# The Fossil Record

## Reading Preview

### Key Concepts

- How do most fossils form?
- How can scientists determine a fossil's age?
- What is the Geologic Time Scale?
- What are some unanswered questions about evolution?

### Key Terms

- petrified fossil
- mold
- cast
- relative dating
- radioactive dating
- radioactive element
- half-life
- fossil record
- extinct
- gradualism
- punctuated equilibria

### Target Reading Skill

**Building Vocabulary** After you read the section, write a definition of each Key Term in your own words.

## Lab zone Discover Activity

### What Can You Learn From Fossils?

1. Look at the fossil in the photograph. Describe the fossil's characteristics in as much detail as you can.
2. From your description in Step 1, try to figure out how the organism lived. How did it move? Where did it live?

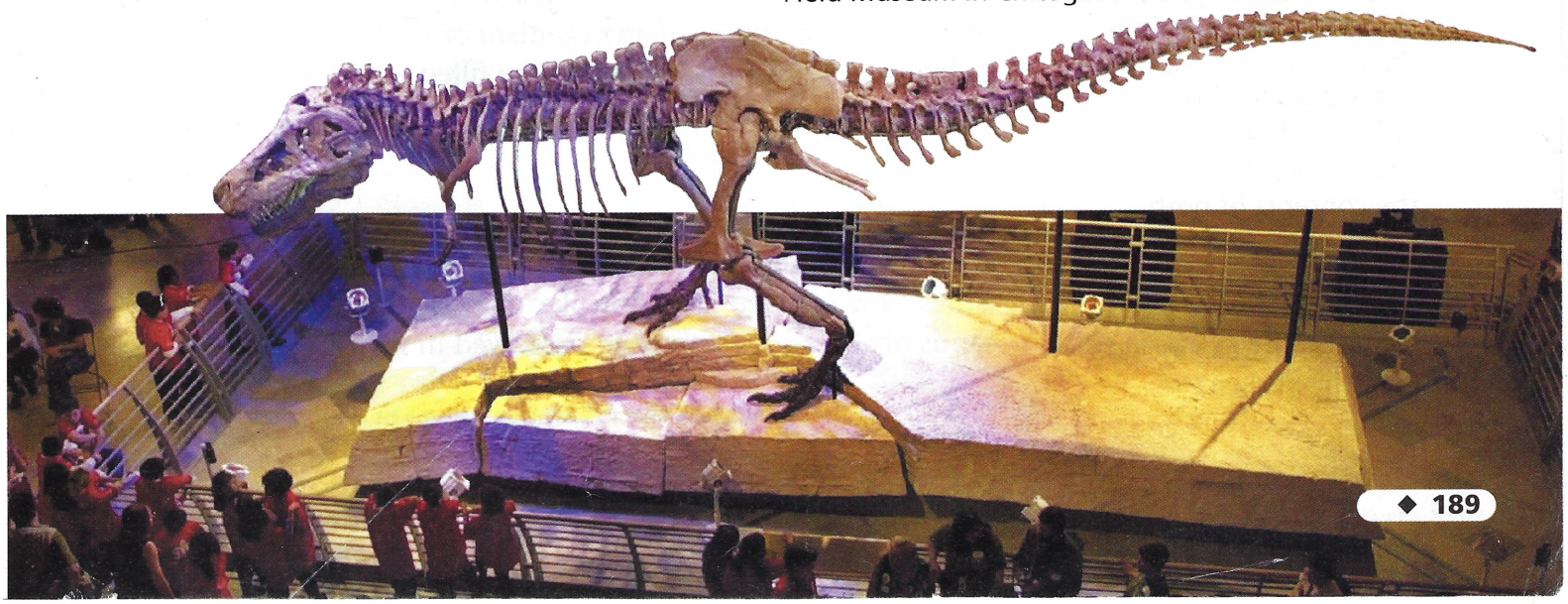
**Think It Over**

**Inferring** What type of present-day organism do you think is related to the fossil? Why?

The fossil dinosaur below has been nicknamed "Sue." If fossils could talk, Sue might say something like this: "I don't mind that museum visitors call me 'Sue,' but I do get annoyed when they refer to me as 'that old fossil.' I'm a 67-million-year old *Tyrannosaurus rex*, and I should get some respect. I was fearsome. My skull is one and a half meters long, and my longest tooth is more than 30 centimeters. Ah, the stories I could tell! But I'll have to let my bones speak for themselves. Scientists can learn a lot from studying fossils like me."

Of course, fossils can't really talk or think. But fossils such as Sue reveal life's history.

**FIGURE 13 Dinosaur Fossil**
The dinosaur nicknamed "Sue" was discovered in 1990 in South Dakota. Sue is now in the Field Museum in Chicago.



