaryotes and eukaryotes?
11. What was LUCA? Is LUCA still alive?
12. Why are banded-iron formations important?
13. Why were cyanobacteria important in the early Earth?
14. How are eukaryotes thought to have originated?

Further Reading / Supplemental Links

Read about the oldest material yet found in the Solar System:http://news.nationalgeographic.com/news/2010/08/100823-oldest-solar-system-two-million-years-older-science/

Points to Consider

- What would life be like on Earth if there were no free oxygen?
- Why did it take so long for eukaryotes or multicellular organisms to evolve?
- How did the evolution of life affect the non-biological parts of the planet?

1.3 Phanerozoic Earth History

Lesson Objectives

- The Phanerozoic is divided into the Paleozoic, Mesozoic, and Cenozoic.
- Marine transgressions and regressions were common during the Paleozoic and Mesozoic.

Vocabulary

- facies
- marine regression
- marine transgression
- orogeny

Introduction

Compared with the long expanse of the Precambrian, the Phanerozoic is recent history. Much more geological evidence is available for scientists to study so the Phanerozoic is much better known.

Paleozoic

The Paleozoic is the furthest back era of the Phanerozoic and it lasted the longest. But the Paleozoic was relatively recent, beginning only 570 million years ago. The paleogeography of the Paleozoic begins and ends with a supercontinent.

Marine Transgressions and Regressions

Some of the most important events of the Paleozoic were the rising and falling of sea level over the continents. Sea level rises over the land during a **marine transgression**. During a **marine regression**, sea level retreats. During the Paleozoic there were four complete cycles of marine transgressions and regressions (**Figure** 1.21).

Geologists know about marine transgressions and regressions from the sedimentary rock record. These events leave characteristic rock layers known as sedimentary **facies**. On a shoreline, sand and other coarse grained rock fragments are commonly found on the beach where the wave energy is high. Away from the shore in lower energy environments, fine-grained silt that later creates shale is deposited. In deeper, low-energy waters, carbonate mud that later hardens into limestone is deposited.

The Paleozoic sedimentary rocks of the Grand Canyon (**Figure** 1.22) contain evidence of marine transgressions and regressions, but even there the rock record is not complete. Look at the sequence in the figure below and see if you can determine whether the sea was transgressing or regressing. At the bottom, the Tonto Group represents a marine transgression: sandstone (11), shale (10), and limestone (9) laid down during 30 million years of the Cambrian Period. The Ordovician and Silurian are unknown because of an unconformity. Above that is freshwater limestone (8), which is overlain by limestone (7) and then shale (6), indicating that the sea was regressing. After another unconformity, the rocks of the Supai Group (5) include limestone, siltstone, and sandstone indicative of a regressing sea. Above those rocks are shale (4), sandstone (3), a limestone and sandstone mix (2) showing that the sea regressed and transgressed and finally limestone (1) indicating that the sea had come back in.

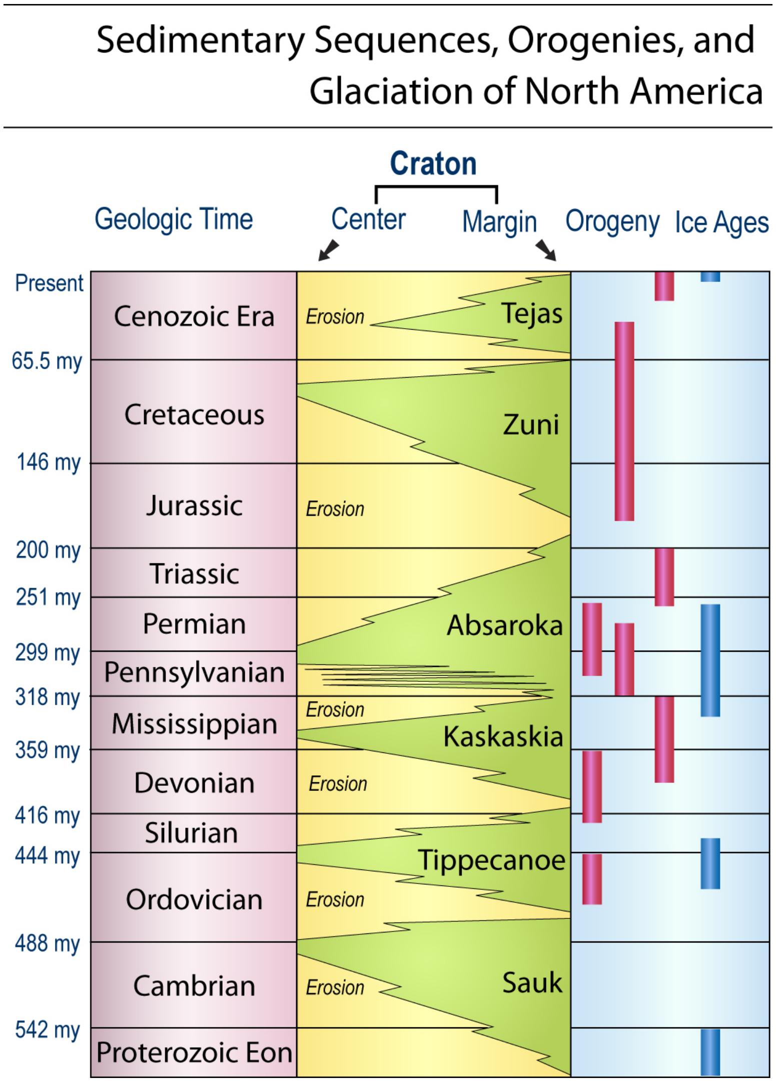


FIGURE 1.21

Six marine transgressions and regressions have occurred during the Phanerozoic.

One of two things must happen for sea level to change in a marine transgression: either the land must sink or the water level must rise. What could cause sea level to rise? When little or no fresh water is tied up in glaciers and ice caps, sea level is high. Sea level also appears to rise if land is down dropped. Sea level rises if an increase in seafloor spreading rate buoys up the ocean crust, causing the ocean basin to become smaller.

What could cause sea level to fall in a marine regression?

Geologists think that the Paleozoic marine transgressions and regressions were the result of the decrease and increase in the size of glaciers covering the lands.

Plate Tectonics

A mountain-building event is called an **orogeny**. Orogenies take place over tens or hundreds of millions of years. At the beginning of the Paleozoic, the supercontinent Rodinia began to split up. At the end, Pangaea came together. As continents smash into microcontinents and island arcs collided, mountains rise.

