ictured here is a fossil ammonite. This marine invertebrate animal lived during the Cretaceous Period. Finding particular fossils indicates the age of the rock in which they are found. What else do you think we could learn from fossils? How do they form? What evidence of their past life do we have?

Cut the top off of a small milk carton and add enough plaster of paris to fill it halfway.
Mix enough water with the plaster so that it's smooth and thick.
Coat a leaf, shell, or bone with a thin layer of petroleum jelly.
Press it into the plaster.
Allow the plaster to dry at least 24 hours and then remove the leaf, shell, or bone.

In your Science Journal, discuss how the imprints compare with the original object. Can you determine, from the imprints alone, what object made them? How do you think imprints of once-living organisms are made?

Traces from Our Past
Fossil Formation
Index Fossils
Fossils and Ancient Environments

The Principle of Superposition
Relative Dating
Unconformities
Correlating Rock Layers

Absolute Dating
Radioactive Decay
Radiometric Dating

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the you will and

the you will

12-1 Fossils

Science Words

fossil
petrified remains
carbonaceous film
mold
cast
index fossil

Objectives

- List the conditions necessary for fossils to form.
- Describe processes of fossil formation.
- Explain how fossil correlation is used to determine rock ages.

Traces from Our Past

The dense forest reverberates as an *Allosaurus* charges forward in pursuit of an evening meal. On the other side of the swamp, a herd of apatosaurs moves slowly and cautiously onward. The adults surround the young to protect them from predators. Soon, night will fall on this prehistoric day, 160 million years ago.

Does this scene sound familiar to you? It's likely that you've read about dinosaurs and other past inhabitants of Earth before. But how do you know they really existed? What evidence do we have of past life on Earth? Scientists reconstruct what an animal looked like from its fossil remains, as in **Figure 12-1.**

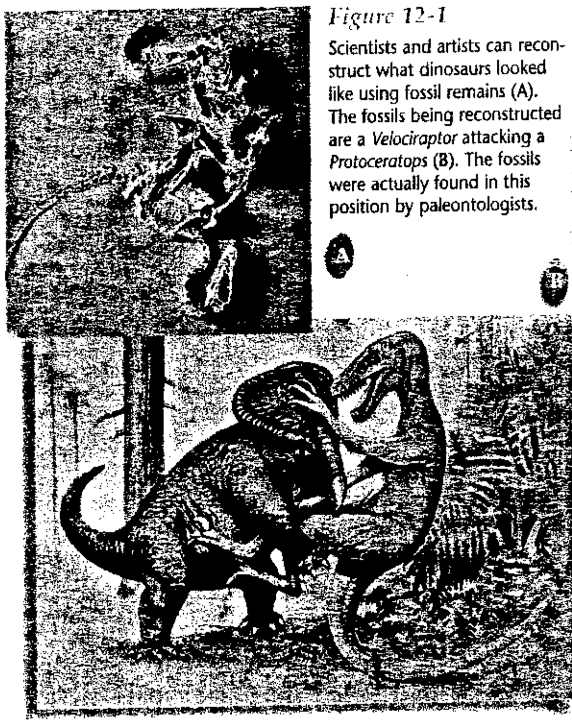
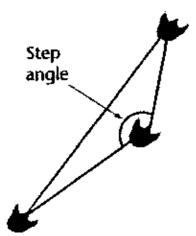


Figure 12-1
Scientists and artists can reconstruct what dinosaurs looked like using fossil remains (A). The fossils being reconstructed are a *Velociraptor* attacking a *Protoceratops* (B). The fossils were actually found in this position by paleontologists.

Using Math

Scientists often study the step angle made by animal footprints.



Design a way to find your step angle.

Figure 12-2
The hard parts of this fossil leaf made its preservation possible.

Fossil Formation

In the Explore Activity on page 325, you made imprints of parts of organisms. The imprints are records, or evidence, of life. Evidence such as the remains, imprints, or traces of once-living organisms preserved in rocks are **fossils.** By studying fossils, geologists help solve mysteries of Earth's past. Fossils have helped geologists and biologists determine approximately when life began, when plants and animals first lived on land, and when certain types of organisms, such as the dinosaurs, disappeared. Fossils tell us not only *when* and *where* organisms once lived, but also *how* they lived.

Usually the remains of dead plants and animals are quickly destroyed. Scavengers eat the dead organisms, or fungi and microorganisms cause them to decay. If you've ever left a banana on the shelf too long, you've seen this process begin. Compounds in the banana cause it to become soft and moist, and microorganisms move in and cause it to decay quickly. What keeps some plants and animals from decaying so they become fossils?

Necessary Conditions

First of all, to become a fossil, the body of a dead organism must be protected from scavengers and microorganisms. One way this can occur is when the body is buried quickly by sediments. If a fish dies and sinks to the bottom of a pond, sediments carried into the pond by a stream will rapidly cover the fish. As a result, no animals or microorganisms can get to it. However, quick burial alone isn't enough to make a fossil.

Organisms have a better chance of being preserved if they have hard parts such as bones, shells, or teeth. As you may know, these hard parts are less likely to be eaten by other organisms, they decay more slowly, and they are less likely to weather away. Most fossils, such as the fossil leaf in **Figure 12-2**, are composed of the hard parts of organisms. Fossils are usually found in sedimentary rocks. The heat and pressure involved in forming igneous and metamorphic rocks often destroy fossil material.

MiniLAB

What type of fossils might be preserved from our time?

Procedure
1. Take a brief walk outside and observe the area near your school.
2. Look around and notice what type of litter has been discarded on the school grounds. Note whether there is a paved road near your school. Note anything else that is human-made.