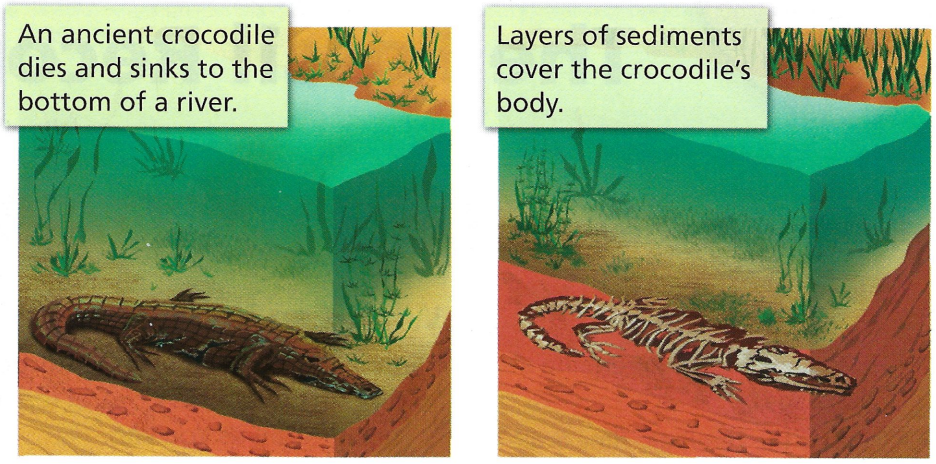



**FIGURE 14**
**Fossil Formation**
Most fossils, such as the fossil crocodile shown here, form in sedimentary rock. **Relating Cause and Effect** *In the process of fossil formation, what materials replace the crocodile's remains?*

## How Do Fossils Form?

The formation of any fossil is a rare event. Usually only the hard parts of the organism, such as the bones or shells of animals, form fossils. **Most fossils form when organisms that die become buried in sediments.** Sediments are particles of soil and rock. When a river flows into a lake or ocean, the sediments that the river carries settle to the bottom. Layers of sediments may cover the dead organisms. Over millions of years, the layers may harden to become sedimentary rock. Figure 14 shows how a fossil can form.

**Petrified Fossils** Some remains that become buried in sediments are actually changed to rock. Minerals dissolved in the water soak into the buried remains. Gradually, the minerals replace the remains, changing them into rock. Fossils that form in this way are called **petrified fossils.**

**Molds and Casts** Sometimes shells or other hard parts buried by sediments gradually dissolve. An empty space remains in the place that the hard part once occupied. A hollow space in sediment in the shape of an organism or part of an organism is called a **mold.** A mold may become filled with hardened minerals, forming a cast. A **cast** is a copy of the shape of the organism that made the mold.

**Preserved Remains** Organisms can also be preserved in substances other than sediments. For example, entire organisms, such as huge elephant-like mammoths that lived thousands of years ago, have been preserved in ice.

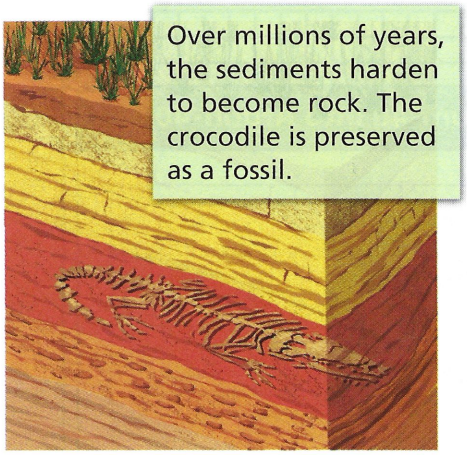
**Reading Checkpoint** **What is the difference between a mold and a cast?**

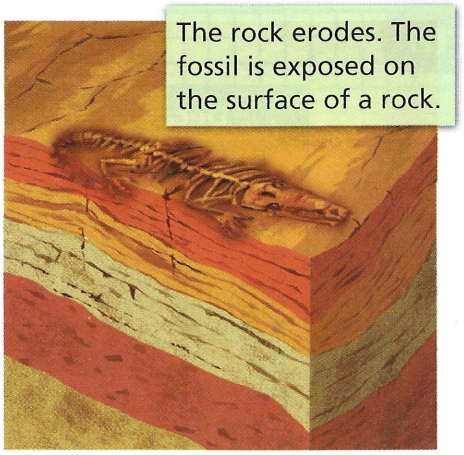
**Lab zone Try This Activity**

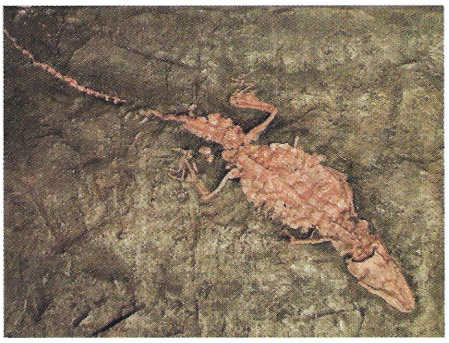
### Preservation in Ice

1. Place fresh fruit, such as apple slices, strawberries, and blueberries, in an open plastic container.
2. Completely cover the fruit with water. Put the container in a freezer.
3. Place the same type and amount of fresh fruit in another open container. Leave it somewhere where no one will disturb it.
4. After three days, observe the contents of both containers.