Geologists find evidence for these collisions in many locations. For example, Laurentia collided with the Taconic Island Arc during the Taconic Orogeny (**Figure** 1.23). The remnants of this mountain range make up the Taconic

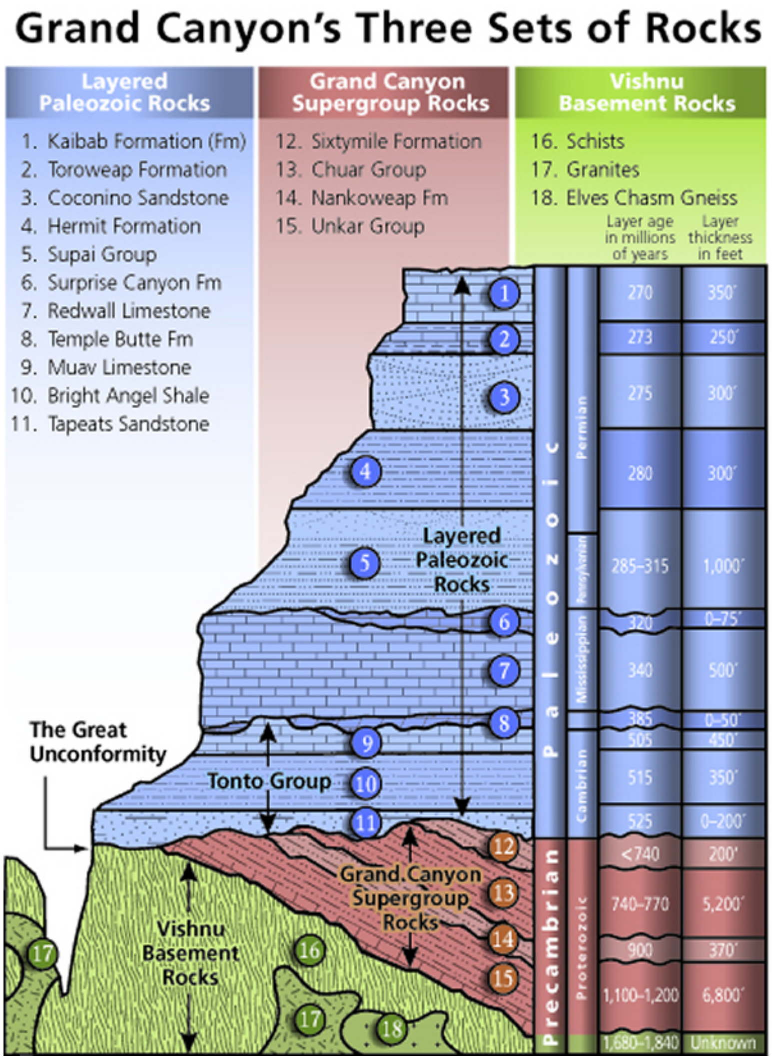


FIGURE 1.22

The Paleozoic sedimentary rocks of the Grand Canyon were deposited during marine transgressions and regressions.

Mountains in New York.

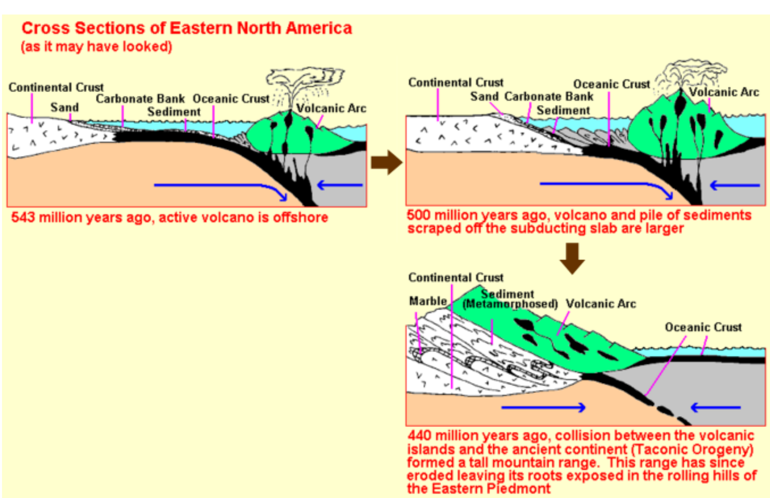


FIGURE 1.23

The Taconic Orogeny is an example of a collision between a continent and a volcanic island arc.

Laurentia experienced other orogenies as it merged with the northern continents. The southern continents came together to form Gondwana. When Laurentia and Gondwana collided to create Pangaea, the Appalachians rose. Geologists think they may once have been higher than the Himalayas are now.

Pangaea was the last supercontinent on Earth. Evidence for the existence of Pangaea was what Alfred Wegener used to create his continental drift hypothesis, which was described in the Plate Tectonics chapter.

As the continents move and the land masses change shape, the shape of the oceans changes too. During the time of Pangaea, about 250 million years ago, most of Earth's water was collected in a huge ocean called Panthalassa (**Figure** 1.24).

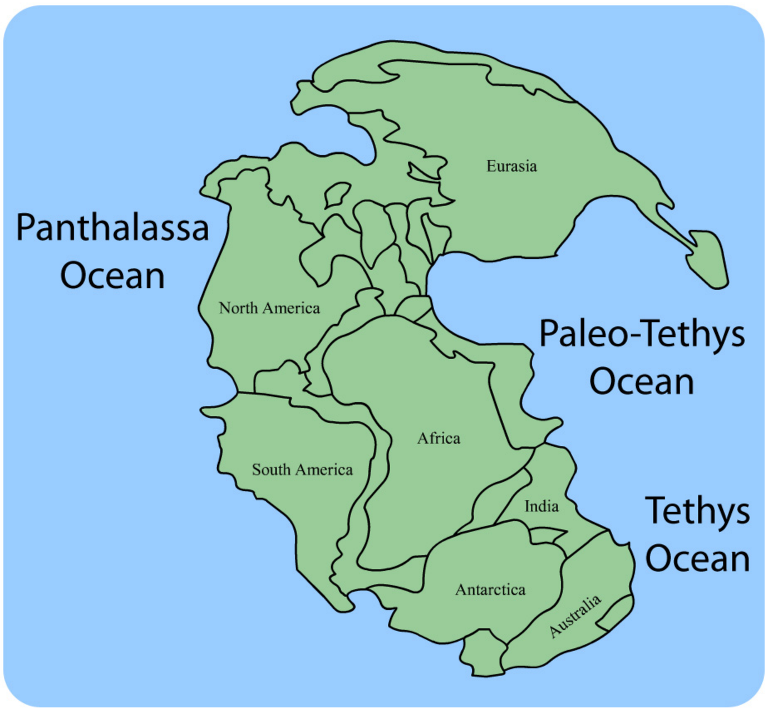


FIGURE 1.24
Pangea was the sole landform 250 million years ago, leaving a huge ocean called Panthalassa, along with a few smaller seas.