Analysis
1. Predict what human-made or natural objects from our time might be preserved far into the future.
2. Explain what conditions would need to exist for these objects to be preserved as fossils.

Figure 12-3

Much of the original matter in these petrified plant remains has been replaced by quartz and other minerals. *Why have the fossils retained the shape of the original plant?*

Petrified Remains

You have some idea of what *Tyrannosaurus rex* looked like because you've seen illustrations of this dinosaur. Perhaps you've seen skeletal remains of other dinosaurs towering above you in museums. Artists who draw *Tyrannosaurus rex* and other dinosaurs base their illustrations on fossil bones. These bones are usually petrified.

Petrified remains are hard and rocklike. Some or all of the original materials in the remains have been replaced by minerals. For example, a solution of water and dissolved quartz may flow through the bones of a dead organism. The water dissolves the calcium in the bone and deposits quartz in its place. Quartz is harder than calcium, so the petrified bone is rocklike.

We learn about past life-forms from bones, wood, and other remains that become petrified, like those in **Figure 12-3.** But there are many other types of fossils to consider.

Figure 12-4

This is a fossil that has been preserved as a carbonaceous film. This organism, called *eurypterid,* lived hundreds of millions of years ago and was a major predator in the seas.

Carbonaceous Films

The tissues of most organisms are made of compounds that contain carbon. Sometimes, the only fossil remains of a dead plant or animal is this carbon. As you know, fossils usually form when a dead organism is buried in sediments. As more and more sediments pile up, the organism is subjected to pressure and heat. These conditions force gases and liquids from the body. A thin film of carbon residue is left, forming an outline of the original organism, resulting in a type of fossil called a **carbonaceous film.** The process of chemically changing organic material is called carbonization, and is shown in **Figure 12-4.**

In swamps and deltas, large volumes of plant matter accumulate. Over millions of years, these deposits become completely carbonized, forming the sedimentary rock coal. Coal is more important as a source of fuel than as a fossil because the structure of the original plant is often lost when the coal forms.

Molds and Casts

Think again about the impressions in plaster of paris you made earlier. In nature, such impressions are made when seashells or other hard parts of organisms fall into soft sediments such as mud. The object and sediments are then buried by more sediments. Compaction and cementation turn the sediments into rock. Pores in the rock let water and air reach the shell or hard part and it then decays, leaving behind a cavity in the rock called a **mold.** Later, other sediments may fill in the cavity, harden into rock, and produce a **cast** of the original object, as shown in **Figure 12-5.**

Figure 12-5

A cast resembling the original organism forms when a mold fills with sediments or mineral crystals from solution.

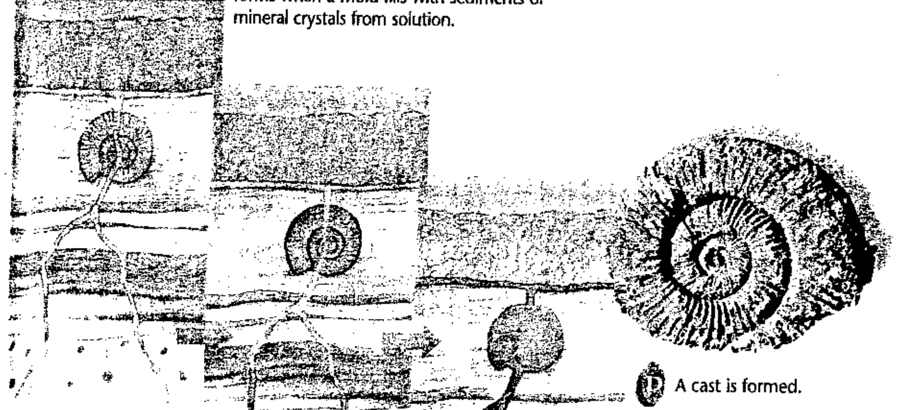


Figure 12-6

This 40-million-year-old grasshopper was trapped in the sticky resin produced by a plant. Over time, the resin crystallized into amber, preserving the insect inside.

Figure 12-7

Tracks made in soft mud, and now preserved in solid rock, can provide information about animal size, speed, and other behavior patterns.

Original Remains

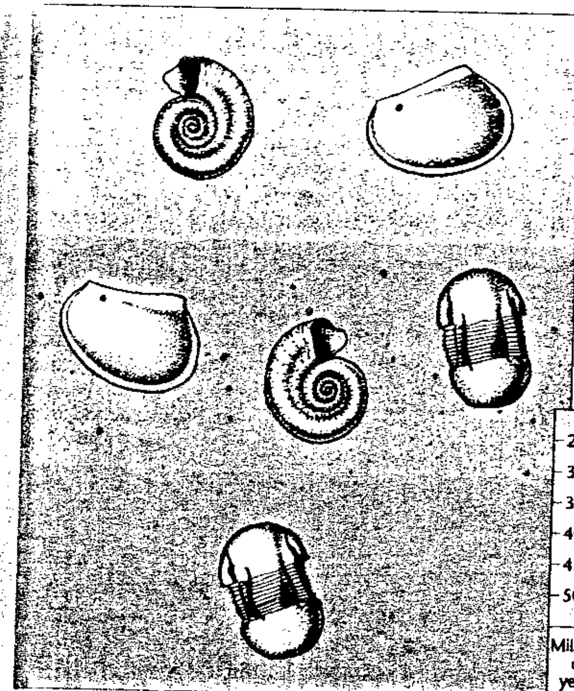
Sometimes the actual organism or parts of the organism are found. **Figure 12-6** shows an insect trapped in amber, a crystallized form of the sticky resin produced by some trees. The amber protects the insect's body from decay and petrification. Other organisms, such as woolly mammoths, have been found preserved in frozen ground. In 1991, the completely intact body of a man who lived 5300 years ago was found frozen in glacial ice in the southern Alps. It is the oldest intact human body ever discovered. Original remains have also been found in tar seeps such as the La Brea tar pit in California.