**Inferring** Use your observations to explain why fossils preserved in ice can include soft, fleshy body parts.



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## Determining a Fossil's Age

To understand how living things have changed through time, scientists need to be able to determine the ages of fossils. They can then determine the order in which past events occurred. This information can be used to reconstruct the history of life on Earth.

For example, suppose a scientist is studying two fossils of ancient snails, Snail A and Snail B. The fossils are similar, but they are different enough that they are not the same species. Perhaps, the scientist hypothesizes, Snail A's species changed over time and eventually gave rise to Snail B's species. To help determine whether this hypothesis could be valid, the scientist must first learn which fossil—A or B—is older. **Scientists can determine a fossil's age in two ways: relative dating and radioactive dating.**

**Relative Dating** Scientists use **relative dating** to determine which of two fossils is older. To understand how relative dating works, imagine that a river has cut down through layers of sedimentary rock to form a canyon. If you look at the canyon walls, you can see the layers of sedimentary rock piled up one on top of another. The layers near the top of the canyon were formed most recently. These layers are the youngest rock layers. The lower down the canyon wall you go, the older the layers are. Therefore, fossils found in layers near the top of the canyon are younger than fossils found near the bottom of the canyon.

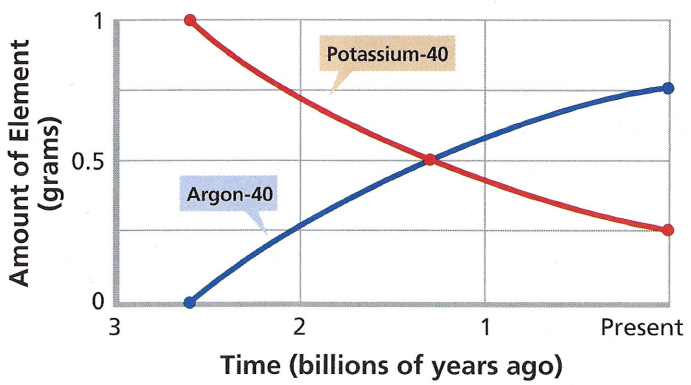
Relative dating can only be used when the rock layers have been preserved in their original sequence. Relative dating can help scientists determine whether one fossil is older than another. However, relative dating does not tell scientists the fossil's actual age.

## Math Analyzing Data

### Radioactive Decay

The half-life of potassium-40, a radioactive element, is 1.3 billion years. This means that half of the potassium-40 in a sample will break down into argon-40 every 1.3 billion years. The graph shows the breakdown of a 1-gram sample of potassium-40 into argon-40 over billions of years.

**Decay of Potassium-40 Into Argon-40**




1. **Reading Graphs** What does the red line represent? What does the blue line represent?
2. **Reading Graphs** At 2.6 billion years ago, how much of the sample consisted of potassium 40? How much of the sample consisted of argon-40?
3. **Reading Graphs** At what point in time do the two graph lines cross?
4. **Interpreting Data** At the point where the graph lines cross, how much of the sample consisted of potassium-40? How much consisted of argon-40? Explain why this is the case.

**Radioactive Dating** A technique called **radioactive dating** allows scientists to determine the actual age of fossils. The rocks that fossils are found near contain **radioactive elements,** which are unstable elements that decay, or break down, into different elements. The **half-life** of a radioactive element is the time it takes for half of the atoms in a sample to decay. The graph in Analyzing Data shows how a sample of potassium-40, a radioactive element, breaks down into argon-40 over time.

Scientists can compare the amount of a radioactive element in a sample to the amount of the element into which it breaks down. This information can be used to calculate the age of the rock, and thus the age of the fossil.

**Reading Checkpoint** What is a half-life?

## What Do Fossils Reveal?

Like pieces in a jigsaw puzzle, fossils can help scientists piece together information about Earth's past. From the fossil record, scientists have learned information about the history of life on Earth. The millions of fossils that scientists have collected are called the **fossil record.**

**Extinct Organisms** Almost all of the species preserved as fossils are now extinct. A species is **extinct** if no members of that species are still alive. Most of what scientists know about extinct species is based on the fossil record.

