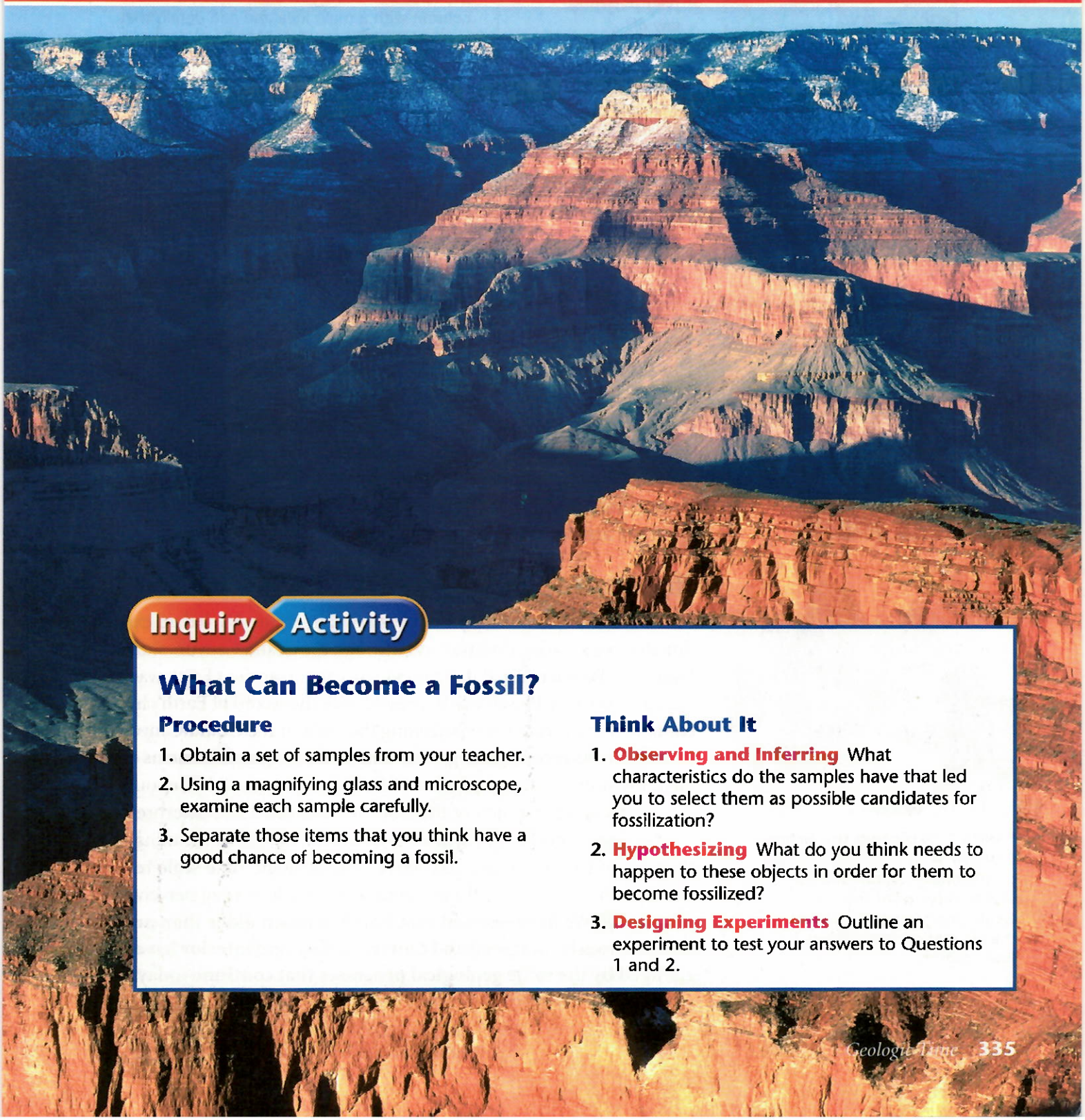
HISTORICAL GEOLOGY

Chapter Preview



Inquiry Activity

What Can Become a Fossil?

Procedure

1. Obtain a set of samples from your teacher.
2. Using a magnifying glass and microscope, examine each sample carefully.
3. Separate those items that you think have a good chance of becoming a fossil.

Think About It

1. **Observing and Inferring** What characteristics do the samples have that led you to select them as possible candidates for fossilization?
2. **Hypothesizing** What do you think needs to happen to these objects in order for them to become fossilized?
3. **Designing Experiments** Outline an experiment to test your answers to Questions 1 and 2.

A Brief History of Geology

The primary goal of geologists is to interpret Earth's history. By studying rocks, especially sedimentary rocks, geologists can begin to understand and explain the past.

In the mid-1600s, Archbishop James Ussher constructed a chronology or time line of both human and Earth history in which he determined that Earth was more than five thousand years old. He believed Earth had been created in 4004 B.C. Ussher published his chronology, and his book earned widespread acceptance among Europe's scientific and religious leaders.

In the late 1700s, James Hutton, a Scottish physician and gentleman farmer, published his *Theory of the Earth.* In this work, Hutton put forth the fundamental principle of **uniformitarianism,** which simply states that the physical, chemical, and biological laws that operate today have also operated in the geologic past. **Uniformitarianism means that the forces and processes that we observe today have been at work for a very long time.** To understand the geologic past, we must first understand present-day processes and their results.

Today, scientists understand that these same processes may not always have had the same relative importance or operated at precisely the same rate. Moreover, some important geologic processes are not currently observable, but evidence that they occur is well established. For example, we know that Earth has been hit by large meteorites even though we have no human witnesses. Such events altered Earth's crust, modified its climate, and strongly influenced life on the planet.

The acceptance of uniformitarianism meant the acceptance of a very long history for Earth. It is important to remember that although many features of our physical landscape may seem to be unchanging over our lifetimes, they are still changing, but on time scales of hundreds, thousands, or even millions of years.

Reading Checkpoint ***How do the laws that govern geological processes change through time?***

Relative Dating—Key Principles

During the late 1800s and early 1900s, several attempts were made to determine the age of Earth. To establish a relative time scale, a few basic principles or rules had to be discovered and applied. These principles were major breakthroughs in thinking at the time, and their discovery and acceptance was an important scientific achievement.

Relative dating means identifying which rock units formed first, second, third, and so on. **Relative dating tells us the sequence in which events occurred, not how long ago they occurred.**

Principle of Cross-Cutting Relationships

The principle of cross-cutting relationships is Steno's third observation. The **principle of cross-cutting relationships** states that when a fault cuts through rock layers, or when magma intrudes other rocks and crystallizes, we can assume that the fault or intrusion is younger than the rocks affected. For example, in Figure 4 you can see that fault A occurred after the sandstone layer was deposited because it "broke" the layer. However, fault A occurred before the conglomerate was laid down, because that layer is unbroken. Because they cut through the layers of sedimentary rock, the faults and dikes clearly must have occurred after the sedimentary layers were deposited.

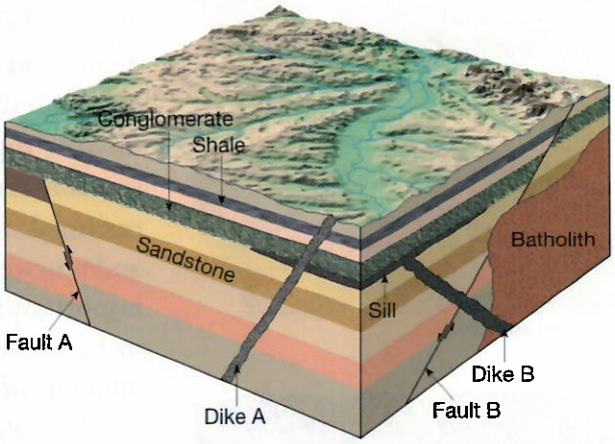


Figure 4 Applying Steno's Principles Cross-cutting relationships are an important principle used in relative dating. An intrusive rock body is younger than the rocks it intrudes. A fault is younger than the rock layers it cuts.
Interpreting Diagrams ***What is the age relationship between the batholith, dike B, dike A, and the sill?***

Inclusions Sometimes inclusions can help the relative dating process. Inclusions are pieces of one rock unit that are contained within another. The rock unit next to the one containing the inclusions must have been there first in order to provide the rock fragments. Therefore, the rock unit containing inclusions is the younger of the two. Figure 5 provides an example. The photograph in Figure 5C shows inclusions of igneous rock within a layer of sedimentary rock. How did they get there? The inclusions indicate that the sedimentary layer was deposited on top of the weathered igneous mass. The sedimentary layer must be younger than the igneous rock because the sedimentary layer contains pieces of the igneous rock. We know the layer was not intruded upon by magma from below that later crystallized because the sedimentary rock is still horizontal.

Formation of Inclusions

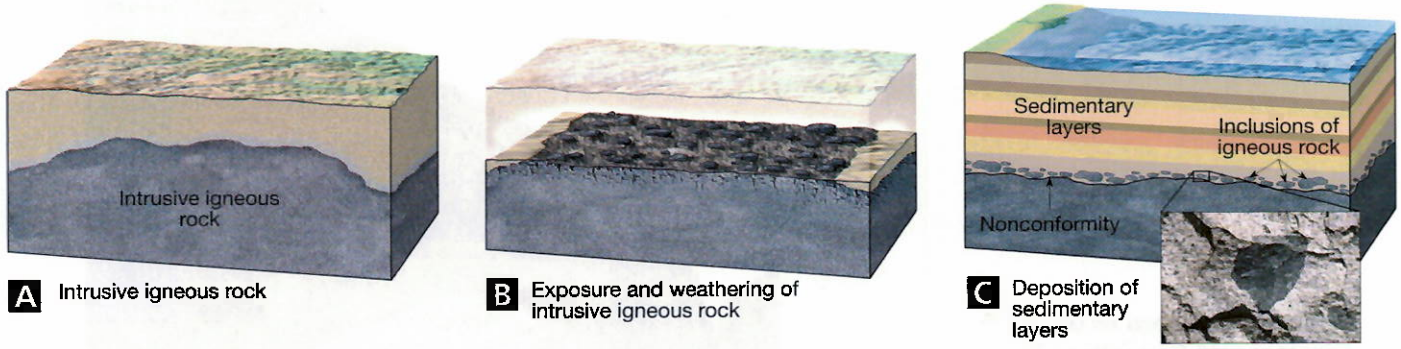


Figure 5 **A** A mass of igneous rock formed from magma that intruded an older rock body. **B** The older rock erodes and exposes the igneous rock to weathering. **C** Sedimentary rock layers form on top of the weathered igneous rock.