Trace Fossils

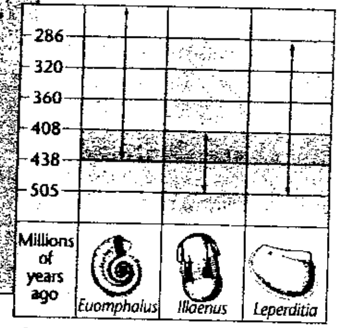
Fossilized tracks and other evidence of animal activity are called *trace fossils*. Perhaps your parents made your handprint or footprint in plaster of paris when you were born. If so, it's a record that tells something about you. From it, we can guess your approximate size and maybe your weight at that age. Animals walking on Earth long ago have left similar tracks, such as those in **Figure 12-7**. In some cases, tracks can tell us more about how an organism lived than any other type of fossil.

For example, from a set of tracks at Davenport Ranch, Texas, we have learned something about the social life of *Apatosaurus*, one of the largest known dinosaurs. The largest tracks of the herd are on the outer edges and the smallest are on the inside. This suggests that the adult apatosaurs surrounded the young as they traveled—probably to protect them from enemies. In fact, a nearby set of allosaur tracks indicates that one was stalking the herd.

Other trace fossils include worm holes and burrows made by marine animals. These, too, tell us something about the lifestyle of these animals. As you can see, a combination of fossils can tell us a great deal about the individuals that inhabited Earth before us.



A Illustration of a sequence of rocks and the fossils they contain.



B Fossil Range Chart

Figure 12-8

The sequence of sedimentary rock (A) and the fossils each contains can be used to date the rocks. The chart (B) shows when each organism inhabited Earth. *Why is it possible to say that the middle layer of rock had to be deposited between 438 and 408 million years ago?*

Index Fossils

One thing we've learned by studying fossils is that organisms are constantly changing, or evolving. Evidence indicates that species inhabit Earth for a certain period of time before they evolve into new species or they die out completely. Some species of organisms inhabit Earth for very long periods of time without changing much. Other species remain unchanged for only a short time. It is these organisms that produce index fossils.

Index fossils are from species that existed on Earth for relatively short periods of time, were abundant, and were widespread geographically. Scientists use index fossils to determine the age of rock layers. Because few fossils meet all the requirements to be an index fossil, groups of fossils are generally used to date rocks. This is how the rock layer in **Figure 12-8** was dated.

CONNECT TO LIFE SCIENCE

You have learned that original remains of animals can be found in tar seeps. ***Hypothesize*** why so many animals became trapped in tar seeps.

USING TECHNOLOGY

Recovering Fossils

When scientists locate an area thought to have fossils, large equipment or explosives are used to remove overlying rocks and soil. Smaller tools are then used as the excavation nears the fossils. In the final phases of recovery, tiny picks and brushes are used to remove soil from the fossils.

Preparing Fossils

In order for the fossils to be removed or transported, they must be strengthened and protected. Large, brittle bones, such as dinosaur remains, are first covered with a layer of shellac. Then, strips of wet newspaper are molded onto the fossils. Finally, a plaster mixture is used to coat burlap strips, which are then applied to the fossils. This final step produces a kind of cast that protects and supports the fossils. The reinforced fossils are now ready to be transported. Some fossils such as dinosaur bones often are so large that heavy machinery, and even helicopters, are used to transport the fossils. They then go to museums or universities, where they will undergo final preparations before being exhibited.

interNET CONNECTION

Visit the Chapter 12 Internet Connection at Glencoe Online Science, **www.glencoe.com/sec/science/earth,** for a link to more information about fossils. What type of things can scientists learn by studying fossils?

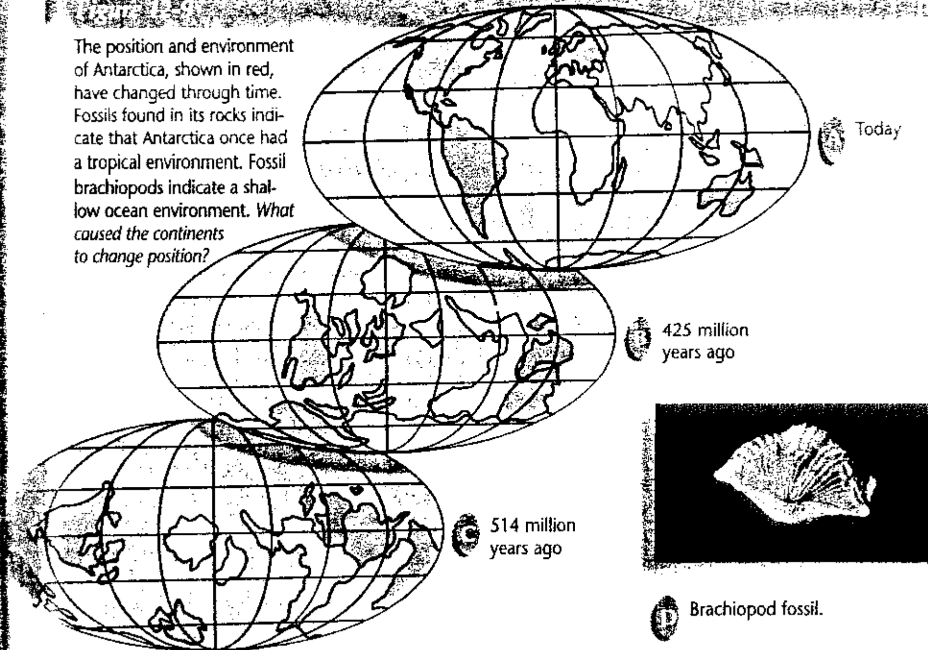
Fossils and Ancient Environments

Fossils can also be used to determine what the environment of an area was like long ago. For example, rocks in Antarctica contain fossils of tropical plants. The environment of Antarctica today certainly isn't tropical, but we know that it was at the time these fossilized plants were living.