Mesozoic

The Mesozoic is known as the age of the dinosaurs, but things were happening geologically as well. The Mesozoic was dominantly warm and tropical.

The Breakup of Pangaea

At the end of the Paleozoic there was one continent and one ocean. When Pangaea began to break apart about 180 million years ago, the Panthalassa Ocean separated into the individual but interconnected oceans that we see today on Earth.

Why would a supercontinent break up after being together for tens of millions of years? A continent is a giant insulating blanket that does not allow mantle heat to escape very effectively. As heat builds up beneath a supercontinent, continental rifting begins. Basaltic lavas fill in the rift and eventually lead to seafloor spreading and the formation of a new ocean basin.

The Atlantic Ocean basin formed as Pangaea split apart. The seafloor spreading that pushed Africa and South America apart is continuing to enlarge the Atlantic Ocean (**Figure** 1.25).

FIGURE 1.25
In the Afar Region of Ethiopia, Africa is splitting apart. Three plates are pulling away from a central point.

Plate Tectonics

As the continents moved apart there was an intense period of plate tectonic activity. Seafloor spreading was so vigorous that the mid-ocean ridge buoyed upwards and displaced so much water that there was a marine transgression. Later in the Mesozoic those seas regressed and then transgressed again.

The moving continents collided with island arcs and microcontinents so that mountain ranges accreted onto the continents' edges. The subduction of the oceanic Farallon plate beneath western North America during the late Jurassic and early Cretaceous produced igneous intrusions and other structures. The intrusions have since been uplifted so that they are exposed in the Sierra Nevada Mountains (**Figure** 1.26).

FIGURE 1.26
The snow-covered Sierra Nevada is seen striking SE to NW across the eastern third of the image. The mountain range is a line of uplifted batholiths from Mesozoic subduction.

A marine transgression during the Cretaceous covered much of the North American continent with water (**Figure** 1.27).

FIGURE 1.27
Lands that had been uplifted during tectonic activity remained above water during this marine transgression that took place during the Cretaceous.

Cenozoic

The Cenozoic began around 65.5 million years ago and continues today. Although it accounts for only about 1.5% of the Earth's total history, as the most recent era it is the one scientists know the most about. Much of what has been discussed in the first chapters of this book describes the geological situation of the Cenozoic.

Plate Tectonics

The paleogeography of the era was very much like it is today. Early in the Cenozoic, blocks of crust uplifted to form the Rocky Mountains, which were later eroded away and then uplifted again. Subduction off of the Pacific Northwest formed the Cascades volcanic arc. The Basin and Range province that centers on Nevada is where crust is being pulled apart.

The San Andreas Fault has grown where the Pacific and North American plates meet. The plate tectonic evolution of that plate boundary is complex and interesting (**Figure** 1.28).

Although most plate tectonic activity involves continents moving apart, smaller regions are coming together. Africa collided with Eurasia to create the Alps. India crashed into Asia to form the Himalayas.

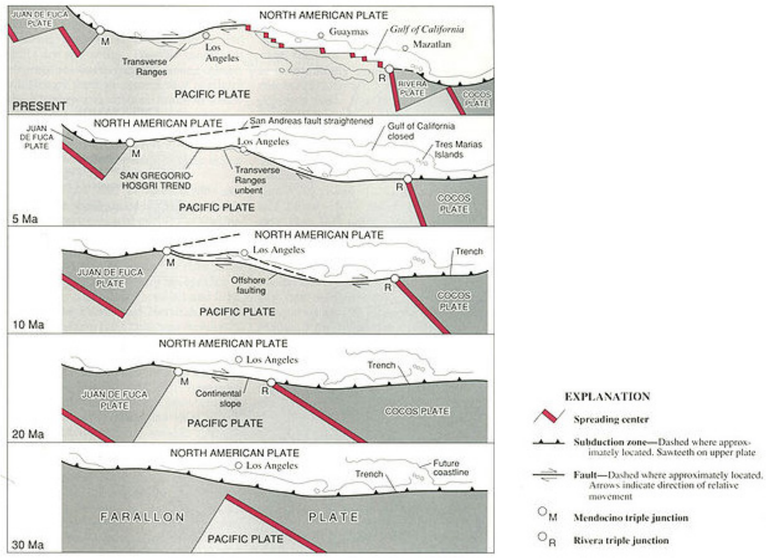


FIGURE 1.28

This figure shows the evolution of the San Andreas Fault zone from 30 million years ago (bottom) to present (top). The Farallon Plate was subducting beneath the North American Plate 30 Ma. By 20 Ma the Pacific Plate and East Pacific Rise spreading center had started to subduct, splitting the Farallon Plate into two smaller plates. Transform motion where the Pacific and North American plates meet formed the San Andreas Fault. The fault moved inland and at present small sea floor spreading basins along with the transform motion of the San Andreas are splitting Baja California from mainland Mexico.

Ice Ages

As the continents moved apart, climate began to cool. When Australia and Antarctica separated, the Circumpolar Current could then move the frigid water around Antarctica and spread it more widely around the planet.

Antarctica drifted over the south polar region and the continent began to grow a permanent ice cap in the Oligocene. The climate warmed in the early Miocene but then began to cool again in the late Miocene and Pliocene when glaciers began to form. During the Pleistocene ice ages, which began 2.6 million years ago, glaciers advanced and retreated four times (**Figure** 1.29). During the retreats, the climate was often warmer than it is today.

These continental ice sheets were extremely thick, like the Antarctic ice cap is today (**Figure** 1.30) .

KQED: Ice Age Bay Area

Imagine a vast grassy plain covered with herds of elephants, bison and camels stretching as far as the eye can see. Lions, tigers, wolves and later, humans, hunt the herds on their summer migration.This was the San Francisco Bay Area at the close of the last Ice Age. Learn more at:http://science.kqed.org/quest/video/ice-age-bay-area/

MEDIA

Click image to the left for more content.

Lesson Summary

- The Phanerozoic began 570 million years ago and continues today.
- The Paleozoic was a time of four marine transgressions and regressions, which left characteristic sedimentary facies.