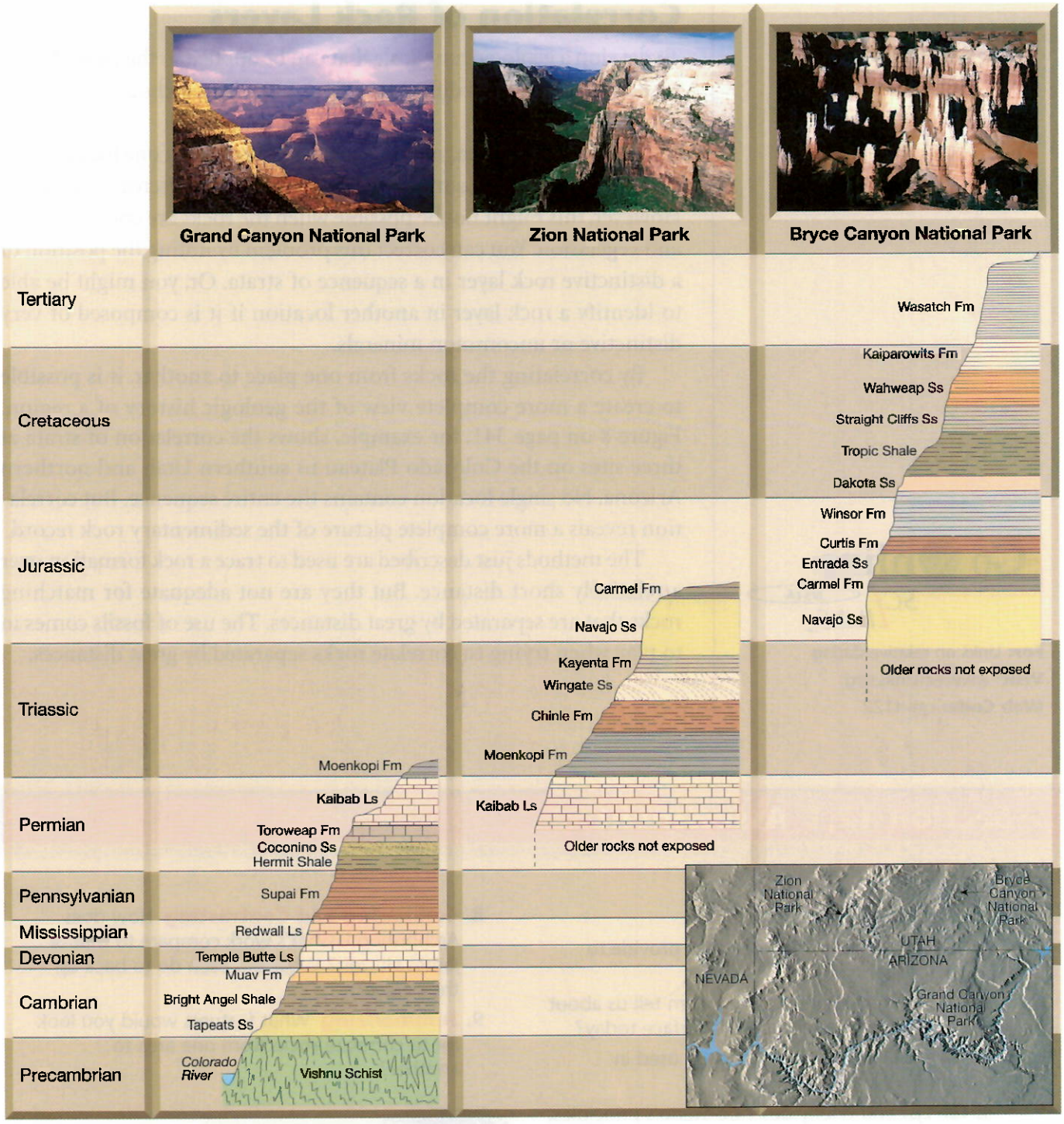


Figure 8 Correlation of strata at three locations on the Colorado Plateau reveals a more complete view of the extent of sedimentary rocks in the region.

12.2 Fossils: Evidence of Past Life

Reading Focus

Key Concepts

- What are fossils?
- What determines if an organism will become a fossil?
- What is the principle of fossil succession?

Vocabulary

- fossil
- index fossil

Reading Strategy

Monitoring Your Understanding Draw and complete a chart like the one below. After you finish this section, correct or add details as needed.

Fossils	How Fossils Form	How Fossils are Used
a. ?	b. ?	c. ?

Fossils are important tools for interpreting the geologic past. **Fossils are the remains or traces of prehistoric life. They are important components of sediment and sedimentary rocks.** Knowing the nature of the life forms that existed at a particular time helps researchers understand past environmental conditions. Further, fossils are important time indicators. They play a key role in correlating rocks of similar ages that are from different places.

Fossil Formation

There are many types of fossils. **The type of fossil that is formed is determined by the conditions under which an organism died and how it was buried.**

Unaltered Remains Some remains of organisms—such as teeth, bones, and shells—may not have been altered, or changed, hardly at all over time. It is far less common to find the remains of an entire animal, including flesh. In Siberia, archaeologists recently found a fully preserved, frozen mammoth, shown in Figure 9. This is an excellent example of unaltered remains.

Altered Remains The remains of an organism are likely to be changed over time. Fossils often become petrified, or "turned into stone." When a fossil is petrified, mineral-rich water soaks into the small cavities and pores of the original organism. The minerals precipitate from the water and fill the spaces. The log of petrified wood in Figure 10E shows the result. In other instances, the cell walls or other solid material of an organism are replaced with mineral matter. Sometimes the microscopic details of the replaced structure are preserved.

Figure 9 Unaltered Remains Frozen animals are an extreme and unusual type of fossilization.

Conditions Favoring Preservation **Two conditions are important for preservation: rapid burial and the possession of hard parts.** The soft parts of a dead animal are usually eaten by scavengers or decomposed by bacteria. However, if the remains are buried quickly by sediment, they are protected from the environment. Then there is a chance that the organism will become a fossil. In addition, organisms have a better chance of being preserved if they have hard parts such as shells, bones, and teeth. Fossils of hard parts dominate the fossil record even though fossils of soft-bodied animals such as jellyfish and worms do exist.

Why are soft parts of dead animals rarely preserved?

Fossils and Correlation

In the late 18th century, William Smith, an English engineer and canal builder, demonstrated the usefulness of fossils to geology. He found that fossils weren't randomly distributed throughout the rock layers he cut through. Instead, each layer contained a distinct assortment of fossils that did not occur in the layers above or below it. Smith also noted that sedimentary rock layers in distant areas could be identified and correlated by the distinct fossils they contained.

Based on Smith's observations and the findings of many geologists who followed, one of the most important principles in historical geology was formulated. **The principle of fossil succession states that fossil organisms succeed one another in a definite and determinable order. Therefore, any time period can be recognized by its fossil content.**

Based on the rock record from around the world, geologists have identified an order of fossils: an Age of Trilobites, an Age of Fishes, an Age of Coal Swamps, an Age of Reptiles, and an Age of Mammals. These "ages" correspond to particular time periods and are characterized by distinct and abundant fossils. This same order of dominant organisms is found on every continent.

Once fossils were recognized as time indicators, they became the most useful means of correlating rocks of similar age in different regions. Geologists pay particular attention to **index fossils.** **Index fossils are widespread geographically, are limited to a short span of geologic time, and occur in large numbers.** Their presence provides an important method of matching rocks of the same age. Rock formations, however, do not always contain a specific index fossil. Then groups of fossils are used to establish the age of a rock layer. Figure 11 shows how an assemblage of fossils can be used to date rocks more precisely than using only one kind of fossil.

12.3 Dating with Radioactivity

Reading Focus

Key Concepts

- What is radioactivity?
- What is half-life?
- What is radiometric dating?
- How is carbon-14 used in radiometric dating?

Vocabulary

- radioactivity
- half-life
- radiometric dating
- radiocarbon dating

Reading Strategy

Monitoring Your Understanding Preview the key concepts, topics, headings, vocabulary, and figures in this section. Copy the chart below. List two things you expect to learn about each. After reading, state what you learned about each item you listed.

What I expect to learn	What I learned
1. a. ?	b. ?
2. c. ?	d. ?

Today, it is possible to obtain reliable numerical dates for events in the geologic past. For example, we know that Earth is about 4.56 billion years old and that the last dinosaurs became extinct about 65 million years ago. Although these great spans of time are hard to imagine, the vast expanse of geologic time is a reality. In this section you will learn how scientists measure time using radioactivity and radiometric dating.

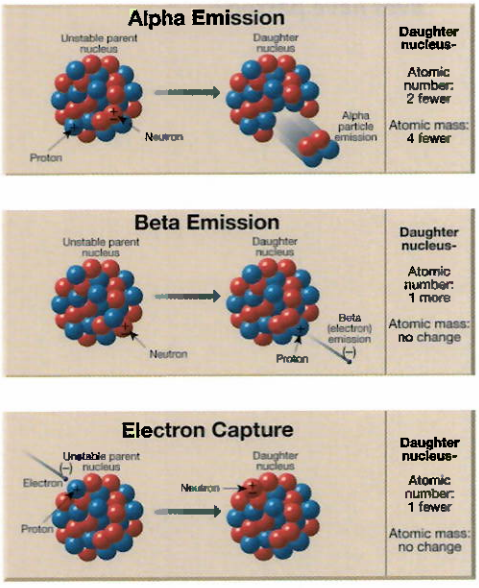
Basic Atomic Structure

Recall from Chapter 2 that each atom has a nucleus containing protons and neutrons and that the nucleus is orbited by electrons. Electrons have a negative electrical charge and protons have a positive charge. A neutron has no charge. The atomic number of an element is the number of protons in its nucleus. Different elements have different atomic numbers, but atoms of the same element always have the same atomic number. An atom's mass number is the number of protons and neutrons in an atom's nucleus. The number of neutrons can vary, and these variants, or isotopes, have different mass numbers.

Radioactivity

The forces that bind protons and neutrons together in the nucleus are usually strong. However, in some isotopes, the forces binding the protons and neutrons together are not sufficiently strong and the nuclei are unstable. **When nuclei are unstable, they spontaneously break apart, or decay, in a process called radioactivity.** An unstable or radioactive isotope of an element is called the parent. The isotopes that result from the decay of the parent are called the daughter products.

Figure 12 Common Types of Radioactive Decay in each case, the number of protons (atomic number) in the nucleus changes, thus producing a different element.



Of the many radioactive isotopes that exist in nature, five have proved particularly useful in providing radiometric ages for ancient rocks. The five radioactive isotopes are listed in Table 1.

Table 1 Radioactive Isotopes Frequently Used in Radiometric Dating

Radioactive Parent	Stable Daughter Product	Currently Accepted Half-Life Values
Uranium-238	Lead-206	4.5 billion years
Uranium-235	Lead-207	713 million years
Thorium-232	Lead-208	14.1 billion years
Rubidium-87	Strontium-87	47.0 billion years
Potassium-40	Argon-40	1.3 billion years

An accurate radiometric date can be obtained only if the mineral remained in a closed system during the entire period since its formation. If the addition or loss of either parent or daughter isotopes occurs, then it is not possible to calculate a correct date. For example, an important limitation of the potassium-argon method stems from the fact that argon is a gas. Argon may leak from minerals and throw off measurements. Cross-checking of samples, using two different radiometric methods, is done where possible to ensure accuracy. Although the basic principle of radiometric dating is simple, the actual procedure is quite complex. The analysis that determines the quantities of parent and daughter must be painstakingly precise. In addition, some radioactive materials do not decay directly into the stable daughter product. Uranium-238, for example, produces thirteen intermediate unstable daughter products before the fourteenth and final daughter product, the stable isotope lead-206, is produced.