How would you explain the presence of fossilized brachiopods, animals that lived in shallow seas, in the rocks of the midwestern United States? A brachiopod fossil is shown in **Figure 12-9D.** The central portion of North America was covered by a shallow sea when the brachiopods were living, as shown in **Figure 12-9.**

Fossils tell us not only about past life on Earth, but also about the history of the rock layers that contain them. Fossils can provide information about environment, climate, and animal behavior, as well as dating the rocks.

The position and environment of Antarctica, shown in red, have changed through time. Fossils found in its rocks indicate that Antarctica once had a tropical environment. Fossil brachiopods indicate a shallow ocean environment. *What caused the continents to change position?*



D Brachiopod fossil.

Section Wrap-up

Review

1. What conditions are needed for most fossils to form?
2. Describe how a mold and cast fossil might form.
3. **Think Critically:** What can be said about the ages of two widely separated layers of rock that contain the same type of fossil?

Skill Builder
Concept Mapping

Make a concept map that compares and contrasts petrified remains and original remains. Use the following terms and phrases: *types of fossils, original remains, evidence of former life, petrified remains, materials replaced by minerals,* and *actual parts of organisms.* If you need help, refer to Concept Mapping in the **Skill Handbook.**

Science Journal

Collect samples of fossils or visit a museum that has fossils on display. In your Science Journal, make an illustration of each fossil. Write a brief description, noting key facts about each. Also, write about how each fossil might have been formed.

12-2 Extinction of Dinosaurs

Science Words

extinct

Objectives

- Discuss the meteorite-impact hypothesis of dinosaur extinction.
- Describe several other hypotheses about why dinosaurs became extinct.

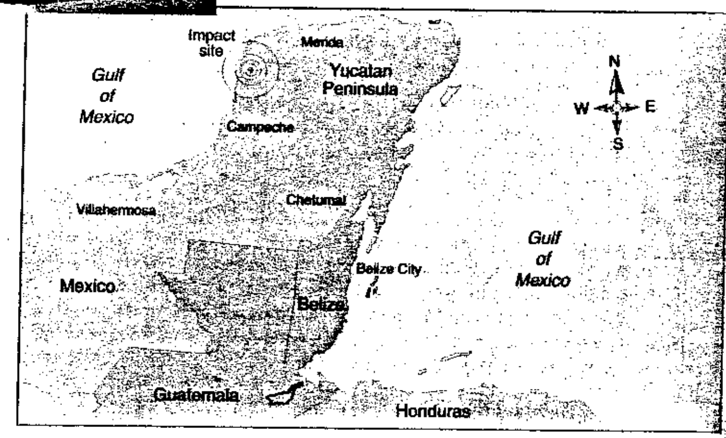
What killed the dinosaurs?

In layers of sedimentary rock in the western United States rest the remains of thousands of dinosaurs. The bones reveal that dinosaurs were fast, agile, intelligent animals that ruled the land for about 160 million years. The last species of dinosaur became extinct about 66 million years ago. When a species becomes **extinct**, it no longer has any living members. What happened to the dinosaurs? Several hypotheses about dinosaur extinction have been proposed by scientists working to solve this mystery.

One hypothesis about dinosaur extinction is that a large meteorite collided with Earth. Such a collision would have thrown huge quantities of dust and debris into the upper atmosphere. It also may have caused raging forest fires that added smoke to the air.

Figure 12-10

Evidence in the rock record indicates that a large meteorite may have struck Earth at about the same time the dinosaurs became extinct. The crater to the left is in New Zealand, and shows the force with which meteors can hit Earth.



If enough dust and smoke were released into the atmosphere, sunlight could have been completely blocked out. Unable to photosynthesize in the resulting darkness, plants would have died. Without their food source, plant-eating dinosaurs also would have died, as would the meat-eating dinosaurs that preyed on them.

Figure 12-11

Volcanic eruptions such as this eject large amounts of ash, gas, and debris into the atmosphere.

2 Points of View

Evidence for the Meteorite Hypothesis

Scientists have found evidence to support the meteorite hypothesis in a layer of clay found in sedimentary rock that was deposited at about the same time dinosaurs became extinct. The layer contains small, deformed grains of quartz similar to those found near meteorite craters. But more importantly, the clay layer is rich in the element iridium. Iridium is rare on Earth's surface, but it is found in greater amounts in meteorites. The iridium in the clay layer may have come from a huge meteorite that exploded on impact.