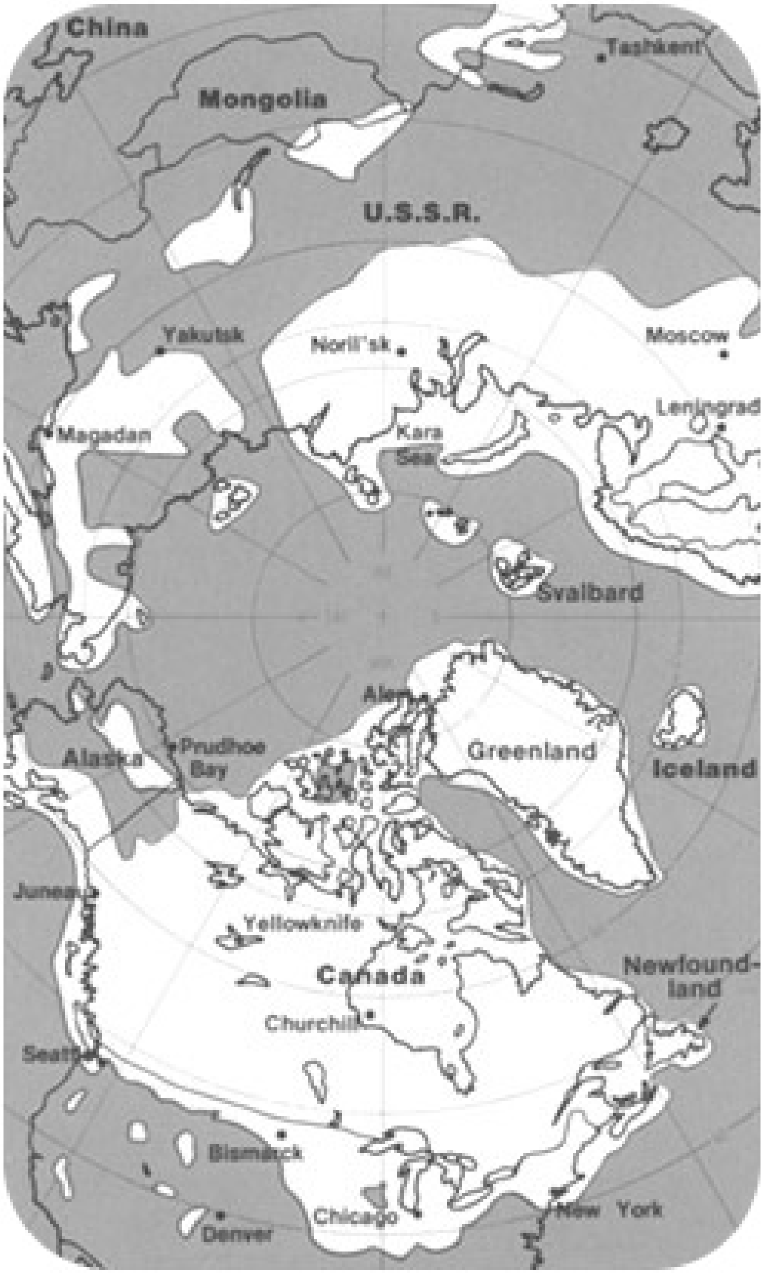


FIGURE 1.29
Glacial ice at its maximum during the Pleistocene.

- An orogeny is a mountain building event that takes place when a continent runs into another continent, a microcontinent, or a volcanic island arc.
- The general climate trend in the Cenozoic was cooling, leading to the Pleistocene ice ages from 2.6 million to about 10,000 years ago.

Review Questions

1. What are the possible causes of a marine transgression? Of a marine regression?
2. What rock sequence indicates a marine transgression? What rock sequence indicates a marine regression?
3. How do the rocks of the Grand Canyon indicate marine transgressions or regressions?

FIGURE 1.30
This continental glacier over Antarctica is up to 4,000 meters (12,000 feet) thick.

4. What was the configuration of oceans during the time of the supercontinent Pangaea?

5. What geologic evidence is left after a continent breaks apart?

6. What was the Pleistocene climate like?

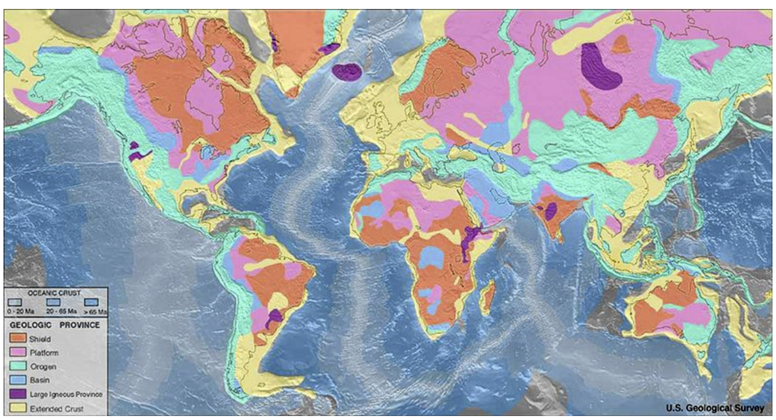


FIGURE 1.31
Describe the geologic history of North America.

7. Using the map (**Figure** 1.31), describe the geologic history of North America. In what order did events occur? What is the cause of the orogenies lining the western and eastern continental margins?

8. Look at Africa. Why is there no orogenic province on the western or eastern margins of the continent? What is the cause of the purple province in the northeast?

9. Where are the mountains of South America located? What is the reason for those mountains?

Points to Consider

- How did the paleogeography of the planet affect the evolution of life?
- How did climate affect the evolution of life?
- How was human evolution related to major climatic events?

1.4 History of Earth's Complex Life Forms

Lesson Objectives

- Describe how adaptations develop.
- Explain how the fossil record shows us that species evolve over time.
- Describe the general development of Earth's life forms over the last 540 million years.

Vocabulary

- adaptation
- adaptive radiation
- amniote egg
- evolution
- mutation
- natural selection
- paleontologist
- tropical
- variation

Introduction

Organisms must adapt to their environment or they will die out. Most of the fossils are the remains of animals that are now extinct. The mechanism for change in a population of organisms is natural selection.

Adaptation and Evolution

The characteristics of an organism that help it to survive in a given environment are called **adaptations**. Adaptations are traits that an organism inherits from its parents. Within a population of organisms are genes coding for a certain number of traits; for example, a human population may have genes for eyes that are blue, green, hazel, or brown, but as far as we know, not purple or lime green.

Adaptations develop when certain **variations** or differences in a population help some members survive better than others (**Figure** 1.32). The variation may already exist within the population, but often the variation comes from a **mutation**, or a random change in an organism's genes. Some mutations are harmful and the organism dies; in that case, the variation will not remain in the population. Many mutations are neutral and remain in the population. If the environment changes, the mutation may be beneficial and it may help the organism adapt to the environment. The organisms that survive pass this favorable trait on to their offspring.

Many changes in the genetic makeup of a species may accumulate over time, especially if the environment is changing. Eventually the descendants will be very different from their ancestors and may become a whole new species. Changes in the genetic makeup of a species over time are known as biological **evolution**.