Reading Checkpoint *Why is a closed system necessary in radiometric dating?*

Dating with Carbon-14

To date recent events, carbon-14 is used in a method called **radiocarbon dating.** Carbon-14 is the radioactive isotope of carbon. Carbon-14 is continuously produced in the upper atmosphere. It quickly becomes incorporated into carbon dioxide, which circulates in the atmosphere and is absorbed by living matter. As a result, all organisms—including you—contain a small amount of carbon-14.

Q & A

Q *In radioactive decay, is there ever a time when all of the parent material is converted into the daughter product?*

A Theoretically, no. During a half-life, half of the parent material is converted into the daughter product. Then half of the remaining parent material is converted to the daughter product in another half life, and so on. By converting only half of the parent material with each half-life, there is never a time when all the parent material would be converted. However, after many half-lives, the parent material can exist in such small amounts that it is essentially undetectable.

Go Online NSTA SCILINKS

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understanding EARTH

Using Tree Rings to Date and Study the Recent Past

If you look at the top of a tree stump or at the end of a log, you will see that it is made of a series of concentric rings, like those shown in Figure 15. Every year in temperate regions trees add a layer of new wood under the bark. Each of these tree rings becomes larger in diameter outward from the center. During favorable environmental conditions, a wide ring is produced. During unfavorable environmental conditions, a narrow ring is produced. Trees growing at the same time in the same region show similar tree-ring patterns.

Because a single growth ring is usually added each year, you can determine the age of the tree by counting the rings. Cutting down a tree to count the rings is not necessary anymore. Scientists can use small, non-destructive core samples from living trees. The dating and study of annual rings in trees is called dendrochronology.

To make the most effective use of tree rings, extended patterns known as ring chronologies are established. They are produced by comparing the patterns of rings among trees in an area. If the same pattern can be identified in two samples, one of which has been dated, the second sample can be dated from the first by matching the ring pattern common to both. This technique, called cross dating, is illustrated in Figure 16. Tree-ring chronologies extending back for thousands of years have been established for some regions. To date a timber sample of unknown age, its ring pattern is matched against the reference chronology.

Tree-ring chronologies have important applications in such disciplines as climate, geology, ecology, and archaeology. For example, tree rings are used to reconstruct long-term climate variations within a certain region. Knowledge of such variations is of great value in studying and understanding the recent record of climate change.

Dendrochronology provides useful numerical dates for events in the historic and recent prehistoric past. Because tree rings are a storehouse of data, they are a valuable tool in the reconstruction of past environments.

Figure 15 Each year's growth for a tree can be seen as a ring. Because the amount of growth (thickness of a ring) depends upon precipitation and temperature, tree rings are useful records of past climates.

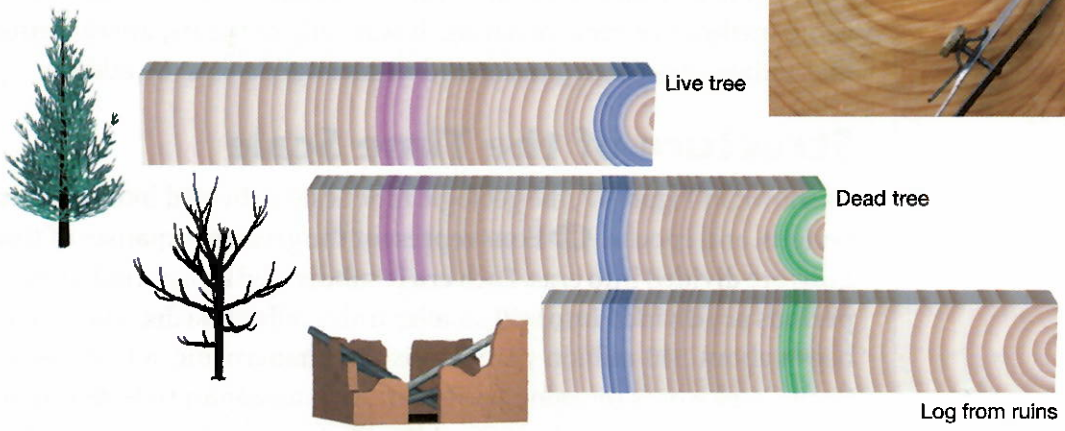

Figure 16 Using Tree Rings to Date Ancient Civilizations Cross dating is used to date an archaeological site by correlating tree-ring patterns using wood from trees of three different ages. First, a tree-ring chronology for the area is established using cores extracted from living trees. This chronology is extended further back in time by matching overlapping patterns from older, dead trees. Finally, cores taken from beams inside the ruin are dated using the chronology established from the other two sites.

There are three eras within the Phanerozoic. The Paleozoic, which means "ancient life," the Mesozoic, which means "middle life," and the Cenozoic, which means "recent life." As the names imply, the eras are bounded by profound worldwide changes in life forms. **Each era is subdivided into periods, each of which is characterized by a somewhat less profound change in life forms as compared with the eras.**

Reading Checkpoint *What do each of the eras within the Phanerozoic Eon mean?*

The periods of the Cenozoic are divided into still smaller units called epochs. The epochs of other periods, however, are not usually referred to by specific names. Instead, the terms early, middle, and late are generally applied to the epochs of these earlier periods.

Precambrian Time

Notice that the detail of the geologic time scale doesn't begin until the start of the Cambrian Period, about 540 million years ago. The more than 4 billion years prior to the Cambrian is divided into eons, as shown in Figure 17. The common name for this huge expanse of time is the Precambrian. The view of the time scale on page 357 gives you a better idea of the expanse of time represented by the Precambrian.

Although it represents about 88 percent of Earth history, the Precambrian is not divided into nearly as many smaller time units as is the Phanerozoic eon. The reason is simple. Precambrian history is not known in great enough detail. The amount of information that geologists have acquired about Earth's past decreases substantially the farther back in time you go. **During Precambrian time, there were fewer life forms. These life forms are more difficult to identify and the rocks have been disturbed often.**

Reading Checkpoint *Why does detail in the geologic time scale begin at the Cambrian Period?*

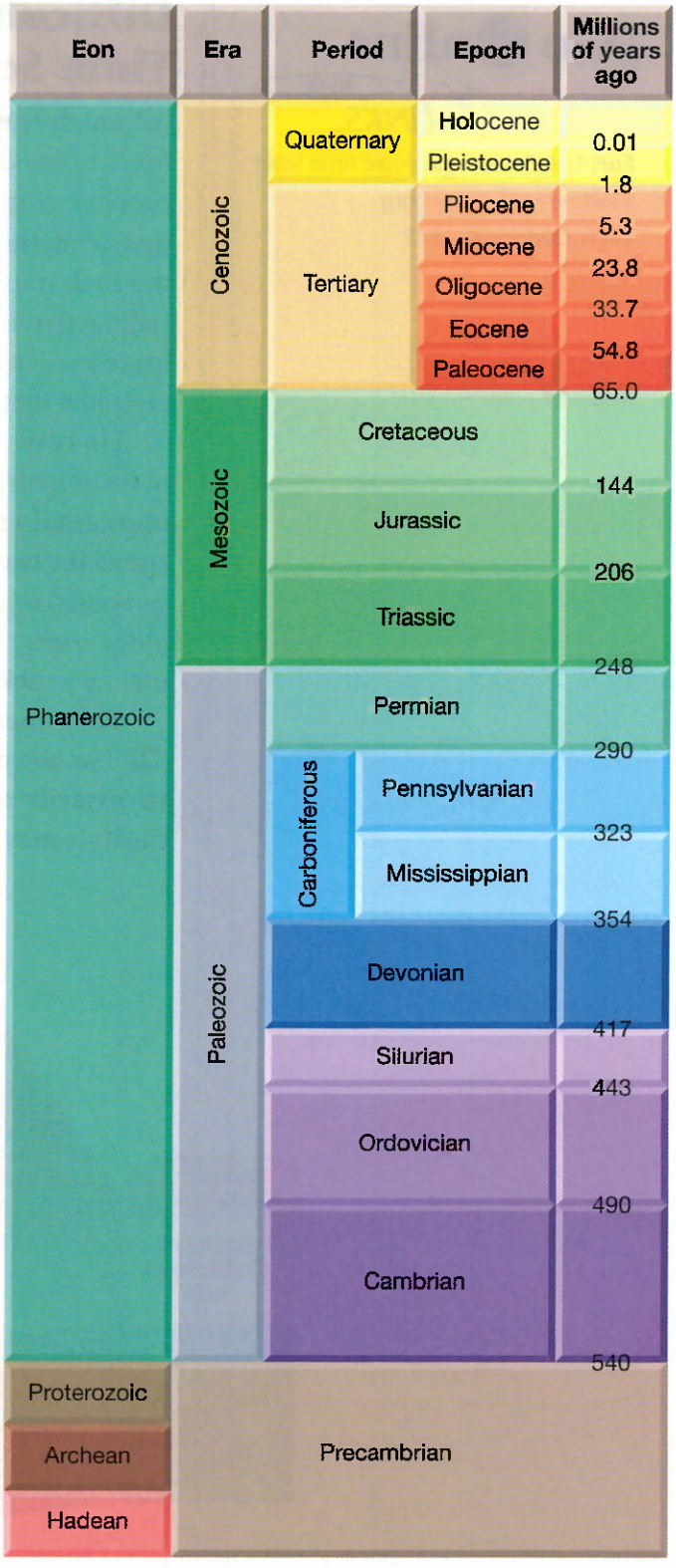

Figure 17 The Geologic Time Scale The numerical dates were added long after the time scale had been established using relative dating techniques.

If samples of sedimentary rocks rarely produce reliable radiometric ages, how can numerical dates be assigned to sedimentary layers? Usually geologists must relate sedimentary rocks to datable igneous masses, as shown in Figure 18. In this example, radiometric dating has determined the ages of the volcanic ash bed within the Morrison Formation and the dike cutting the Mancos Shale and Mesaverde Formation. Both formations are igneous rock. The area covered by the Morrison Formation includes the following states: Montana, North and South Dakota, Nebraska, Kansas, Oklahoma, Texas, New Mexico, Arizona, Colorado, Utah, Wyoming, and Idaho. Using the principle of superposition, you can tell that the sedimentary beds below the ash are older than the ash, and all the layers above the ash are younger. Using the principle of cross-cutting relationships, you can see that the dike is younger than the Mancos Shale and the Mesaverde Formation. But the dike is older than the Wasatch Formation because the dike does not intrude the Tertiary rocks.