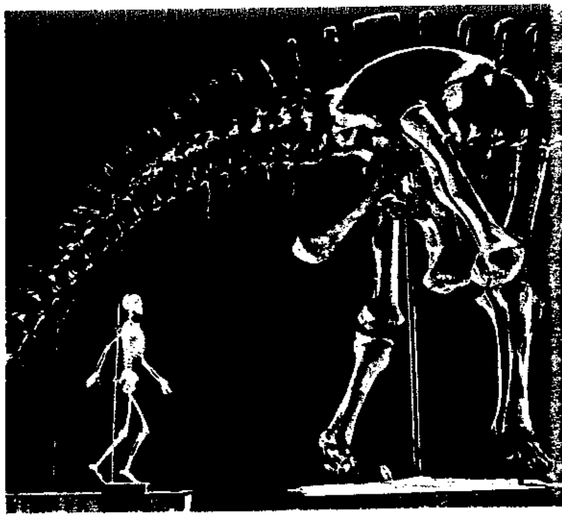
Strong support for the meteorite hypothesis came in the early 1990s, when a massive crater was discovered along the coast of Mexico's Yucatan Peninsula. The crater is roughly 180 km in diameter, large enough to have been formed by a meteorite at least 10 km across. The crater was formed 65 million years ago—the same time that the dinosaurs disappeared.

Evidence for Alternative Hypotheses

Some scientists disagree with the meteorite hypothesis and have suggested other explanations for dinosaur extinction. For example, there is evidence that a series of major volcanic eruptions took place on Earth about 65 million years ago. Because iridium is fairly abundant in molten lava, large-scale volcanic activity could explain the iridium-rich clay layer. Volcanoes also could have changed global climate by adding huge amounts of dust and gas to the atmosphere, as shown in **Figure 12-11**. The rock record indicates that global temperatures did start to decrease at about that time. Perhaps the dinosaurs could not adapt to such a changing climate, and so they died out.

Another hypothesis suggests that there was nothing unusual about the extinction of dinosaurs and that they disappeared gradually because of slow environmental changes. Perhaps these changes were brought about by shifts in the position of the continents caused by plate tectonics. Many

Figure 12-12
Dinosaurs dominated Earth for 160 million years. But like us, they were dependent on their environment, and when it changed too drastically, they became extinct.



questions remain about dinosaur extinction, and the debate continues. But one thing we have learned from studying dinosaurs is that all organisms are dependent on their environments, as explained in **Figure 12-12**.

CONNECT TO CHEMISTRY

Radiometric dating of tektites found near a buried crater on Mexico's Yucatan Peninsula indicates that the crater formed about 66 million years ago. If this age is correct, the meteorite impact may have been related to dinosaur extinction. ***Analyze*** what radiometric dating is and how it can be used to determine the tektites' age.

Section Wrap-up

Review

1. Discuss two theories that explain how iridium could have gotten into the clay layer deposited about 66 million years ago.
2. Explain how the inability of plants to photosynthesize would be harmful to the dinosaurs.

Explore the Issue

In 1995, a paleontologist discovered a massive bed of fossil fish bones on an island off the Antarctic Peninsula. The bones cover an area of more than 50 square kilometers and lie immediately above the 66-million-year-old layer of iridium-rich clay. Could this finding be used to support the meteorite impact hypothesis? Why or why not? Explain your reasoning.

SCIENCE & SOCIETY

12•3 Relative Ages of Rocks

Science Words

principle of superposition
relative dating
unconformitiy

Objectives

- Describe several methods used to date rock layers relative to other rock layers.
- Interpret gaps in the rock record.
- Give an example of how rock layers may be correlated with other rock layers.

The Principle of Superposition

It's a hot summer day in July and you're getting ready to meet your friends at the local park. You put on your helmet and pads and grab your skateboard. But the bearings in one of the wheels are worn, and the wheel isn't spinning freely. You remember reading an article in a skateboarding magazine about how to replace wheels, and you decide to look it up. In your room is a stack of magazines from the past year, as seen in **Figure 12-13**. You know that the article came out in the January edition, so it must be near the bottom of the pile. As you dig downward, you find magazines from March, then February. January must be next.

How did you know that the January issue of the magazine would be on the bottom? To find the older edition under newer ones, you applied the principle of superposition.

Youngest Rocks on Top

The **principle of superposition** states that in an undisturbed layer of rock, the oldest rocks are on the bottom and the rocks become progressively younger toward the top. Why is this the case, and is it always true?

As you know, sediments are often deposited in horizontal beds, forming layers of sedimentary rock. The first layer to form is usually on the bottom. Each additional layer forms on top of the previous one. Unless forces, such as those generated by tectonic activity, overturn the layers, the oldest rocks are found at the bottom. When layers have been overturned, geologists use other clues in the rock layers to determine their original positions.

Figure 12-13
The pile of magazines illustrates the principle of superposition, which states that the oldest rock layer (or magazine) is on the bottom.

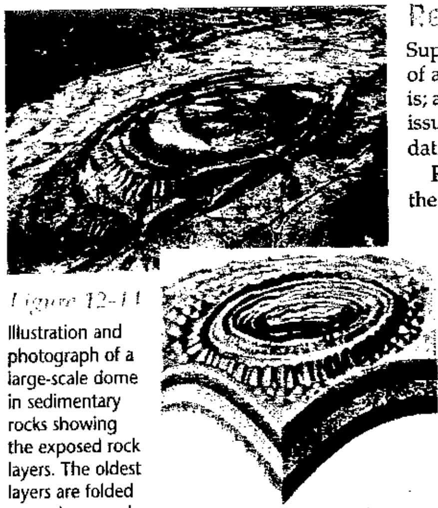


Figure 12-14 Illustration and photograph of a large-scale dome in sedimentary rocks showing the exposed rock layers. The oldest layers are folded up and exposed in the center.

Relative Dating

Suppose you now want to look for another issue of a magazine. You're not sure exactly how old it is; all you know is that it arrived after the January issue. You can find it in the stack by using relative dating.