The mechanism for evolution is **natural selection**. Traits become more or less common in a population depending on whether they are beneficial or harmful. An example of evolution by natural selection can be found in the deer mouse, species Peromyscus maniculatus. In Nebraska this mouse is typically brown, but after glaciers carried lighter sand over the darker soil in the Sand Hills, predators could more easily spot the dark mice. Natural selection favored the light mice, and over time, the population became light colored.

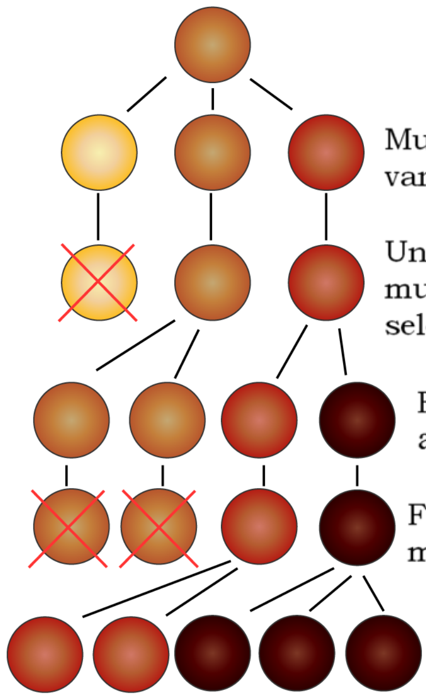


FIGURE 1.32
An explanation of how adaptations develop.

This story is covered in more detail here: http://news.harvard.edu/gazette/story/2009/08/mice-living-in-sand-hills-quickly-evolved-lighter-coloration/.

This animation begins with the Big Bang, which will be discussed in the chapter about the solar system, and goes through the history of life on Earth: http://www.johnkyrk.com/evolution.html.

Ediacara Fauna

Although the explosion in the number and type of life forms did not come until the beginning of the Cambrian, life at the end of the Precambrian became more complex. Paleontologists find worldwide evidence of a group of extremely diverse multicellular organisms toward the end of the Precambrian (580-542 Ma). The Ediacara Fauna have a variety of forms of symmetry, range from soft to rigid, and they take the form of discs, bags, or even "quilted mattresses" (**Figure** 1.33). The organisms seem to have appeared as Earth defrosted from its worldwide glaciation.

No one knows quite how to categorize these organisms. Some scientists think that they are the ancestors of organisms that came later. Others think that the Ediacara fauna died out and that the organisms that took over during the Cambrian were a different group. It may not be possible to know the solution to this problem.

Why did it take 4 billion years for organisms as complex as the Ediacara biota to evolve? Scientists do not really know, although there are many possible explanations:

- Evolutionary processes are slow and it took a long time for complexity to evolve.
- There was no evolutionary advantage to being larger and more complex.
- Atmospheric oxygen was limited so complex organisms could not evolve.
- The planet was too cold for complex life.
- Complex life evolved but was wiped out by the massive global glaciations.

FIGURE 1.33
An example of an Ediacara organism.

Scientists also do not know why the Ediacaran biota died out. Some possibilities include:

- The evolution of predators with skeletons in the Cambrian.
- Competition from more advanced Cambrian organisms.
- Changes in environmental conditions caused by supercontinent breakups such as rising sea level, limited nutrients, or changing atmospheric and oceanic chemistry.

The existence of the Ediacaran biota does show that a diversity of life forms existed before the Cambrian.

Phanerozoic Eon

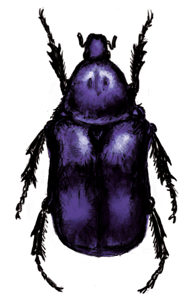
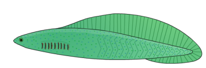
The **Phanerozoic Eon** is divided into three eras—the Paleozoic, the Mesozoic, and the Cenozoic–spanning from about 540 million years ago to the present (**Table** 1.1). Life has undergone fantastic changes during the long span of the Phanerozoic Eon.

Notice that different types of organisms developed at different times.

TABLE 1.1: Development of Life During the Phanerozoic Eon

Era	Millions of Years Ago	Major Forms of Life
Cenozoic	0.2 (200,000 years ago)	First humans
	35	First grasses; grasslands begin to dominate the land
Mesozoic	130	First plants with flowers
	150	First birds on Earth
	200	First mammals on Earth

TABLE 1.1: (continued)

Era	Millions of Years Ago	Major Forms of Life	
	251	Age of dinosaurs begins	
Paleozoic	300	First reptiles on Earth	
	360	First amphibians on Earth	
	400	First insects on Earth	
	475	First plants and fungi begin growing on land	
	500	First fish on Earth	

Extinction and Radiation

The eras of the Phanerozoic Eon are separated by mass extinctions. A mass extinction occurs when large numbers of species become extinct in a short amount of time. The causes of different mass extinctions are different: collisions with comets or asteroids, massive volcanic eruptions, or rapidly changing climate are all possible causes of some of these disasters (**Figure 1.34).**

After a mass extinction, many habitats are no longer inhabited by organisms because they have gone extinct. A change in the environment from one in which organisms live in all the available habitats to one in which many habitats are available gives an advantage to organisms that can adapt to new environments. Evolutionary processes act rapidly during these times and many new species evolve to fill those available habitats. The process in which many new species evolve in a short period of time to fill available niches is called **adaptive radiation**.

Paleozoic Life

The Cambrian began with a tremendous diversification of life forms. Shallow seas covered the lands so every major marine organism group evolved during this time. With the evolution of hard body parts, fossils are much more abundant and better preserved from this period than from the Precambrian.

The Burgess Shale formation in the Rocky Mountains of British Columbia, Canada, contains an amazing diversity of middle Cambrian life forms, from about 505 million years ago. One organism had a soft body like a worm, five

FIGURE 1.34
An extinct Tyrannosaurus rex. This fossil resembling a living organism.

eyes, and a long nose like a vacuum cleaner hose (**Figure** 1.35). Paleontologists do not agree on whether the Burgess Shale fossils can all be classified into modern groups of organisms or whether many represent lines that have gone completely extinct.

FIGURE 1.35
This bizarre animal with five eyes lived during the Cambrian, which began about 540 million years ago.

Throughout the Paleozoic, seas transgressed and regressed. When continental areas were covered with shallow seas, the number and diversity of marine organisms increased. During regressions the number shrank. Large extinction events separate the periods of the Paleozoic. After extinctions, new life forms evolved (**Figure** 1.36). For example, after the extinction at the end of the Ordovician, fish and the first tetrapod animals appeared. Tetrapods are four legged vertebrates, but the earliest ones did not leave shallow, brackish water.