Reading Checkpoint ***How can geologists overcome the problem of sedimentary rocks and dating the time units of the geologic time scale?***

The Morrison Formation is one example of literally thousands that illustrates how datable materials are used to bracket the various episodes in Earth history within specific time periods. It shows the necessity of combining laboratory methods with field observations of rocks.

Section 12.4 Assessment

Reviewing Concepts

1. What is the geologic time scale?
2. What subdivisions make up the geologic time scale?
3. What is the basis on which the subdivisions are made?
4. What is the geologic time scale used for?
5. Why can it be difficult to assign dates to the divisions of the geologic time scale?

Thinking Critically

6. **Connecting Ideas** Explain how igneous intrusions and Steno's laws help geologists get around the problem of dating sedimentary rock layers.
7. **Inferring** What might have happened at the end of the Precambrian Eon and the beginning of the Phanerozoic Eon to allow geologists to mark this boundary on the time scale?

Connecting Concepts

Hypothesizing The boundaries of the geologic time scale are based on significant geologic events, while the epochs of the Cenozoic are based on the percentage occurrence of different fossil animals. Explain why you think it is possible to do this.

Analyze and Conclude

1. **Reading Graphs** What is the age of the hypothetical rock layer that these fossils were collected from?
2. **Inferring** Based on the age determined, do you think that this group of fossils could be considered index fossils? Why or why not?
3. **Inferring** A species of the trilobite listed in line 7 of the data table *(phacops logani)* is limited to rocks of lower Devonian age. Trilobite fossils are widespread throughout North America. Can this fossil be considered an index fossil? Why or why not?
4. **Connecting Concepts** These fossils were collected from limestone and shale rocks. Based on what you have learned about the formation of these rock types, what type of environment did these organisms live in?
5. **Understanding Concepts** Shale often contains fossils of leaves. If the gastropods listed in line 3 and line 6 were collected from shale containing leaf fossils, could you use radiocarbon dating to assign a numerical date to this rock unit? Explain.

Go Further Use the library or Internet to research these fossils. Find out how some of them are used in the oil industry or the cosmetics industry.

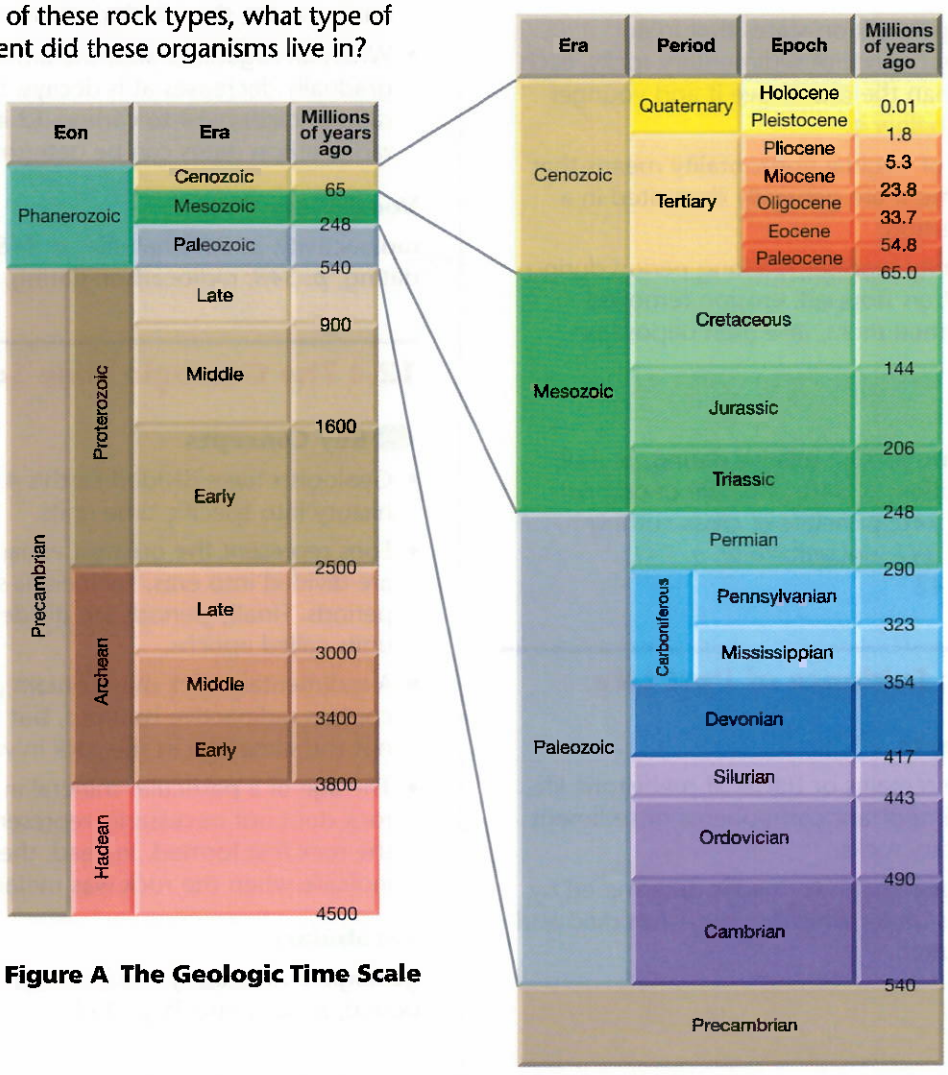

Figure A The Geologic Time Scale

CHAPTER 12

Assessment

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Reviewing Content

1. What is the name of the doctrine that states the physical, chemical and biological laws that operate today have also operated in the geologic past?
   a. uniformitarianism
   b. unity
   c. Earth science
   d. law of superposition

2. What is the name of the process that matches up rocks of similar ages in different regions?
   a. indexing
   b. correlation
   c. succession
   d. superposition

3. What name is given to fossils that are widespread geographically, are abundant in number, and are limited to a short span of time?
   a. key
   b. succeeding
   c. relative
   d. index

4. What is the name of the process during which atomic nuclei decay?
   a. fusion
   b. fission
   c. nucleation
   d. radioactivity

5. Which unit of geologic time is the greatest span of time?
   a. era
   b. eon
   c. period
   d. epoch

6. What are remains or traces of prehistoric life called?
   a. indicators
   b. replicas
   c. fossils
   d. fissures

7. What name is given to layers of tilted rocks that are overlain by younger, more flat-lying rock layers?
   a. disconformity
   b. angular unconformity
   c. nonconformity
   d. fault

8. What are atoms with the same atomic number but different mass numbers called?
   a. protons
   b. isotopes
   c. ions
   d. nucleotides

9. Which of Steno's principles states that most layers of sediments are deposited in a horizontal position?
   a. original horizontality
   b. cross-cutting relationships
   c. fossil succession
   d. superposition

10. What name is given to pieces of rock that are contained within another, younger rock?
    a. intrusions
    b. interbeds
    c. hosts
    d. inclusions

11. About how old is Earth?
    a. 4,000 years
    b. 4.0 million years
    c. 5.8 million years
    d. 4.56 billion years

Understanding Concepts

12. How have the processes that affect Earth's surface changed through time?

13. Why does the law of superposition apply primarily to sedimentary rocks?

14. How are cross-cutting relationships used in relative dating?

15. How do unconformities form?

16. List and briefly describe three different types of fossils.

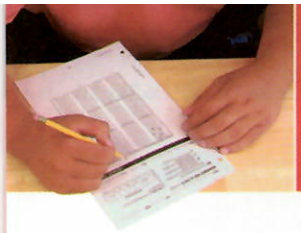
17. What two conditions increase an organism's chance of becoming a fossil?

18. Why can certain fossils, such as corals, be used to indicate former water temperature?

19. What is a half-life?

20. Explain how radioactivity and radiometric dating are related.

21. Why can't radiometric dating be used with accuracy on metamorphic rocks?



Standardized Test Prep

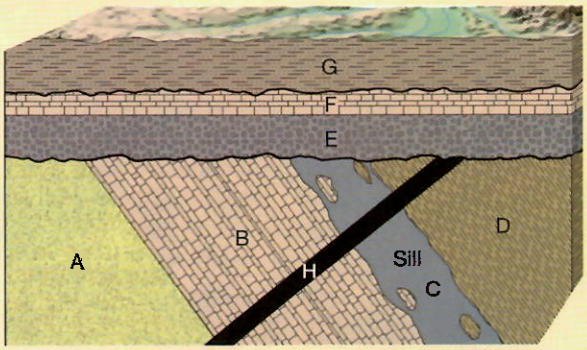
Test-Taking Tip

Simplify the Diagram

When examining a diagram, it is important not to be confused by unnecessary information. It helps to identify only the features that relate to the question being asked. Reread the question with these features in mind and then answer the question. In the diagram below, you do not need to know what rock types are present.

How can you tell that dike C is older than fault H?

(A) The top of dike C is eroded.
(B) Dike C is broken by fault H.
(C) Fault H ends at the eroded layer E.
(D) Both dike C and fault H end at layer E.



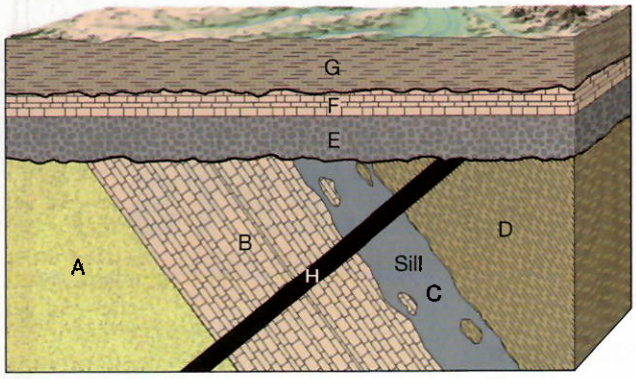
(Answer: B)

Choose the letter that best answers the question or completes the statement.

1. Who was the scientist that formulated the theory of uniformitarianism?
   (A) Archbishop Ussher
   (B) James Hutton
   (C) William Smith
   (D) Louis Agassiz

2. Using relative dating methods, which of the following are scientists able to do?
   (A) Identify the order in which rock units formed.
   (B) Assign a numerical date to each rock layer studied.
   (C) Determine the age of the fossils within each layer.
   (D) Identify what rock types are present.

Use the diagram below to answer Questions 3–5.



3. Which choice correctly lists the order of deposition of rock layers A through D?
   (A) A, B, C, D
   (B) D, C, B, A
   (C) B, C, D, A
   (D) A, B, D, C

4. When were rock layers A though D uplifted and tilted?
   (A) after deposition of layer G
   (B) after deposition of layer F and before deposition of layer G
   (C) after deposition of layer D and before deposition of layer E
   (D) after deposition of layer A and before deposition of layer G

5. When was sill C intruded? Explain.

Answer the following in complete sentences.