Relative dating is used in geology to determine the order of events and the relative age of rocks by examining the position of rocks in a sequence. For example, if layers of sedimentary rock are offset by a fault, you know that the layers had to be there first before a fault could cut through them. The relative age of the rocks is older than the relative age of the fault.

Relative dating doesn't tell you anything about the exact age of rock layers. You don't know if a layer is 100 million or 10 000 years old, only that it's younger than the layers below it and older than the fault cutting through it.

Other Clues Help

Relative dating works well if rocks haven't been folded or overturned by tectonic processes. For example, look at **Figure 12-14.** Which layer is the oldest? In cases where rock layers have been disturbed, you may have to look for fossils and other clues to date the rocks. If you find a fossil in the top layer that's older than a fossil in a lower layer, you can hypothesize that layers have been overturned or faulted.

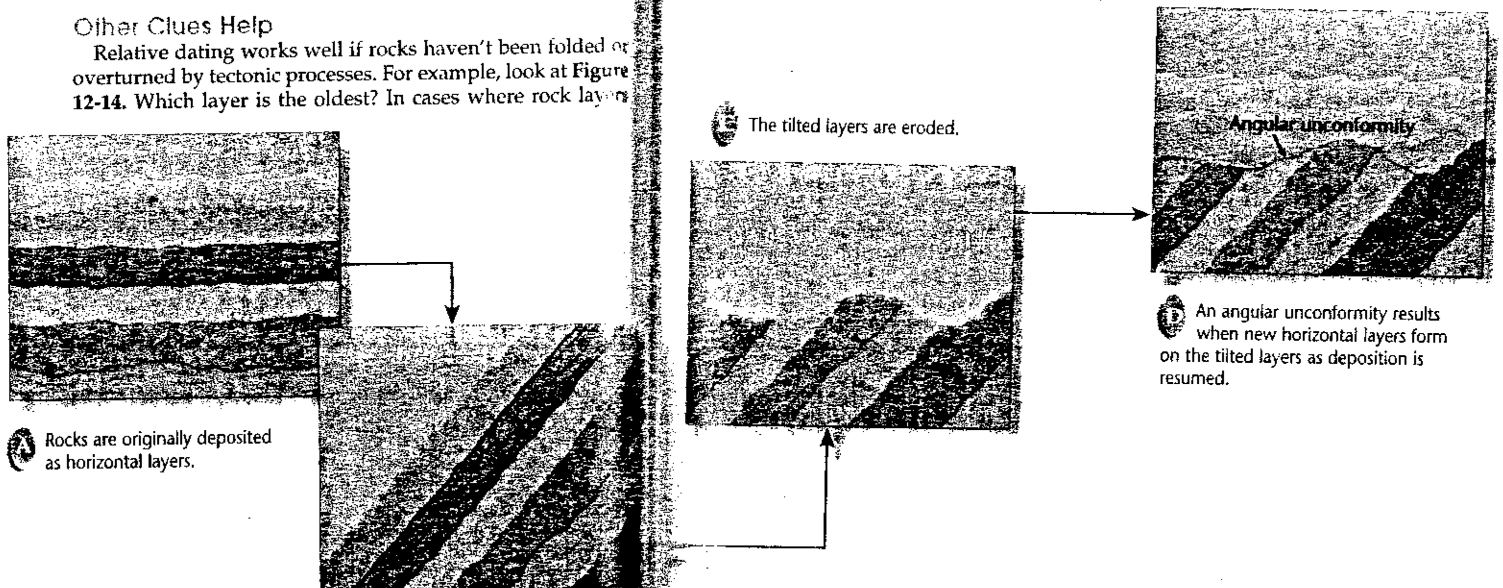
Unconformities

As you have seen, a layer of rock is a record of past events. But most rock records are incomplete—there are layers missing. These gaps in rock layers are called **unconformities.**

Unconformities develop when agents of erosion remove existing rock layers. They also form when a period of time passes without any new deposition occurring to form new layers of rock.

Angular Unconformities

Figure 12-15 illustrates one way an unconformity can form. Horizontal layers of sedimentary rock are tilted and uplifted, so that agents of erosion and weathering wear them down. Eventually, younger sediment layers are deposited horizontally on top of the eroded and tilted layers. Such an unconformity is called an angular unconformity.



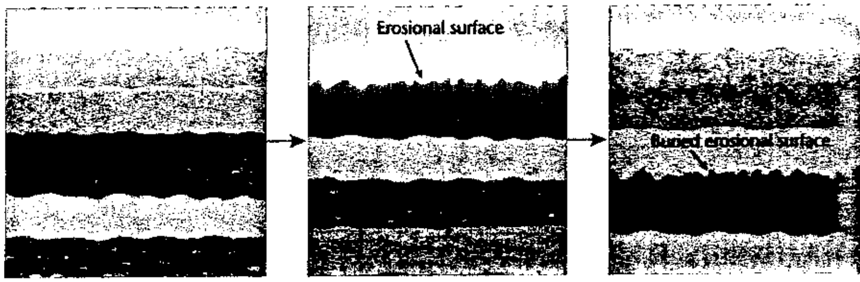
An angular unconformity results when horizontal layers overlie tilted layers.

A Rocks are originally deposited as horizontal layers.

B The horizontal rock layers are tilted as they are deformed by tectonic forces.

C The tilted layers are eroded.

D An angular unconformity results when new horizontal layers form on the tilted layers as deposition is resumed.



A Sedimentary rock layers are deposited horizontally.

B The layers are uplifted, exposed, and eroded.