**The Geologic Time Scale** The fossil record provides clues about how and when new groups of organisms evolved. Using radioactive dating, scientists have calculated the ages of many different fossils and rocks. From this information, scientists have created a "calendar" of Earth's history that spans more than 4.6 billion years. Scientists have divided this large time span into smaller units called eras and periods. **This calendar of Earth's history is sometimes called the Geologic Time Scale.**

The largest span of time in the Geologic Time Scale is Precambrian Time, also called the Precambrian (pree KAM bree un). It covers the first 4 billion years of Earth's history. Scientists know very little about the Precambrian because there are few fossils from these ancient times. After the Precambrian, the Geologic Time Scale is divided into three major blocks of time, or eras. Each era is further divided into shorter periods. In Figure 16 on the next two pages, you can see the events that occurred during each time period.

Reading Checkpoint **What is the largest span in the Geologic Time Scale?**

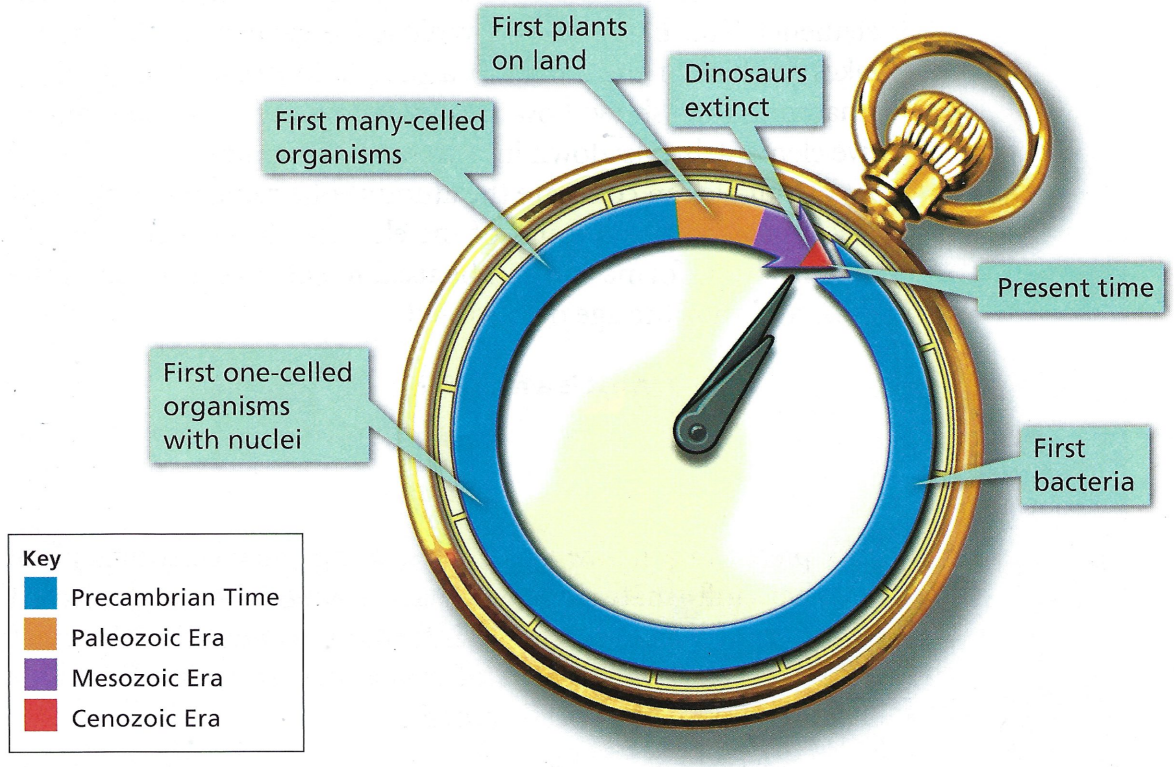



**FIGURE 15**
**Earth's History as a Clock**
Fossils found in rock layers tell the history of life on Earth. The history of life can be compared to 12 hours on a clock.
**Interpreting Diagrams** *At what time on a 12-hour time scale did plants appear on land?*

FIGURE 16

## The Geologic Time Scale

**Sequencing** *Which organisms appeared first—amphibians or fishes?*

### Precambrian Time

4.6 billion–544 million years ago

Early bacteria

Early algae

Jellyfish-like animal

Sea pen

Precambrian Time begins with the formation of Earth. The first living things — bacteria — appeared in seas 3.5 billion years ago. Algae and fungi evolved 1 billion years ago. Animals first appeared 600 million years ago.