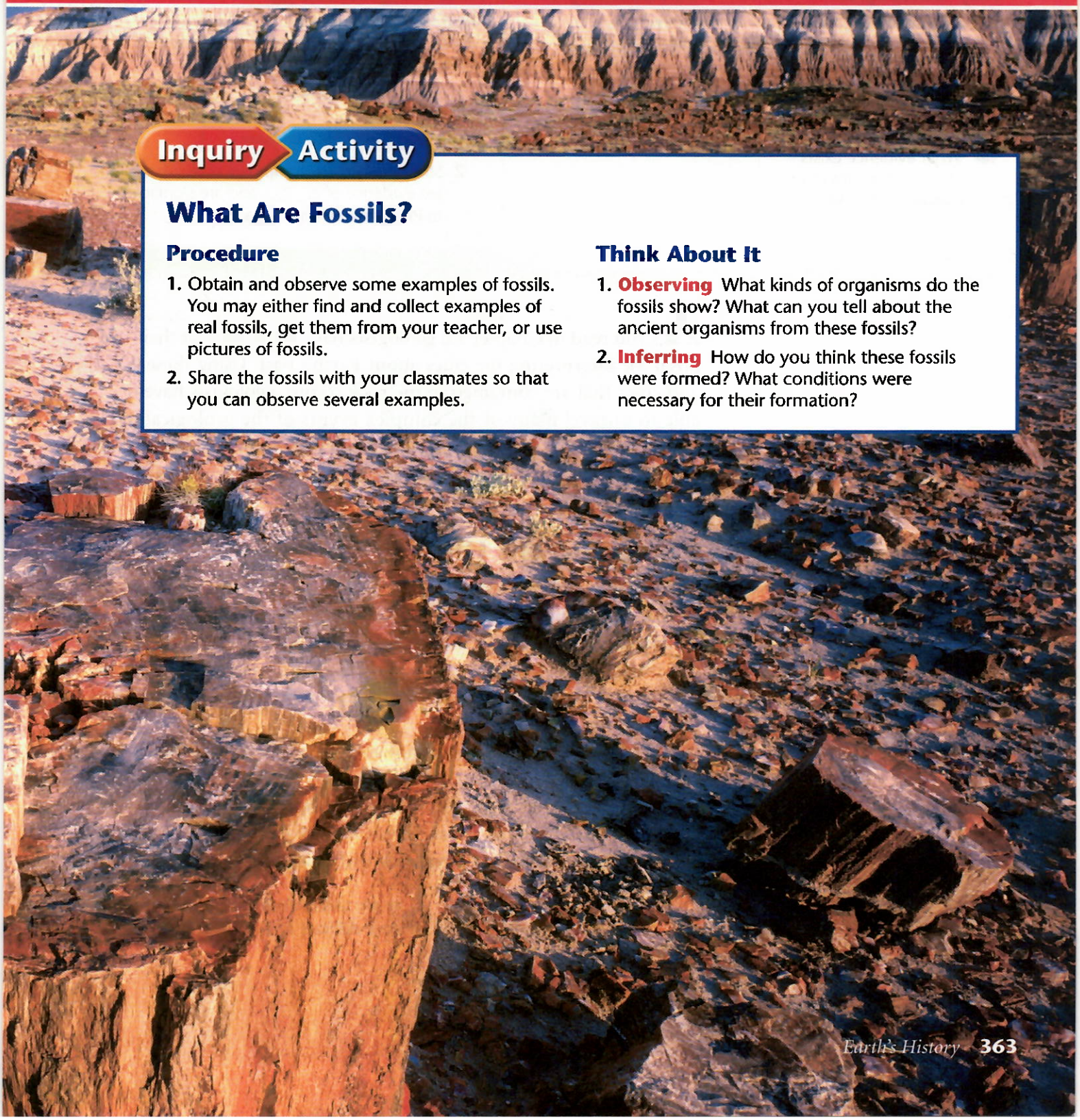
6. Explain why decay rates can be used with confidence in radiometric dating.

7. Describe the relationship between uniformitarianism and time.

8. Explain the difference in fossilization between a mammoth frozen in ice and a seashell embedded in rock.

9. Explain why the time periods of the Paleozoic and Mesozoic are subdivided into early, middle, and late instead of named epochs, as they are in the Cenozoic.

Chapter Preview



Inquiry Activity

What Are Fossils?

Procedure

1. Obtain and observe some examples of fossils. You may either find and collect examples of real fossils, get them from your teacher, or use pictures of fossils.
2. Share the fossils with your classmates so that you can observe several examples.

Think About It

1. **Observing** What kinds of organisms do the fossils show? What can you tell about the ancient organisms from these fossils?
2. **Inferring** How do you think these fossils were formed? What conditions were necessary for their formation?

Geologic Time Scale

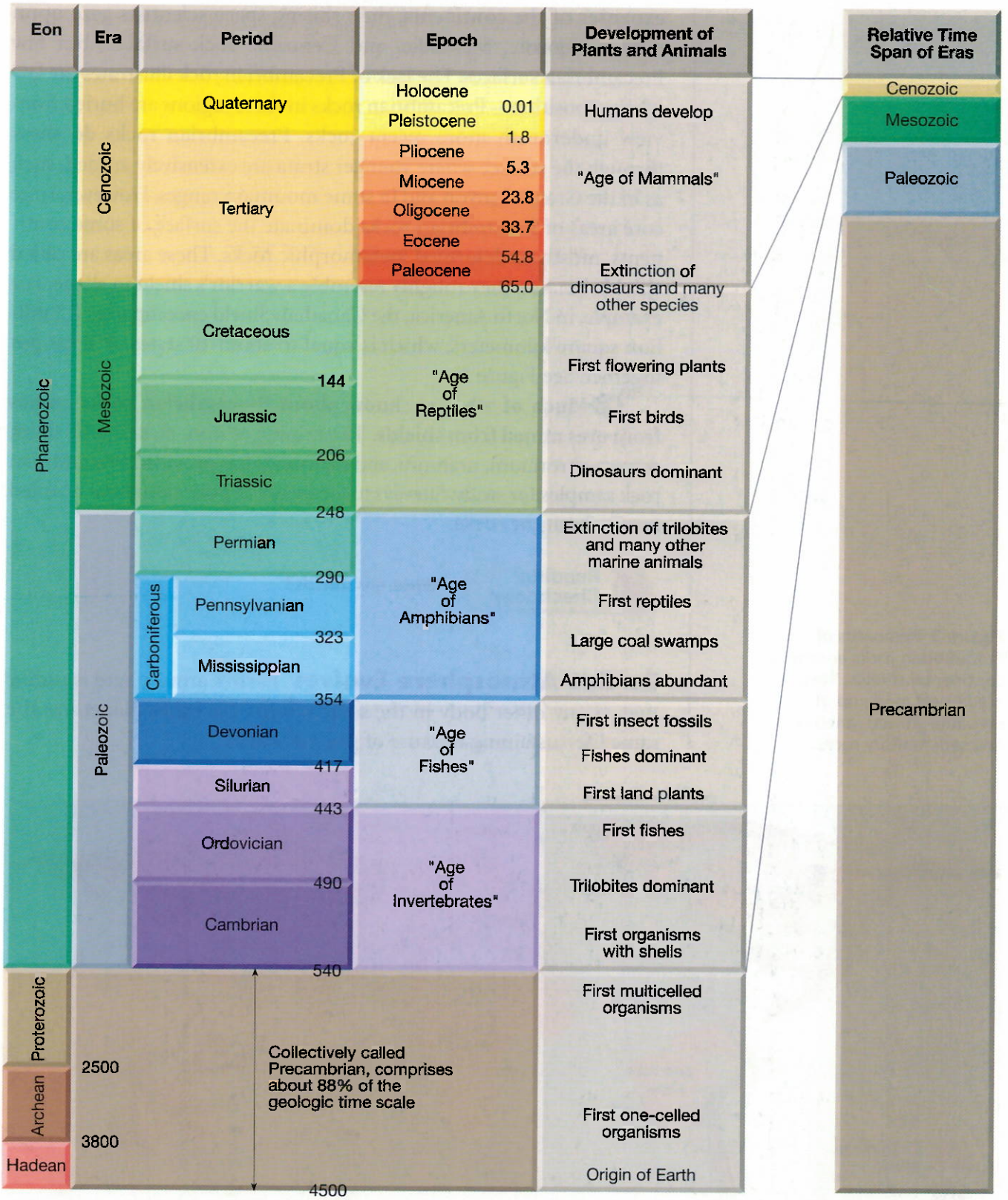


Figure 2 Numbers on the time scale represent time millions of years before the present.
Analyzing ***The Precambrian accounts for approximately what percentage of geologic time?***

Today, the air you breathe is a stable mixture of nitrogen, oxygen, a small amount of argon, and trace gases like carbon dioxide and water vapor. But our planet's original atmosphere, several billion years ago, was far different.

Early in Earth's history, the high-velocity impact of nebular debris caused at least the outer shell of our planet to melt. After this period of bombardment subsided, Earth slowly cooled and the molten surface solidified into a crust. The gases that had been dissolved in the molten rock were gradually released. **Earth's original atmosphere was made up of gases similar to those released in volcanic eruptions today—water vapor, carbon dioxide, nitrogen, and several trace gases, but no oxygen.**

As the planet continued to cool, the water vapor condensed to form clouds, and great rains began. At first the rain water evaporated in the hot air before reaching the ground or quickly boiled or evaporated when it did reach the ground. This evaporation sped up the cooling of Earth's surface. Torrential rains continued and slowly filled low areas, forming the oceans. This rain and the forming of the oceans reduced not only the water vapor in the air but also the amount of carbon dioxide, which became dissolved in the water. A nitrogen-rich atmosphere remained.

The first life forms on Earth did not need oxygen. **Later, primitive organisms evolved that used photosynthesis and released oxygen.** These organisms, primarily cyanobacteria, did not adapt to Earth's atmosphere. They actually influenced it, dramatically changing the make up of Earth's atmosphere by using carbon dioxide and releasing oxygen. Slowly, the oxygen content of Earth's atmosphere increased. The influence the ancestors of plants had on the atmosphere is a good example of how Earth operates as a giant system in which living things interact. The Precambrian rock record suggests that much of the first free oxygen did not remain free because it combined with iron. Iron combines with oxygen to form iron oxides, or rust, at any opportunity.

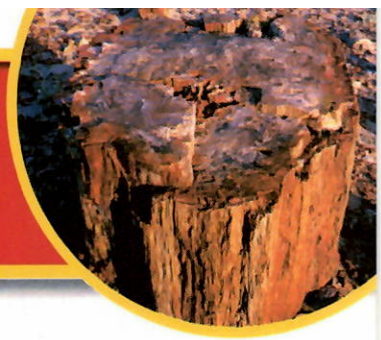
Once the available iron finished reacting, oxygen began to accumulate in the atmosphere. By the beginning of the Paleozoic era—about 4 billion years into Earth's existence—the fossil record reveals abundant ocean-dwelling organisms that require oxygen to live. These fossils show that the composition of Earth's atmosphere has evolved together with its life forms, from an oxygen-free envelope to today's oxygen-rich environment. **Oxygen began to accumulate in the atmosphere about 2.5 billion years ago.**

Reading Checkpoint *How did Earth's oceans form?*

Q *The era names refer to "ancient," "middle," and "recent" life. What is the origin of period names?*

A There is no overall scheme for naming the periods; rather, these names have diverse origins. Several names refer to places that have prominent strata of that age. For example, the Cambrian period is taken from the Roman name for Wales (Cambria). The Permian is named for the province of Perm in Russia, while the Jurassic period gets its name from the Jura Mountains located between France and Switzerland.