C When deposition resumes, younger horizontal sediments are deposited on the buried erosional surface.

The buried erosional surface in the far right illustration is a disconformity. *How could you determine how much time and/or rock is missing?*

Disconformity

Suppose you're looking at a sequence of sedimentary rocks. They look complete, but actually, there are layers missing. If you look closely you may find an old erosional surface. This records a time when the rocks were exposed and eroded. Later, younger rocks formed above the erosional surface when sediment deposition began again. Even though all the layers are horizontal, there's still a gap in the record. This type of unconformity, called a disconformity, is illustrated in **Figure 12-16.**

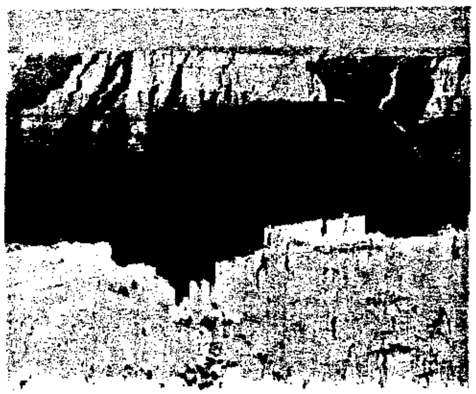


Figure 12-17

These rock layers, exposed in the Grand Canyon, can be correlated across large areas of the western U.S.

Nonconformity

Another type of unconformity, called a nonconformity, occurs when sedimentary rock layers form above metamorphic or intrusive igneous rocks. The metamorphic or igneous rock is uplifted and eroded. Sedimentary rocks are then deposited on top of this erosional surface.

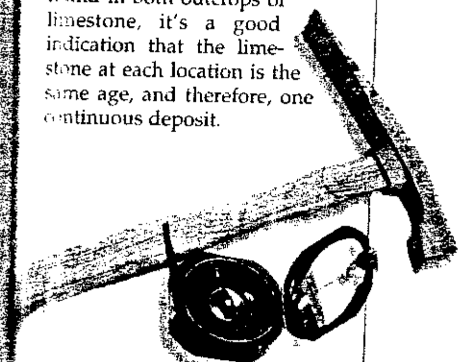
Correlating Rock Layers

Suppose you're studying a layer of sandstone in Bryce Canyon in Utah. Later, when you visit Canyonlands National Park, you notice that a layer of sandstone there looks just like the sandstone in Bryce Canyon, 250 kilometers away. Above the sandstone in the Canyonlands is a layer of limestone and then another sandstone layer. You return to Bryce Canyon and find the same sequence—sandstone, limestone, and sandstone. What do you conclude?

It's likely that you're actually looking at the same rocks at the two locations. These rocks are parts of huge deposits that covered this whole area of the western U.S. as seen in **Figure 12-17.** The sandstone and limestone you found at the two parks are the exposed surfaces of the same rock layers.

Evidence Used for Correlation

Geologists match up, or correlate layers of rocks over great distances, as seen in **Figure 12-18.** It's not always easy to say that a rock layer exposed in one area is the same as a rock layer exposed in another area. Sometimes it's possible to simply walk along the layer for kilometers and prove that it's a continuous unit. In other cases, such as at the Canyonlands area and Bryce Canyon, the rock layers are exposed only where rivers have cut down through overlying layers of rock and sediment. How can you prove that the limestone sandwiched between the two layers of sandstone in Canyonlands is the same limestone as at Bryce Canyon? One way is to use fossil evidence. If the same types of fossils are found in both outcrops of limestone, it's a good indication that the limestone at each location is the same age, and therefore, one continuous deposit.



Rock Correlation

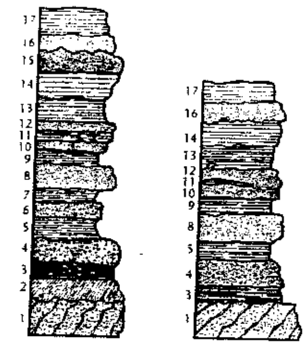
Keiko and Masao spent part of their summer vacation on a field trip through Colorado and Utah. They observed many rock outcrops and recorded what they saw in journals. The geologic column on the left was drawn by Keiko from observations made in Green River, Utah. The column on the right was made by Masao from the data he collected in Westwater, Colorado. Help them reconstruct the geologic history of the area by answering the following questions.

Solve the Problem:

1. **How many unconformities, and what types, can you recognize in each column?**
2. **How are the rock types similar in the two locations?**

Think Critically:

Explain the geologic history of the Green River area in terms of erosion and deposition. Why are some formations missing from the Westwater column?

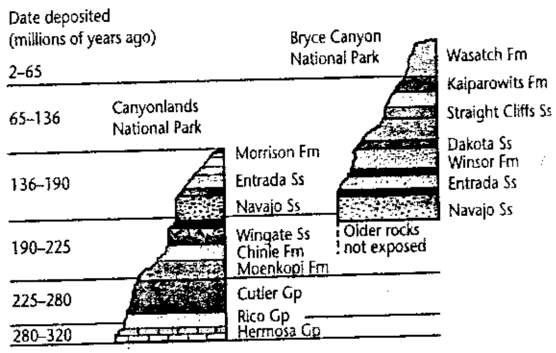


Green River, Utah Westwater, Colorado

Figure 12-15

The many rock layers, or formations, in Canyonlands and Bryce Canyon have been dated and named. Some formations have been correlated between the two canyons. *Which layers are present at both canyons?* (NOTE: Fm = formation, Ss = sandstone, Gp = group.)