### Paleozoic Era

544–245 million years ago

| Cambrian | Ordovician | Silurian | Devonian | Carboniferous |
|---|---|---|---|---|
| 544–505 million years ago | 505–438 million years ago | 438–408 million years ago | 408–360 million years ago | 360–286 million years ago |
| *Pikaia* | *Brachiopod* | Jawed fish | Devonian forest | Cockroach |
| Sponges | Jawless fish | *Arachnid* | Shark | Dragonfly |
| Trilobite | *Crinoid* | *Eurypterid* | Lung fish | Coal forest |
| Clam | *Cephalopod* | Land plant | Bony fish | Amphibian |
| *Dinomischus* | | | | |
| Invertebrate sea animals such as sponges, snails, clams, and worms evolve. | The earliest fishes evolve. Although many new species of animals arise, many become extinct by the end of the period. | Land plants and animals evolve. The plants are similar to present-day mosses. | Many types of fishes live in the seas. Early amphibians evolve. They are fishlike animals that have legs and can breathe air. Ferns and cone-bearing plants appear on land. | Tropical forests become widespread. Many different insects and amphibians evolve. The earliest reptiles appear. |

## Mesozoic Era
245–66 million years ago

## Cenozoic Era
66 million years ago to the present

### Permian
286–245 million years ago

Conifer

*Dimetrodon*

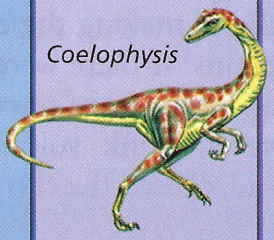
*Dicynodon*

Seed plants, insects, and reptiles become common. Reptile-like mammals appear. At the end of the period, most sea animals and amphibians become extinct.

### Triassic
245–208 million years ago

Cycad

Early mammal



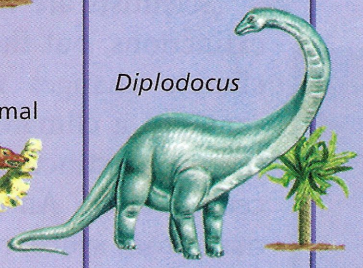
*Coelophysis*

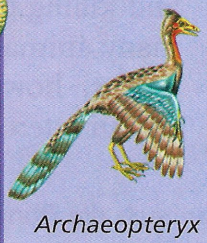
The first dinosaurs evolve. First turtles and crocodiles appear. Mammals first appear. Cone-bearing trees and palmlike trees dominate forests.

### Jurassic
208–144 million years ago

*Morganucodon*

*Diplodocus*





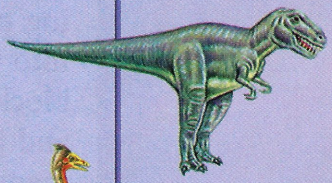
*Archaeopteryx*

Large dinosaurs roam the world. The first birds appear. Mammals become more common and varied.

### Cretaceous
144–66 million years ago

*Triceratops*

*Magnolia*



*Tyrannosaurus rex*

Creodont

The first flowering plants appear. At the end of the period, a mass extinction causes the disappearance of many organisms, including the dinosaurs.

### Tertiary
66–1.8 million years ago

*Uintatherium*

*Plesiadapis*

*Hyracotherium*

New groups of animals, including the first monkeys and apes, appear. Flowering plants become the most common kinds of plants. First grasses appear.

### Quaternary
1.8 million years ago to the present

Saber-toothed cat

*Megatherium*

*Homo sapiens*

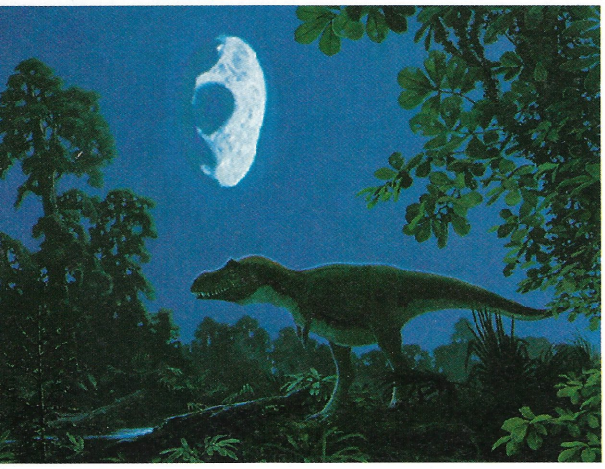
Mammals, flowering plants, and insects dominate land. Humans appear. Later in the period, many large mammals, including mammoths, become extinct.

FIGURE 17

## Mass Extinctions

An asteroid may have caused the mass extinction that occurred about 65 million years ago.