Simple plants began to colonize the land during the Ordovician, but land plants really flourished when seeds evolved during the Carboniferous (**Figure** 1.37). The abundant swamps became the coal and petroleum deposits that are the source of much of our fossil fuels today. During the later part of the Paleozoic, land animals and insects greatly

FIGURE 1.36
Trilobites were shallow marine animals that flourished during the lower Paleozoic.

increased in numbers and diversity.

FIGURE 1.37
A modern rainforest has many seed-bearing plants that are similar to those that were common during the Carboniferous.

The largest mass extinction in Earth history occurred at the end of the Permian period, about 250 million years ago. In this catastrophe, it is estimated that more than 95% of marine species on Earth went extinct. Marine species with calcium carbonate shells and skeletons suffered worst. About 70% of terrestrial vertebrates (land organisms) also went extinct. This was also the only known mass extinction of insects.

This mass extinction appears to have taken place in three pulses, with three separate causes. Gradual environmental change, an asteroid impact, intense volcanism, or changes in the composition of the atmosphere may all have played a role.

Mesozoic Life

At the beginning of the Mesozoic, Pangaea began to break apart so more beaches and continental shelf areas were available for colonization. Climate during the entire era was warm and **tropical**. With many niches available after the mass extinction, a great diversity of organisms evolved.

Tiny marine plants called phytoplankton arose to become the base of the marine food web. On land, seed plants and trees diversified. Flowering plants evolved during the Cretaceous (**Figure** 1.38).

FIGURE 1.38
The earliest known fossil of a flowering plant is this 125 million year old Cretaceous fossil.

Mammals appeared near the end of the Triassic but the Mesozoic is known as the age of the reptiles. In a great advance over amphibians, which must live near water, reptiles developed adaptations for living away from water. Their thick skin keeps them from drying out and the evolution of the amniotic egg allowed them to lay their eggs on dry land. The **amniote egg** has a shell and contains all the nutrients and water required for the developing embryo.

Of course the most famous Mesozoic reptiles were the dinosaurs. Dinosaurs reigned for 160 million years and had tremendous numbers and diversity. Species of dinosaurs filled all the niches that are currently filled by mammals. Dinosaurs were plant eaters, meat eaters, bipedal, quadrupedal, endothermic (warm-blooded), exothermic (cold-blooded), enormous, small, and some could swim or fly. Although nearly all species of dinosaurs went extinct, modern birds evolved from theropod dinosaurs (**Figure** 1.39).

Between the Mesozoic and the Cenozoic, 65 million years ago, about 50% of all animal species, including the dinosaurs, became extinct. Although there are other hypotheses, most scientists think that this mass extinction took place when a giant meteorite struck Earth with the energy of the most powerful nuclear weapon (**Figure** 1.40).

The impact kicked up a massive dust cloud and when the particles rained back onto the surface they heated the atmosphere until it became as hot as a kitchen oven. Animals roasted. Dust that remained in the atmosphere blocked sunlight for a year or more, causing a deep freeze and temporarily ending photosynthesis. Sulfur from the impact mixed with water in the atmosphere to form acid rain, which dissolved the shells of the tiny marine plankton that form the base of the food chain. With little food being produced by land plants and plankton, animals starved. Carbon dioxide was also released from the impact and eventually caused global warming. Life forms could not

FIGURE 1.39
Archeopteryx, the earliest known bird, lived during the late Jurassic.

FIGURE 1.40
An artist

survive the dramatic temperature swings.

Asteroid impacts have profoundly affected earth history from the very beginning, by bringing in water and amino acids for the oceans, atmosphere, and life, and by forming the Moon. Mass extinctions that have occurred throughout Earth history may also have been caused by asteroid impacts. The best known is the impact that brought about the extinction of the dinosaurs **(1f)**:

http://www.youtube.com/watch?v=z2CnH_0V5_I (2:01), http://www.youtube.com/watch?feature=player_profilepage&v=uEFYkOh3YYA (1:23), http://www.youtube.com/watch?v=oYNsBVJ2Hv0 (10:00).

MEDIA

Click image to the left for more content.

MEDIA

Click image to the left for more content.

MEDIA

Click image to the left for more content.

Cenozoic Life

The extinction of so many species again left many niches available to be filled. Although we call the Cenozoic the age of mammals, birds are more common and more diverse.

The adaptations allow mammals to spread to even more environments than reptiles because mammals are endothermic and have fur, hair, or blubber for warmth. Mammals can swim, fly, and live in nearly all terrestrial environments. Mammals initially filled the forests that covered many early Cenozoic lands. Over time, the forests gave way to grasslands, which created more niches for mammals to fill.

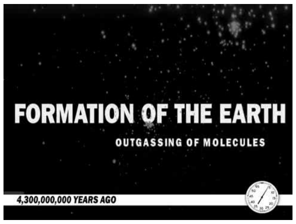
As climate cooled during the ice ages, large mammals were able to stand the cold weather and so many interesting megafauna developed (**Figure** 1.41).

A lecture from Yale University on the effect of life on Earth and Earth on life during 4.5 billion years. Glaciations appear at minute mark 23:30-26:20 and then the video goes into mass extinctions **(6c)**: http://www.youtube.com/watch?v=K6Dl_Vs-ZkY&feature=player_profilepage (47:10).

MEDIA

Click image to the left for more content.

The Evolution of Life in 60 Seconds scales all 4.6 billion years of Earth history into one minute. Don't blink at the end **(1i - IE Stand.)**: http://www.youtube.com/watch?v=YXSEyttblMI&feature=related (1:03).



MEDIA
Click image to the left for more content.

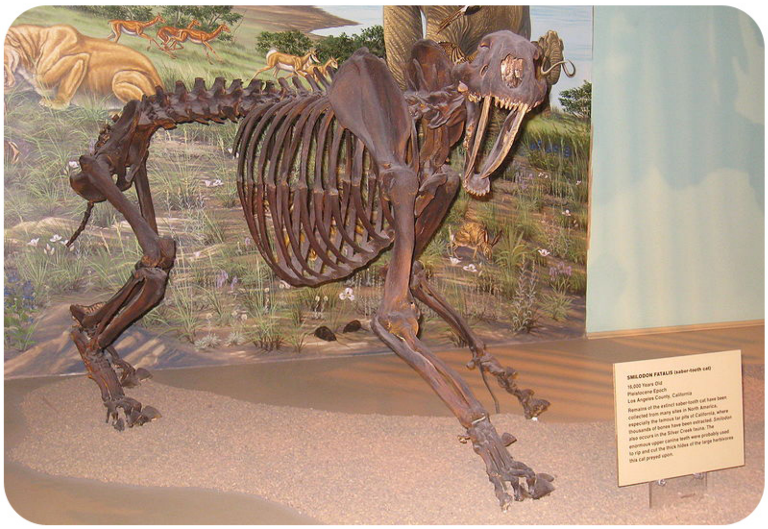


FIGURE 1.41
The saber-tooth cat lived during the Pleistocene.