13.2 Paleozoic Era: Life Explodes



Reading Focus

Key Concepts

- When was the Paleozoic era?
- How did tectonic movements affect the locations and formations of the continents during the Paleozoic era?
- What kind of life existed in the early Paleozoic?
- How did life evolve during the Paleozoic era?

Vocabulary

- Gondwana
- Laurasia

Reading Strategy

Identifying Details Copy the table below. As you read the section, fill out the table with notes.

	Continental positions	Plant life	Animal life
Early Paleozoic			
Middle Paleozoic			
Late Paleozoic			

As the Precambrian came to a close, the fossil record disclosed diverse and complete multicelled organisms. This set the stage for more complex plants and animals to evolve at the dawn of the Paleozoic era. **Following the long Precambrian, the most recent 540 million years of Earth's history are divided into three eras: Paleozoic, Mesozoic, and Cenozoic.** The Paleozoic era encompasses about 292 million years and is by far the longest of the three.

Before the Paleozoic, life forms possessed no hard parts, such as shells, scales, bones, or teeth. Hard parts greatly enhanced a life form's chance of being preserved as part of the fossil record. The Paleozoic era contains many more diverse fossils due to the emergence of life forms with hard parts.

Abundant Paleozoic fossils have allowed geologists to construct a far more detailed time scale for the last one-eighth of geologic time than for the preceding seven-eighths, the Precambrian. Moreover, because every organism is associated with a particular environment, the greatly improved fossil record provided invaluable information for learning about ancient environments. For our brief tour of the Paleozoic, we divide it into Early Paleozoic (Cambrian, Ordovician, Silurian periods) and Late Paleozoic (Devonian, Mississippian, Pennsylvanian, Permian periods).

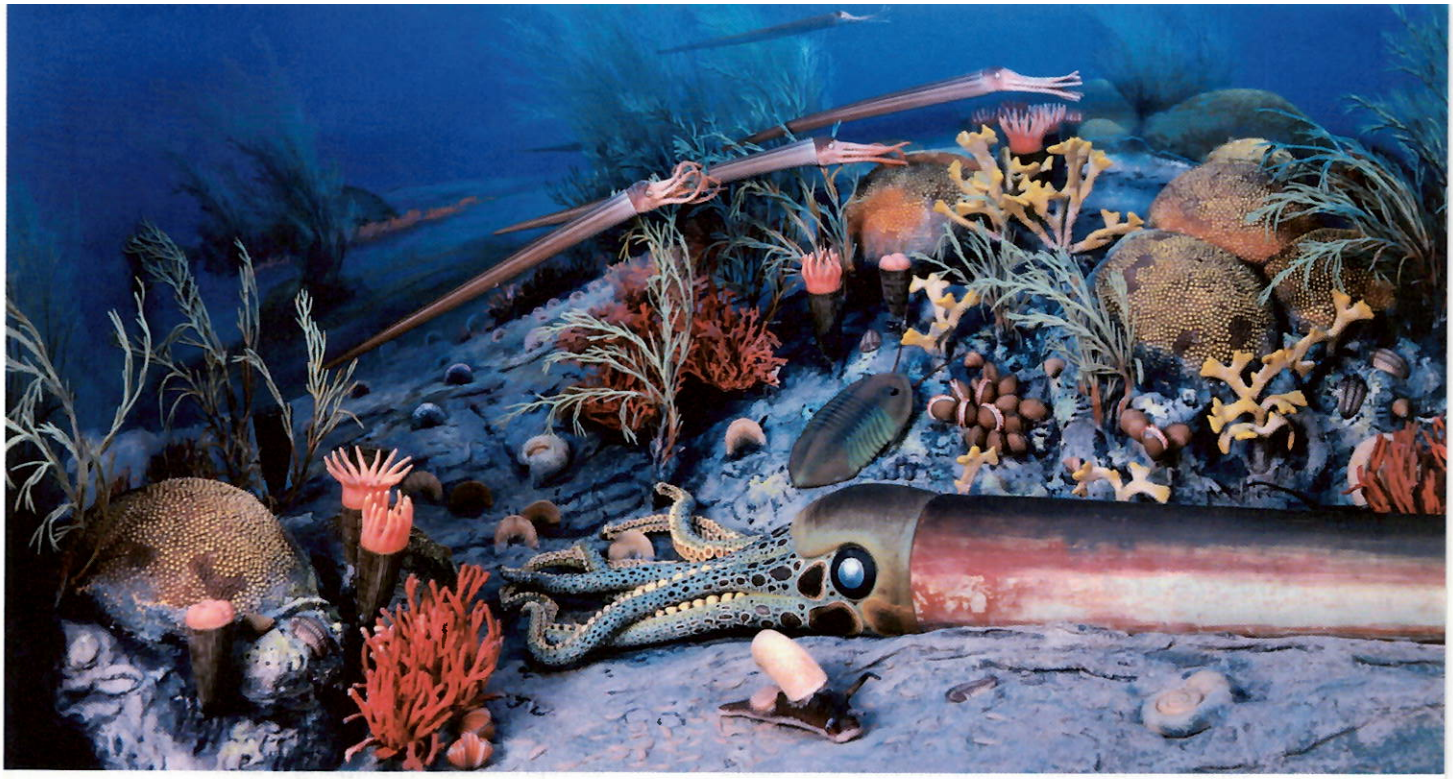


Figure 6 Cephalopods, trilobites, brachiopods, snails, and corals inhabited the waters of the Ordovician period.

Early Paleozoic Life

Life in early Paleozoic time was restricted to the seas. Vertebrates had not yet evolved, so life consisted of several invertebrate groups. The Cambrian period was the golden age of trilobites. More than 600 types of these mud-burrowing scavengers flourished worldwide. By Ordovician times, brachiopods outnumbered the trilobites. Brachiopods are among the most widespread Paleozoic fossils and, except for one modern group, are now extinct. The adult brachiopods lived attached to the seafloor, but the young larvae were free swimming. This mobility accounts for the group's wide geographic distribution.

The Ordovician also marked the appearance of cephalopods—mobile and highly developed mollusks that became the major predators of the time. Squid and octopus are descendents of these early cephalopods. Cephalopods were the first truly large organisms on Earth. Figure 6 shows some cephalopods and other organisms of the Ordovician.

The beginning of the Cambrian period marks an important event in animal evolution. For the first time, organisms appeared that secreted material that formed hard parts, such as shells. Hard parts clearly served many useful purposes and aided adaptations to new ways of life. Mollusks, such as clams and snails, secreted external shells that protected them and allowed body organs to function in a more controlled environment. The successful trilobites developed an exoskeleton of a protein called chitin, which permitted them to burrow through soft sediment in search of food. The fossil in Figure 7 shows the exoskeleton of a trilobite.

Reading Checkpoint ***How did the formation of hard parts benefit animals?***

Figure 7 Trilobite Fossil
Inferring ***When did trilobites live?***

Late Paleozoic Plate Movements

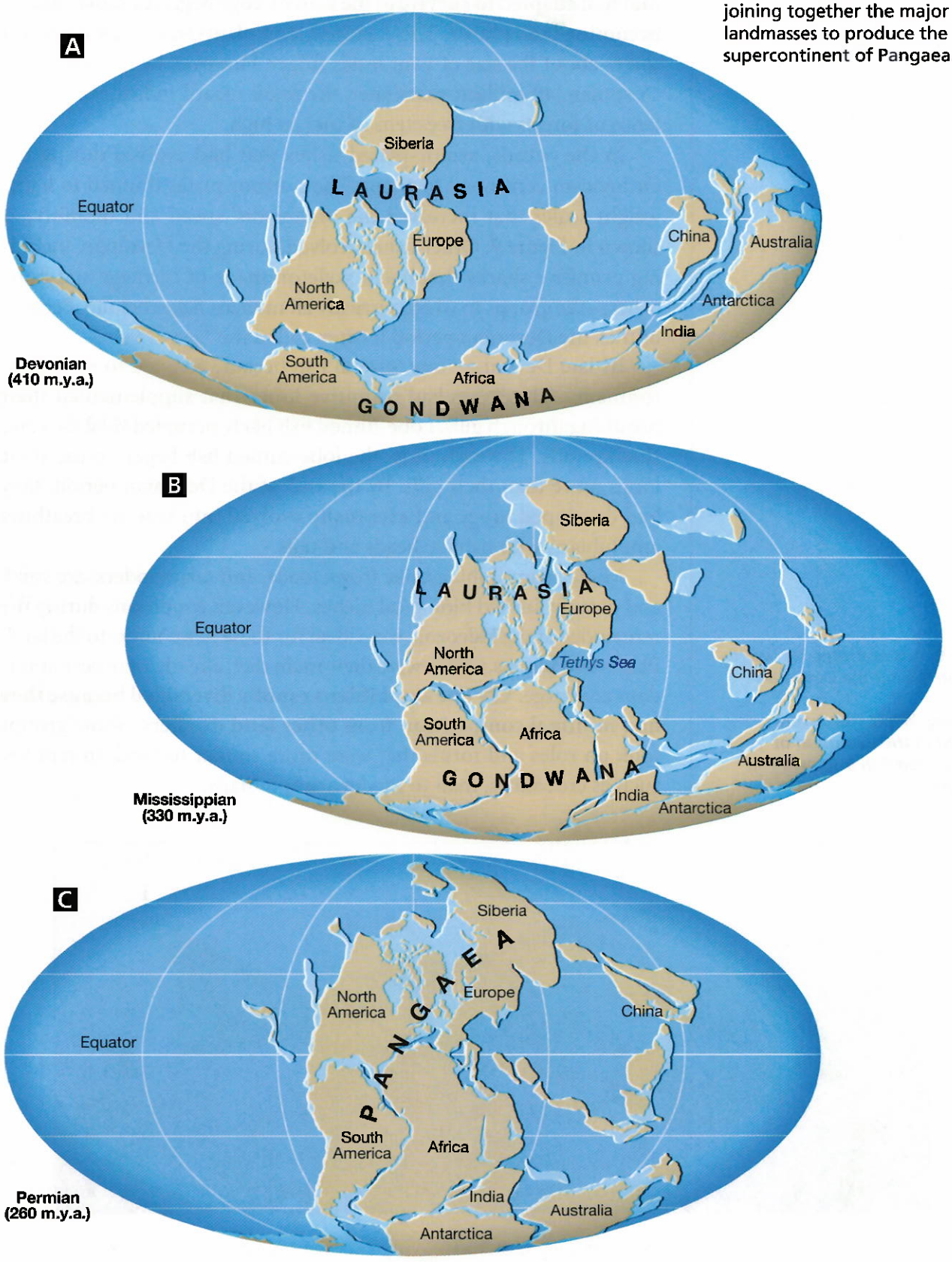


Figure 8 During the late Paleozoic, plate movements were joining together the major landmasses to produce the supercontinent of Pangaea.