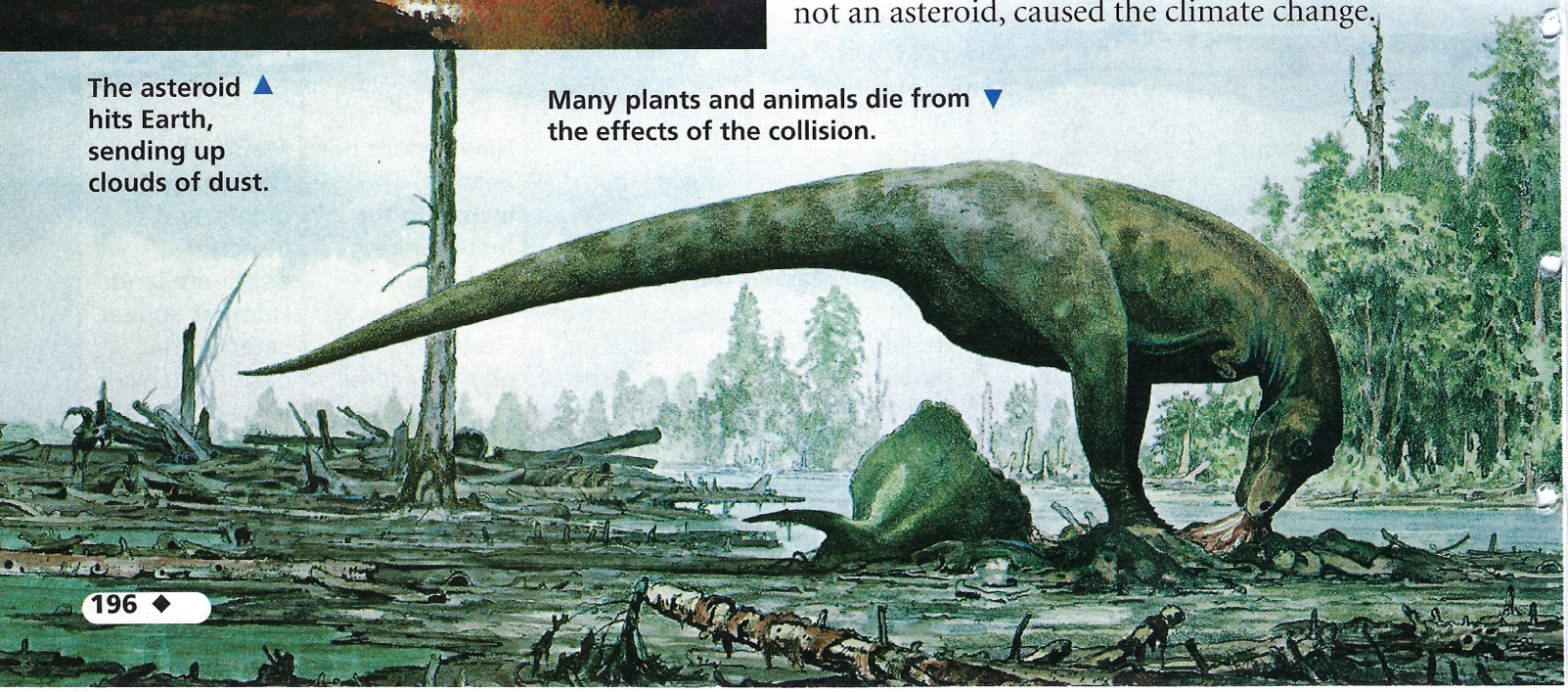
**Relating Cause and Effect** *How could an asteroid have caused climate change?*



▲ An asteroid zooms toward Earth.

The asteroid ▲ hits Earth, sending up clouds of dust.

Many plants and animals die from ▼ the effects of the collision.



# Unanswered Questions

The fossil record has provided scientists with a lot of important information about past life on Earth. The fossil record, however, is incomplete, because most organisms died without leaving fossils behind. These gaps in the fossil record leave many questions unanswered. **Two unanswered questions about evolution involve the causes of mass extinctions and the rate at which evolution occurs.**

**Mass Extinctions** When many types of organisms become extinct at the same time, a mass extinction has occurred. Several mass extinctions have taken place during the history of life. One mass extinction, for example, occurred at the end of the Cretaceous Period, about 65 million years ago. During the Cretaceous mass extinction, many kinds of plants and animals, including the dinosaurs, disappeared forever.

Scientists are not sure what causes mass extinctions, but they hypothesize that major climate changes may be responsible. For example, a climate change may have caused the mass extinction at the end of the Cretaceous Period. An asteroid, which is a rocky mass from space, may have hit Earth, throwing huge clouds of dust and other materials into the air. The dust clouds would have blocked sunlight, making the climate cooler, and killing plants. If there were fewer plants, many animals would have starved. Some scientists, however, think volcanic eruptions, not an asteroid, caused the climate change.

**Gradualism** Scientists also are not sure how rapidly species change. One theory, called **gradualism,** proposes that evolution occurs slowly but steadily. According to this theory, tiny changes in a species gradually add up to major changes over very long periods of time. This is how Darwin thought evolution occurred.