Humans also evolved during the later Cenozoic. Bipedal primates first appeared about 6 million years ago when grasslands were common. Standing on two feet allows an organism to see and also to use its hands and arms for hunting (**Figure** 1.42). The brain size of this bipedal primate grew rapidly.

The genus Homo appeared about 2 million years ago. Humans developed tools and cultures (**Figure** 1.43). Homo sapiens, our species, originated about 200,000 years ago in Africa.

The ice ages allowed humans to migrate. During the ice ages water was frozen in glaciers and so land bridges such as the Bering Strait allowed humans to walk from the old world to the new world.

Modern Biodiversity

There are more than 1 million species of plants and animals known to be currently alive on Earth (**Figure** 1.44) and many millions more that have not been discovered yet. The tremendous variety of creatures is due to the tremendous numbers of environments. (**Figure** 1.45).

Many adaptations protect organisms from the external environment (**Figure** 1.46).

Other adaptations help an organism move or gather food. Reindeer have sponge-like hoofs that help them walk on snowy ground without slipping and falling. Hummingbirds have long thin beaks that help them drink nectar from flowers. Organisms have special features that help them avoid being eaten. When a herd of zebras run away from lions, the zebras' dark stripes confuse the predators so that they have difficulty focusing on just one zebra during the chase. Some plants have poisonous or foul-tasting substances in them that keep animals from eating them. Their brightly colored flowers serve as a warning.

FIGURE 1.42
Australopithecus afarensis is a human ancestor that lived about 3 million years ago.

FIGURE 1.43
Evidence of a spiritual life appears about 32,000 years ago with stone figurines that probably have religious significance.

Lesson Summary

- Adaptations are favorable traits that organisms inherit. Adaptations develop from variations within a population and help organisms to survive in their given environment.
- Changes in populations accumulate over time; this is called evolution.
- The fossil record shows us that present day life forms evolved from earlier life forms.
- Beginning about 540 million years ago more complex organisms developed on Earth. During the Phanerozoic Eon all of the plant and animal types we know today evolved.

FIGURE 1.44
There is an amazing diversity of organisms on Earth. How do the organisms in this picture each make their living?

FIGURE 1.45
Polar bears have thick fur coats to stay warm as they hunt in icy waters.

- Many types of organisms that once lived are now extinct. Earth's overall environment, especially the climate, has changed many times, and organisms change over time, too.

Review Questions

1. Describe how an adaptation comes about.

2. What is evolution? How is natural selection the mechanism for evolution?

3. How might a hard external skeleton, called an exoskeleton, be a favorable adaptation for the soft bodied organisms that had lived before?

4. Explain why unfavorable traits usually do not get passed to offspring.

5. Why did it take 4 billion years of Earth history for multicellular organisms to evolve and diversify to the point of the Ediacara biota?

6. List the order in which the major types of animals appeared on Earth.

7. How might climate have affected the ability of plants to grow over large areas during a given time?

8. One cause of mass extinctions is a meteorite or comet impact. What might be some additional causes of mass extinctions?

9. What happens immediately after a mass extinction to the diversity of organisms? What happens thousands or

FIGURE 1.46
Cacti have thick, water- retaining bodies that help them conserve water.

millions of years later?

10. Describe the big advance reptiles had over amphibians.

11. Why are there so many different species on Earth today?

Points to Consider

- How did life on Earth change from one period of geologic time to the next?
- How did climate affect the evolution of life?
- Evolution is well documented in the fossil record. Why is it so controversial?

- Elapied. http://en.wikipedia.org/wiki/File:Venus_of_Brassempouy.jpg. Public Domain.
- Merikanto. http://en.wikipedia.org/wiki/File:Spriggina_Floundensi_4.png. CC-BY 2.5.
- Courtesy of US Geological Survey. http://en.wikipedia.org/wiki/File:Pleistocene_north_ice_map.jpg. Public Domain.
- Image copyright Joao Virissimo, 2010. http://www.shutterstock.com/. Used under license from Shutterstock.com.
- Kieff. http://en.wikipedia.org/wiki/File:Pangaea_continents.svg. GNU-FDL 1.2.
- Courtesy of NASA. http://en.wikipedia.org/wiki/File:Apollo_15_Genesis_Rock.jpg. Public Domain.
- Kristian Peters (Fabelfroh). *affine laminazellen.jpeg* . GNU-FDL 1.2.
- Courtesy of the National Park Service. http://www.nature.nps.gov/geology/parks/grca/age/image_popup/yardstick.htm. Public Domain.
- Image Copyright Nicola Gavin, 2010. http://www.shutterstock.com/. Used under license from Shutterstock.com.
- Fredrik. http://en.wikipedia.org/wiki/File:Impact_event.jpg. Public Domain.