Figure 10 Model of a Pennsylvanian Coal Swamp Shown are scale trees (left), seed ferns (lower left), and scouring rushes (right). Note the large dragonfly.

By the Pennsylvanian period, large tropical swamps extended across North America, Europe, and Siberia. Trees approached 30 meters, with trunks over a meter across. The coal deposits that we use today for fuel originated in these swamps. See Figure 10. These lush swamps allowed the amphibians to evolve quickly into a variety of species.

The Great Paleozoic Extinction

The Paleozoic ended with the Permian period, a time when Earth's major landmasses joined to form the supercontinent Pangaea. This redistribution of land and water and changes in the elevations of landmasses brought pronounced changes in world climates. Broad areas of the northern continents became elevated above sea level, and the climate became drier. These climate changes are believed to have triggered extinctions of many species on land and sea.

By the close of the Permian, 75 percent of the amphibian families had disappeared, and plants had declined in number and variety. Although many amphibian groups became extinct, their descendants, the reptiles, would become the most successful and advanced animals on Earth. Much of the marine life did not adapt and survive. At least 80 percent, and perhaps as much as 95 percent, of marine life disappeared. Many marine invertebrates that had been dominant during the Paleozoic, including all the remaining trilobites as well as some types of corals and brachiopods, could not adapt to the widespread environmental changes.

13.3 Mesozoic Era: Age of Reptiles

Reading Focus

Key Concepts

- What continental movements occurred during the Mesozoic era?
- What plant and animal life dominated the Mesozoic?
- What caused the extinction that marks the end of the Mesozoic?

Vocabulary

- dinosaur
- gymnosperm

Reading Strategy

Summarizing List the blue headings from the section, leaving space to write after each heading. Use a bulleted list to write a brief summary of the text for each heading.

I. Mesozoic History

- Begins with most areas above sea level.
- Shallow seas invade most continents.
- _____ ? _____

Mesozoic Era

The Mesozoic era spanned about 183 million years, and it is divided into three periods: the Triassic, Jurassic, and Cretaceous. The Mesozoic era marked the beginning of the breakup of the supercontinent Pangaea. During this era, organisms that survived the great Permian extinction began to diversify in amazing ways. On land, **dinosaurs** became dominant and remained unchallenged for over 100 million years.

Mesozoic History The Mesozoic era began with much of the world's land above sea level. In fact, very few marine fossils are found in North America from the Triassic period.

As the Jurassic period gave way to the Cretaceous, shallow seas invaded much of western North America, the Atlantic, and Gulf coastal regions. These shallow seas created great swamps like those of the Paleozoic era, forming Cretaceous coal deposits that are very important economically to the western United States and Canada.

A major event of the Mesozoic era was the breakup of Pangaea. Follow this breakup in Figure 11. A rift developed between what is now the eastern United States and western Africa, marking the birth of the Atlantic Ocean and the beginning of the breakup of Pangaea, a process that continued for 200 million years, through the Mesozoic and into the Cenozoic.

As Pangaea broke apart, the westward-moving North American plate began to override the Pacific plate. Tectonic activity began a continual wave of deformation that moved inland along the entire western part of the continent. The tectonic activity that began in the Jurassic continued throughout the Cretaceous. This activity formed the vast mountains of western North America, like those in Figure 12. Toward the end of the Mesozoic, the ranges of the Rocky Mountains located in Colorado and surrounding states began to form.

Reading Checkpoint *Explain how the Atlantic Ocean was formed.*

Mesozoic Life When the Mesozoic era began, its life forms were the survivors of the great Paleozoic extinction. These survivors were diversified in many ways and filled the biological emptiness created at the end of the Paleozoic. On land, conditions favored life that could adapt to drier climates. Among plants, the **gymnosperms** were a group of seed-bearing plants that did not depend on free-standing water for fertilization. Unlike the first plants to invade the land, gymnosperms were not restricted to living near the water's edge, and they could take advantage of nutrients and space available in dry areas.

The gymnosperms quickly became the dominant plants of the Mesozoic. Gymnosperm trees included the cycads, the conifers, and the ginkgoes. The cycads resembled a large pineapple plant. The ginkgoes had fan-shaped leaves, much like their modern relatives. The largest plants were the conifers, whose modern descendants include the pines, firs, and junipers.

Figure 12 Mountain ranges such as the Canadian Rockies were formed throughout the Cretaceous.
Relating Cause and Effect ***What forces created the mountains?***

At the end of the Mesozoic, many reptile groups became extinct. Only a few types of reptiles survived to recent times, including the turtles, snakes, crocodiles, and lizards. The huge land-dwelling dinosaurs, the marine plesiosaurs, and the flying pterosaurs are known only through the fossil record. Most scientists believe that the extinction of these reptiles was caused by a large meteorite that collided with Earth. They believe this collision created huge quantities of dust that blocked out the sun, causing plants to die because they could not turn sunlight into food. Without plants, the huge herbivores could not find enough to eat and eventually could not survive. Then, the carnivores who ate the herbivores could no longer find food. The smaller animals probably survived because they needed less food than the huge dinosaurs.

Figure 14 A fossil skull of a large crocodile—*Sarcosuchus imperator*

Q & A

Q *Many dinosaurs were very large. Were they the only large reptiles?*

A No. One well-publicized example is a crocodile known as *Sarcosuchus imperator,* shown in Figure 14. This huge river dweller lived in Africa about 110 million years ago during the Cretaceous period. By age 50 or 60, the animal weighed 8 metric tons and was about 12 meters long—as long as *Tyrannosaurus rex* and much heavier. Its jaws were roughly as long as an adult human. This animal has appropriately been dubbed "supercroc." Paleontologists indicate that the teeth and jaw suggest a diet of large vertebrates, including fish and dinosaurs.

Section 13.3 Assessment

Reviewing Concepts

1. How did plate tectonics create dramatic changes in the continental land mass during the Mesozoic?
2. What advantage allowed both reptiles and gymnosperms to dominate as life forms in the Mesozoic?
3. What caused the extinction of so many of the reptile groups that had flourished?

Critical Thinking

4. **Comparing and Contrasting** Compare and contrast the physical environment of the Mesozoic era with the Paleozoic.
5. **Predicting** Why do scientists find so many more fossils from the Mesozoic era than from the Paleozoic?

Connecting Concepts

Hypothesizing The fluid in many eggs is similar to seawater, causing some scientists to refer to shelled eggs as "private aquariums." Propose a hypothesis on how environmental conditions might cause shelled eggs to develop and allow animals to move onto land.

Cenozoic Life

Mammals replaced reptiles as the dominant land animals in the Cenozoic. The Cenozoic is often called the "age of mammals" because land animals came to dominate land life. It could also be called the "age of flowering plants" because the angiosperms enjoyed a similar status in the plant world. **Angiosperms—flowering plants with covered seeds—replaced gymnosperms as the dominant land plants.** Marine invertebrates took on a modern look.

The advances in seed fertilization and dispersal allowed angiosperms to experience a rapid development and expansion as the Mesozoic drew to a close. As the Cenozoic era began, angiosperms were already the dominant land plants.

Development of the flowering plants strongly influenced the evolution of both birds and mammals. Birds that feed on seeds and fruits, for example, evolved rapidly during the Cenozoic in close association with the flowering plants. During the middle Tertiary, grasses developed rapidly and spread over the plains. This fostered the emergence of herbivorous mammals that were mainly grazers. In turn, the development and spread of grazing animals established the setting for the evolution of the carnivorous mammals that preyed upon them.

Q *What are the La Brea tar pits?*

A The La Brea tar pits, located in downtown Los Angeles, are famous because they contain rich and very well preserved fossils, as shown in Figure 15. These organisms roamed southern California from 8000 to 40,000 years ago. The collection of fossils includes 59 species of mammals and more than 130 species of birds. Hundreds of invertebrate and plant fossils are also preserved.

Mammals Replace Reptiles

Back in the Mesozoic, an important evolutionary event was the appearance of primitive mammals in the late Triassic, about the same time the dinosaurs emerged. Yet throughout the period of dinosaur dominance, mammals remained as small and primitive. By the close of the Mesozoic era, dinosaurs and other reptiles no longer dominated the land. It was only after these large reptiles became extinct that mammals became the dominant land animals. The transition is a major example in the fossil record of the replacement of one large group by another.

Mammals are distinct from reptiles in important ways. Mammalian young are born alive rather than in eggs, and mammals maintain a steady body temperature—they are "warm-blooded." Because mammals are warm-blooded, they could survive in cold regions and search for food during any season or time of day. Other adaptations included the development of insulating body hair and more efficient heart and lungs. **These adaptations allow mammals to lead more active lives than reptiles.**

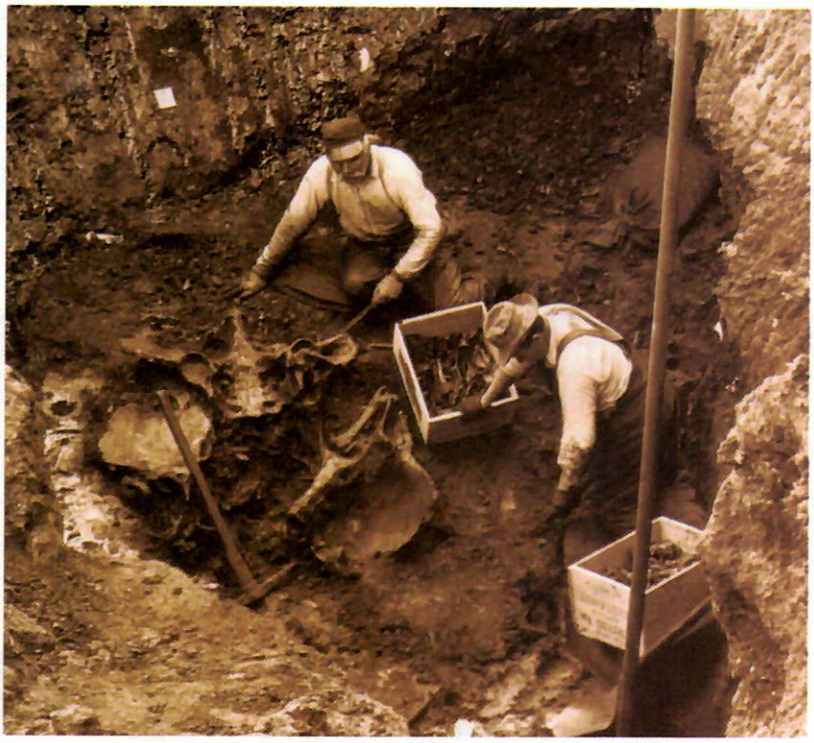


Figure 15 Fossils being excavated from the La Brea tar pits in 1914. **Inferring** ***What kinds of fossils were found in the La Brea tar pits?***

understanding EARTH

Demise of the Dinosaurs

The boundary between the Mesozoic era—"middle life"—and Cenozoic era—"recent life"—about 65 million years ago is of special interest. Around this time, more than half of all plant and animal species died out in a mass extinction. This boundary marks the end of the era in which dinosaurs and other reptiles dominated the landscape and the beginning of the era when mammals become very important.