If the theory of gradualism is correct, the fossil record should include intermediate forms between a fossil organism and its descendants. However, there are often long periods of time in which fossils show little or no change. Then, quite suddenly, fossils appear that are distinctly different. One possible explanation for the lack of intermediate forms is that the fossil record is incomplete. Scientists may eventually find more fossils to fill the gaps.

**Punctuated Equilibria** The theory of **punctuated equilibria** accounts for the gaps in the fossil record. According to this theory, species evolve quickly during relatively short periods. These periods of rapid change are separated by long periods of little or no change. Today most scientists think that evolution can occur gradually at some times and more rapidly at others.

Reading Checkpoint **What theory proposes that evolution occurs slowly but steadily?**

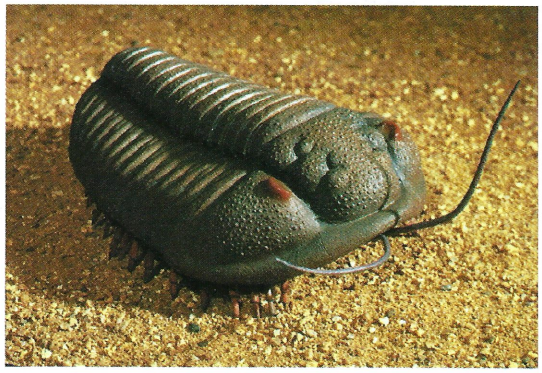


**FIGURE 18**
**Trilobite**
Trilobites were once common in Earth's oceans, but they were destroyed in a mass extinction.

## Section 3 Assessment

**Target Reading Skill** **Building Vocabulary** Use your definitions to help you answer the questions below.

### Reviewing Key Concepts

1. a. **Reviewing** What are sediments? How are they involved in the formation of fossils?
   b. **Classifying** Identify three types of fossils.
   c. **Comparing and Contrasting** Which of the major types of fossils do not form in sediments? Describe how this type can form.
2. a. **Identifying** What are the two methods of determining a fossil's age?
   b. **Describing** Describe each method.
   c. **Applying Concepts** Some fossil organisms are frozen rather than preserved in sediment. Which method of dating would you use with frozen fossils? Why?
3. a. **Defining** What is the Geologic Time Scale? Into what smaller units is it divided?
   b. **Interpreting Diagrams** Look at Figure 16. Did the organisms during Precambrian Time have hard body parts?
   c. **Relating Cause and Effect** Give one reason why there are few Precambrian fossils.
4. a. **Reviewing** What are two unanswered questions about evolution?
   b. **Comparing and Contrasting** How are the theories of gradualism and punctuated equilibria different? How are they similar?

Lab zone **At-Home Activity**

**Modeling Fossil Formation** With an adult family member, spread some mud in a shallow pan. Use your fingertips to make "footprints" across the mud. Let the mud dry and harden. Explain how this is similar to fossil formation.

# Chapter 6 Study Guide

## 1 Darwin's Theory

### Key Concepts

- Darwin's important observations included the diversity of living things, the remains of ancient organisms, and the characteristics of organisms on the Galápagos Islands.
- Darwin reasoned that plants or animals that arrived on the Galápagos Islands faced conditions that were different from those on the mainland. Perhaps, Darwin hypothesized, the species gradually changed over many generations and became better adapted to the new conditions.
- Darwin proposed that, over a long period of time, natural selection can lead to change. Helpful variations may gradually accumulate in a species, while unfavorable ones may disappear.

### Key Terms

species
fossil
adaptation
evolution
scientific theory
natural selection
variation

## 2 Evidence of Evolution

### Key Concepts

- Fossils, patterns of early development, and similar body structures all provide evidence that organisms have changed over time.
- Scientists have combined the evidence from DNA, protein structure, fossils, early development, and body structure to determine the evolutionary relationships among species.
- A new species can form when a group of individuals remains separated from the rest of its species long enough to evolve different traits.

### Key Terms

homologous structures
branching tree

## 3 The Fossil Record

### Key Concepts

- Most fossils form when organisms that die become buried in sediments.
- Scientists can determine a fossil's age in two ways: relative dating and radioactive dating.
- The calendar of Earth's history is sometimes called the Geologic Time Scale.
- Two unanswered questions about evolution involve mass extinctions and the rate at which evolution occurs.