- Moussa Direct Ltd.. http://en.wikipedia.org/wiki/File:Kainops_invius_lateral_and_ventral.JPG. CC-BY-SA 3.0.
- Courtesy of the National Park Service. http://en.wikipedia.org/wiki/File:Vishnu_Basement_rocks.JPG. Public Domain.
- Courtesy of Jesse Allen/NASA's Earth Observatory. http://earthobservatory.nasa.gov/IOTD/view.php?id=41385. Public Domain.
- Stemonitis. http://commons.wikimedia.org/wiki/Image:Animalia_diversity.jpg. CC-BY-SA 2.5.
- Shizhao. http://en.wikipedia.org/wiki/File:Archaefructus_liaoningensis.jpg. CC-BY-SA 2.5.
- Miles Orchinik. http://miles-home.smugmug.com/Nature/Spring-in-the-Superstitions/6813517_wZcv5#435460705_gtC5J. Used with permission.
- CK-12 Foundation. . CC-BY-NC-SA 3.0.
- Courtesy of the US Geological Survey, modified by CK-12 Foundation. *orogeny.png* . Public Domain.
- Courtesy of Jesse Allen/NASA's Earth Observatory. http://earthobservatory.nasa.gov/IOTD/view.php?id=4962. Public Domain.
- Courtesy of NASA. http://en.wikipedia.org/wiki/File:Giantimpact.gif. Public Domain.
- Image courtesy of Jesse Allen/NASA's Earth Observatory. http://earthobservatory.nasa.gov/IOTD/view.php?id=35567. Public Domain.
- Courtesy of NASA Ames Research Center/K. Jobse, P. Jenniskens. http://en.wikipedia.org/wiki/File:Comet_Parts.jpg. Public Domain.
- Courtesy of the US Geological Survey. http://en.wikipedia.org/wiki/File:Cretaceous_seaway.png. Public Domain.
- YassineMrabet. *experiment-en.svg* . CC-BY-SA 3.0.
- CK-12 Foundation/Christopher Auyeung. . CC-BY-NC-SA 3.0.
- Mariana Ruiz Villarreal (LadyofHats). . Public Domain.
- Billion. http://en.wikipedia.org/wiki/File:Stan_the_Trex_at_Manchester_Museum.jpg. GNU-FDL 1.2.
- Ansgar Walk. http://commons.wikimedia.org/wiki/File:Ursus_maritimus_4_1996-08-04.jpg. CC-BY-SA 2.5.
- Courtesy NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team. http://earthobservatory.nasa.gov/IOTD/view.php?id=5819. Public Domain.
- Esv. http://en.wikipedia.org/wiki/File:A.afarensis.jpg. Public Domain.
- P. Carrara, NPS. http://en.wikipedia.org/wiki/File:Stromatolites.jpg. Public Domain.
- Linuxerist, modified by CK-12 Foundation. http://commons.wikimedia.org/wiki/File:Earth_layers_model.png. GNU-FDL 1.2.
- Courtesy of US Geological Survey. http://en.wikipedia.org/wiki/File:San_Andreas_Fault_Sequential_Diagrams.jpg. Public Domain.
- Daderot. http://en.wikipedia.org/wiki/File:Smilodon_fatalis_UMNH.jpg. Public Domain.
- CK-12 Foundation. . CC-BY-NC-SA 3.0.
- NIAID. http://en.wikipedia.org/wiki/File:EscherichiaColi_NIAID.jpg. Public Domain.
- Courtesy of the US Geological Survey. http://commons.wikimedia.org/wiki/File:World_geologic_provinces.jpg. Public Domain.
- Miles Orchinik. http://miles-home.smugmug.com/Nature/Yellowstone-journal/9367656_bN4r9#626958722_LVQR2. Used with permission.
- Courtesy of Kristan Hutchinson/National Science Foundation. http://en.wikipedia.org/wiki/File:Kanadagletscher.jpg. Schools, educational and encyclopedia publishers, and similar institutions may use the photos freely to further educational awareness of Antarctica. No one may reproduce the photos for personal or commercial profit..
- Scott Robinson (Clearly Ambiguous). http://commons.wikimedia.org/wiki/File:Arenal_at_night.jpg. CC-BY 2.0.
- Nobu Tamura. http://en.wikipedia.org/wiki/File:Opabinia_BW2.jpg. CC-BY 3.0.
- H. Raab. http://en.wikipedia.org/wiki/File:AllendeMeteorite.jpg. CC-BY-SA 3.0.
- Raimond Spekking (Raymond). http://en.wikipedia.org/wiki/File:Naturkundemuseum_Berlin_-_Archaeopteryx_-_Eichst%C3%A4tt.jpg. CC-BY-SA 3.0.

- André Karwath (Aka). *ironstone (aka).jpg* . CC-BY-SA 2.5.
- CK-12 Foundation based on information from the US Geological Survey. *[Original from: http://commons.wikimedia.org/wiki/File:Geologic_time_scale.gif]*. CC-BY-NC-SA 3.0.
- CK-12 Foundation. . CC-BY-NC-SA 3.0.

Opening image courtesy of Miles Orchinik, http://miles-home.smugmug.com/Nature/Yellowstone-journal/9367656_bN4r9#626950317_v3xJ3, used with permission.

For **Table** 1.1, from top to bottom:

- Mariana Ruiz Villarreal (LadyofHats). http://commons.wikimedia.org/wiki/File:Abrictosaurus_dinosaur.png. Public Domain.
- Meul. http://commons.wikimedia.org/wiki/File:Scarabe_dessin_retouche_violet.jpg. CC-BY-SA 3.0.
- Giant Blue Anteater. http://en.wikipedia.org/wiki/File:Haikouichthys4.png. Public Domain.

1.5 References

1. . HS-ES-12-01-Allende-meteorite.jpg.
2. . ES-12-02-Earth-layers-model.png.
3. . ES-12-03-impact.png.
4. . ES-12-04-genesis-rock.jpg.
5. . ES-12-05-arenal-at-night.jpg.
6. . HS-ES-12-06-comet-tail.jpg.
7. . ES-12-06-geologic-time-scale.png.
8. . ES-12-08-candian-shield.jpg.
9. . ES-12-09-hopewell-islands.jpg.
10. . ES-12-10-Vishnu-Basement-rocks.jpg.
11. . ES-12-11-rodinia.jpg.
12. . HS-ES-12-12-Amino-acids.png.
13. . HS-ES-12-13-Miller-Urey.png.
14. . HS-ES-12-14-Escherichia-coli.jpg.
15. . HS-ES-12-15-Bacterium.png.
16. . HS-ES-12-16-Chloroplasts.jpeg.
17. . HS-ES-12-17-Banded-iron.jpg.
18. . HS-ES-12-18-Thermophilic.jpg.
19. . HS-ES-18-31-Nitrogen-run-off.
20. . Stromatolites.jpg.
21. . HS-ES-12-21-Transgressions.
22. . HS-ES-12-22-Paleozoic-sedimentary-rocks.
23. . HS-ES-12-24-taconic-orogeny.png.
24. . ES pangea oceans new.
25. . HS-ES-12-26-Ethiopia.jpg.
26. . 12-27-snow-covered-Sierra-nevada.jpg.
27. . HS-ES-12-28-tectonic-activity.png.
28. . HS-ES-12-29-san-andreas-fault.jpg.
29. . EarSci-1703-01.jpg.
30. . HS-ES-12-31-conitnental-glacier.jpg.
31. . Geologic-history-of-NA.
32. . EarSci-1203-05.png.
33. . HS-ES-12-34-Ediacara.png.
34. . Stan the Trex at Manchester Museum.
35. . EarSci-1203-02.jpg.
36. . HS-ES-12-37-Trilobites.JPG.
37. . EarSci-1203-11.jpg.
38. . HS-ES-12-39-fossil.jpg.
39. . HS-ES-12-41-Archeopterx.jpg.
40. . HS-ES-25-47-astroid-strikes-earth.jpg.
41. . HS-ES-12-43-saber-tooth.jpg.
42. . HS-ES-12-44-Australopithecus.jpg.
43. . HS-ES-12-45-evidence-spiritual-life.jpg.
44. . EarSci-1203-03.jpg.
45. . EarSci-1203-04.jpg.

46. . HS-ES-17-07-Cactus.jpg.