The extinction of the dinosaurs is generally attributed to the group's inability to adapt to some radical change in the environment's conditions. What event could have caused the rapid extinction of the dinosaurs—one of the most successful groups of land animals ever to have lived?

The most strongly supported hypothesis about the extinction of the dinosaurs states that about 65 million years ago a large meteorite about 10 kilometers in diameter collided with Earth; see Figure 16. The speed of the meteorite impact was believed to be 70,000 kilometers per hour. The force of the impact vaporized the meteorite and trillions of tons of Earth's crust. Huge quantities of dust and other metamorphosed debris were blasted high into the atmosphere.

For months the encircling dust cloud would have greatly restricted the sunlight reaching Earth's surface. Without sunlight for photosynthesis, delicate food chains would have collapsed. By the time the sunlight returned, more than half of the species on Earth, including numerous marine organisms, had become extinct.

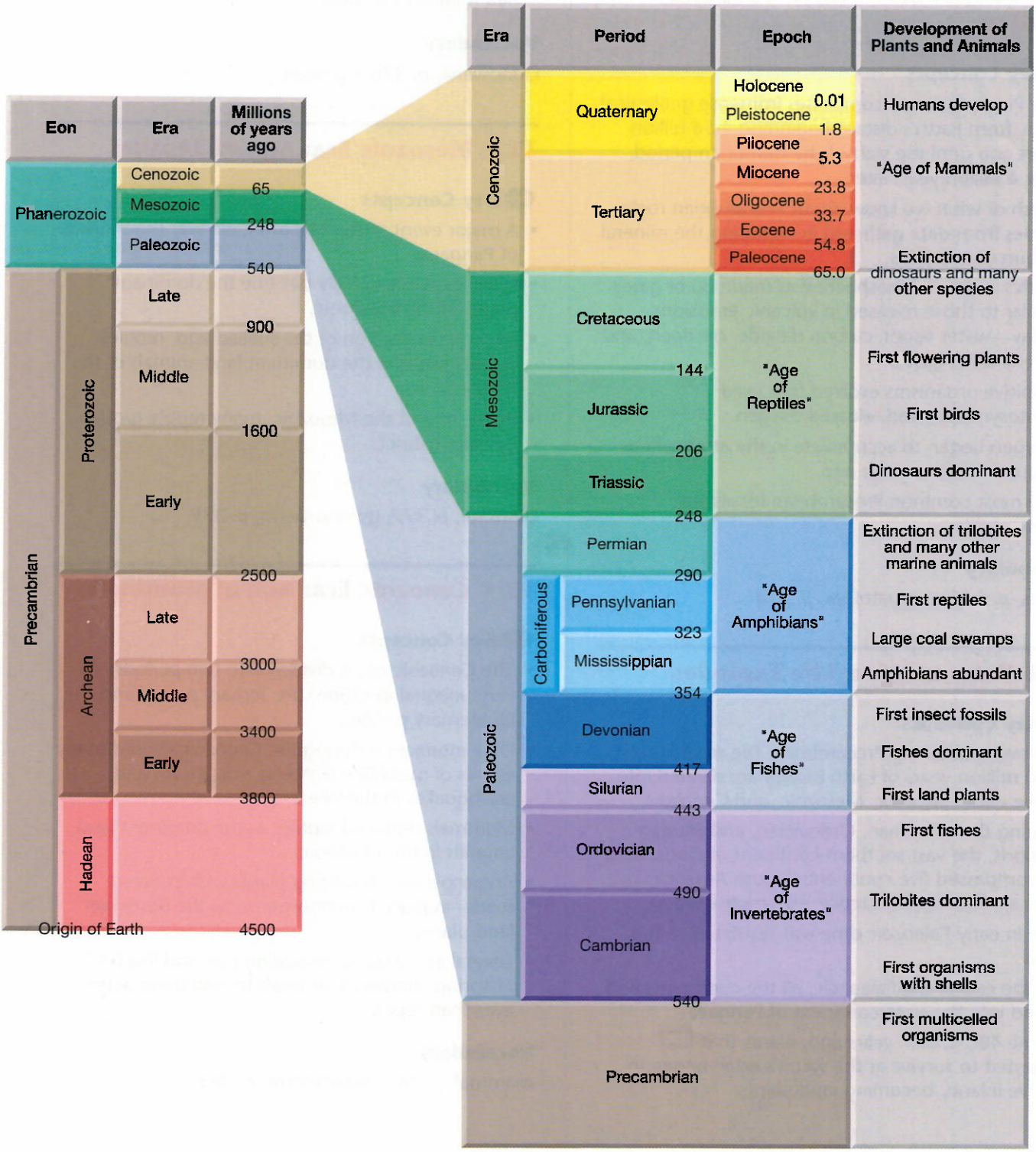
What evidence points to such a catastrophic collision 65 million years ago? First, a thin layer of sediment nearly 1 centimeter thick has been discovered worldwide. This sediment contains a high level of the element iridium, which is rare in Earth's crust but is found in high proportions in stony meteorites. Could this layer be the scattered remains of the meteorite that was responsible for the environmental changes that led to the demise of many reptile groups?

Despite its growing support, some scientists disagree with the impact hypothesis. These scientists suggest that huge volcanic eruptions led to the breakdown in the food chain. They cite enormous outpourings of lavas in the Deccan Plateau of southern and central India about 65 million years ago as support for their thesis. It could be that both volcanism and a catastrophic impact played a role.

Whatever caused the extinction, we now have a greater appreciation of the role of catastrophic events in shaping the history of our planet and the life that occupies it. Could a catastrophic event having similar results occur today? This possibility may explain why an event that occurred 65 million years ago has captured the interest of so many.

Figure 16 Some researchers believe that the Chicxulub crater is the impact site that resulted in the demise of the dinosaurs.

Geologic Time Scale



CHAPTER 13

Assessment

Interactive textbook with assessment at PHSchool.com

Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. Which era spans the least amount of time on the geologic scale?
   a. Cenozoic
   b. Mesozoic
   c. Paleozoic
   d. Precambrian

2. The most common Precambrian fossils are
   a. fish.
   b. stromatolites.
   c. trilobites.
   d. ferns.

3. Which era is known as the "age of reptiles"?
   a. Cenozoic
   b. Mesozoic
   c. Paleozoic
   d. Proterozoic

4. Modern squids descended from what type of early Paleozoic organisms?
   a. cephalopods
   b. trilobites
   c. brachiopods
   d. amphibians

5. The Devonian period is known as the
   a. "age of reptiles."
   b. "age of amphibians."
   c. "age of fishes."
   d. "age of invertebrates."

6. Which adaptation allowed gymnosperm plants to colonize and dominate land?
   a. stems
   b. seeds
   c. leaves
   d. flowers

7. Reptiles that were adapted to fly included the
   a. plesiosaurs.
   b. pterosaurs.
   c. ichthyosaurs.
   d. tyrannosaurs.

8. Humans first appeared during the
   a. Cretaceous period.
   b. Jurassic period.
   c. Quaternary period.
   d. Tertiary period.

9. Insulating body hair is a characteristic of
   a. mammals.
   b. amphibians.
   c. reptiles.
   d. invertebrates.

10. What development caused the emergence of animals that were grazing herbivores?
    a. seed plants
    b. grasses
    c. fruits
    d. carnivorous mammals

Understanding Concepts

11. How did plants help change Earth's early atmosphere?

12. What are shields? What kind of information is gained from shields?

Use the photograph below to answer Question 13.

13. This photograph shows evidence of what kind of organism?

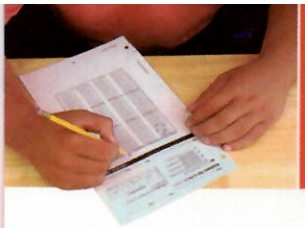
14. What significant tectonic activity occurred during the Mesozoic?

15. What present-day continents made up Gondwana?

16. Which kind of animals are trilobites and cephalopods?

17. Modern fishes and sharks both evolved from what type of ancient animals?

18. What development allowed mammals to adapt to different environments successfully?



Standardized Test Prep

Test-Taking Tip

Anticipate the Answer

When answering multiple-choice questions, a useful strategy is to cover up the given answers and supply your own answer. Then compare your answer with those listed and select the one that most closely matches.

Practice anticipating the answer in this question.

Early in Earth's history, which gas was largely removed from the atmosphere and became more concentrated in seawater?

(A) oxygen
(B) carbon dioxide
(C) argon
(D) hydrogen

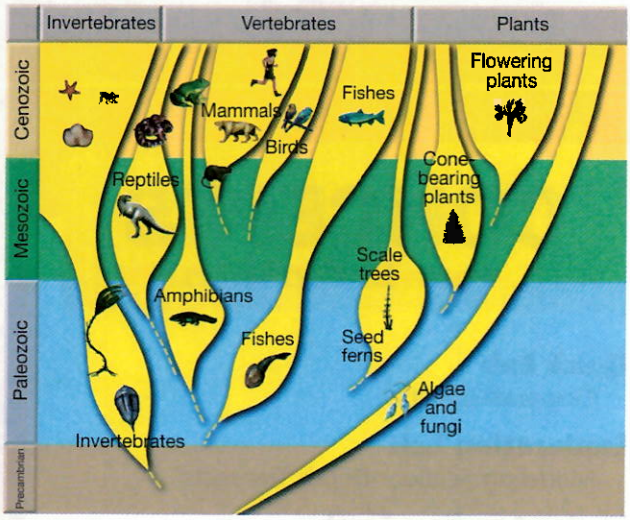
(Answer: B)

Choose the letter that best answers the question or completes the statement.

1. Which of the following modern-day continents was NOT a part of Gondwana?
   (A) Africa
   (B) North America
   (C) South America
   (D) Antarctica

2. Where did the water that makes up Earth's oceans originally come from?
   (A) Water vapor as part of the original atmosphere.
   (B) Water vapor dissolved in molten rock.
   (C) Liquid water came from beneath Earth's surface and from comets.
   (D) Liquid water settled into low areas of the surface.

Use the diagram below to answer Questions 3 and 4.



3. According to the diagram, which group of organisms appeared first?
   (A) invertebrates
   (B) flowering plants
   (C) algae and fungi
   (D) fishes

4. According to the diagram, when did the first mammals appear?
   (A) Precambrian
   (B) Paleozoic
   (C) Mesozoic
   (D) Cenozoic

Answer the following questions in complete sentences.

5. What are two hypotheses for the extinction of the dinosaurs and many other plant and animal groups at the end of the Mesozoic era?

6. Why is so little known about the Precambrian era?

7. List and describe four traits that separate mammals from reptiles.