### Key Terms

petrified fossil
mold
cast
relative dating
radioactive dating
radioactive element
half-life
fossil record
extinct
gradualism
punctuated equilibria

# Review and Assessment

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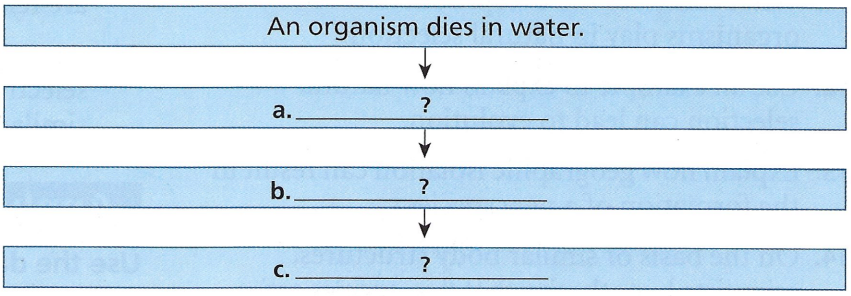
## Organizing Information

**Sequencing** Copy the flowchart about fossil formation onto a separate sheet of paper. Complete the flowchart by writing a sentence describing each stage in the process of fossil formation. Then add a title. (For more on Sequencing, see the Skills Handbook.)




## Reviewing Key Terms

**Choose the letter of the best answer.**

1. Changes in a species over long periods of time are called
   **a.** half-life.
   **b.** evolution.
   **c.** homologous structures.
   **d.** developmental stages.
2. A trait that helps an organism survive and reproduce is called a(n)
   **a.** variation.
   **b.** adaptation.
   **c.** species.
   **d.** selection.
3. Similar structures that related species have inherited from a common ancestor are called
   **a.** adaptations.
   **b.** punctuated equilibria.
   **c.** ancestral structures.
   **d.** homologous structures.
4. Fossils formed when an organism dissolves and leaves an empty space in a rock are called
   **a.** casts.
   **b.** mold.
   **c.** preserved remains.
   **d.** petrified fossils.
5. The rate of decay of a radioactive element is measured by its
   **a.** year.
   **b.** era.
   **c.** period.
   **d.** half-life.

**If the statement is true, write *true*. If it is false, change the underlined word or words to make the statement true.**

6. Darwin's idea about how evolution occurs is called natural selection.
7. Most members of a species show differences, or variations.
8. A diagram that shows how organisms might be related is called gradualism.
9. The technique of relative dating can be used to determine the actual age of a fossil.
10. According to the theory of punctuated equilibria, evolution occurs slowly but steadily.

## Writing in Science

**Notebook Entry** Imagine that you are a biologist exploring the Galápagos Islands. Write a notebook entry on one of the unusual species you have found on the islands. Include a description of how it is adapted to its environment.

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# Review and Assessment

## Checking Concepts

11. What role does the overproduction of organisms play in natural selection?
12. Use an example to explain how natural selection can lead to evolution.
13. Explain how geographic isolation can result in the formation of a new species.
14. On the basis of similar body structures, scientists hypothesize that two species are closely related. What other evidence would the scientists look for to support their hypothesis?
15. Explain why similarities in the early development of different species suggest that the species are related.
16. What is meant by *extinct?* How do scientists obtain information about extinct species?
17. What are mass extinctions? What may cause mass extinction?

## Thinking Critically

18. **Relating Cause and Effect** Why did Darwin's visit to the Galápagos Islands have such an important influence on his development of the theory of evolution?
19. **Applying Concepts** Some insects look just like sticks. How could this be an advantage to the insects? How could this trait have evolved through natural selection?
20. **Predicting** Which of the organisms shown below is least likely to become a fossil? Explain your answer.

Snail

Dandelion

Squirrel

21. **Making Judgments** What type of evidence is the best indicator of how closely two species are related? Explain your anwer.
22. **Comparing and Contrasting** How are selective breeding and natural selection similar? How are they different?

## Applying Skills

**Use the data in the table below to answer Questions 23–25.**

*Radioactive carbon-14 decays to nitrogen with a half-life of 5,730 years. The table contains information about the amounts of carbon-14 and nitrogen in three fossils. The table also gives information about the position of each fossil in rock layers.*

| Fossil | Amount of Carbon-14 in Fossil | Amount of Nitrogen in Fossil | Position of Fossil in Rock Layers |
|---|---|---|---|
| A | 1 gram | 7 grams | Bottom layer |
| B | 4 grams | 4 grams | Top layer |
| C | 2 grams | 6 grams | Middle layer |

23. **Inferring** Use the positions of the fossils in the rock layers to put the fossils in their probable order from the youngest to the oldest.
24. **Calculating** Calculate the age of each fossil using the data about carbon-14 and nitrogen.
25. **Drawing Conclusions** Do your answers to Questions 23 and 24 agree or disagree with each other? Explain.

## Lab zone Chapter Project

**Performance Assessment** Complete both your timelines. Display your completed timelines for the class. Be prepared to explain why you chose the scale that you did. Also, describe how your timelines are related to each other.