Are there other ways to correlate layers of rock? Sometimes relative dating isn't enough, and other dating methods must be used. In Section 12-4, you'll see how the actual age of rocks can be determined and how geologists have used this information to determine the age of Earth.



Section Wrap-up

Review

1. Suppose you haven't cleaned out your locker all year. Where would you expect to find papers from the beginning of the year? What principle in geology would you use to find these old papers?
2. Why is it more difficult to recognize a disconformity than an angular unconformity?
3. **Think Critically:** What are the relative ages of an igneous intrusion and overlying sedimentary rock layers that dome upward? Explain.

Using Computers

Spreadsheet Use the information about unconformities on pages 339 and 340 to prepare a spreadsheet listing the types of unconformities, their differences, and their similarities.

Skill Builder

Interpreting Data

A geologist finds a series of rocks. The sandstone contains a fossil that is 400 million years old. The shale contains fossils that are between 500 and 550 million years old. The limestone, which lies under the sandstone, contains fossils that are between 400 and 500 million years old. Which rock bed is oldest? Explain. If you need help, refer to Interpreting Data in the **Skill Handbook**.

Activity 12-1

Relative Age Dating of Geologic Features

Which of your two friends is older? To answer this question, you'd need to know the relative ages of the two. You wouldn't need to know the exact age of either of your friends, just who was born first. The same is sometimes true for rock layers. Geologists can also learn a lot about rock layers without knowing their exact ages.

Problem

Can the relative ages of rocks be determined by studying the rock layers and structures?

Procedure

1. Study Figures A and B. The legend will help you interpret the figures.
2. Determine the relative ages of the rock layers, unconformities, igneous dikes, and fault in each figure.

Analyze

Figure A

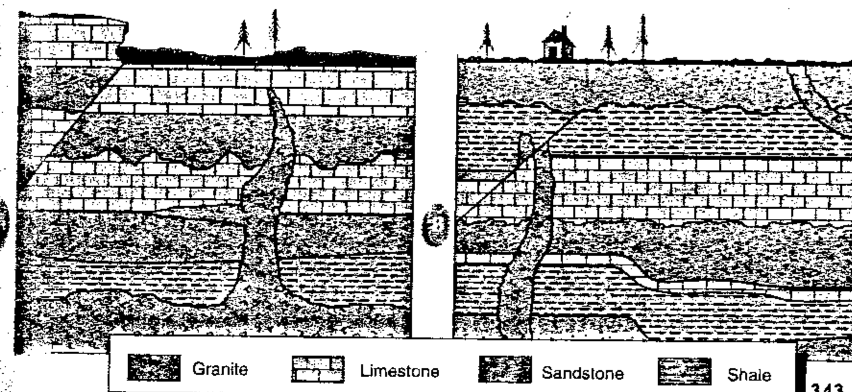
1. Were any layers of rock deposited after the igneous dike formed? Explain.
2. What type of unconformity is shown? Is it possible that there were originally more layers of rock than are shown here? Explain.
3. What type of fault is shown?
4. Is it possible to determine whether the igneous dike formed before or after the fault occurred? Explain.

Figure B

5. What type of fault is shown?
6. Is the igneous dike on the left older or younger than the unconformity nearest the surface? Explain.
7. Are the two igneous dikes shown the same age? How do you know?
8. Which two layers of rock may have been much thicker at one time than they are now?

Conclude and Apply

9. Make a sketch of Figure A. On it, **identify** the relative age of each rock layer, igneous dike, fault, and unconformity. For example, the shale layer is the oldest, so mark it with a *1*. Mark the next-oldest feature with a *2*, and so on.
10. Repeat the procedure in question 9 for Figure B.



12-4 Absolute Ages of Rocks

Science Words

absolute dating
radioactive decay
half-life
radiometric dating
uniformitarianism

Objectives

- Identify how absolute dating differs from relative dating.
- Describe how the half-lives of isotopes are used to determine a rock's age.

Integrated Physics

Absolute Dating

As you continue to shuffle through your stack of magazines looking for articles about wheels and bearings, you decide you need to restack them into a neat pile. By now, they're a jumble and no longer in order of their relative ages, as shown in **Figure 12-19.** How can you stack them so the oldest are on the bottom and the newest on top? Fortunately, magazines have their dates printed on their covers. Thus, stacking magazines in order is a simple process. Unfortunately for geologists, rocks don't have their ages stamped on them. Or do they?

Absolute dating is a method used by geologists to determine the age, in years, of a rock or other object. Absolute dating is a process that uses the properties of atoms in rocks and other objects to determine their ages.

Radioactive Decay

In Chapter 2, you learned that an element can have atoms with different numbers of neutrons in their nuclei. Some of these isotopes undergo a process called radioactive decay. When an atom of some isotopes decays, one of its neutrons breaks down into a proton and an electron. The electron leaves the atom as a beta particle. The nucleus loses a neutron, but gains a proton. Other isotopes give off two protons and two neutrons in the form of an alpha particle as seen in **Figure 12-20.** As you know, when the number of protons in an atom is changed, as it is in **radioactive decay,** a new element is formed. For example, when an atom of the radioactive isotope uranium-238 decays, it eventually forms an atom of lead-206. Lead-206 isn't radioactive, so it will not decay any further.

In the case of uranium decaying to lead, uranium-238 is known as the parent material and lead-206 as the daughter product. Another example of a parent material is carbon-14, which decays to its daughter, nitrogen-14. Each radioactive parent material has a certain rate at which it decays to its daughter product. This rate is known as its half-life.

Figure 12-19

The magazines that have been shuffled through no longer illustrate the principle of superposition.

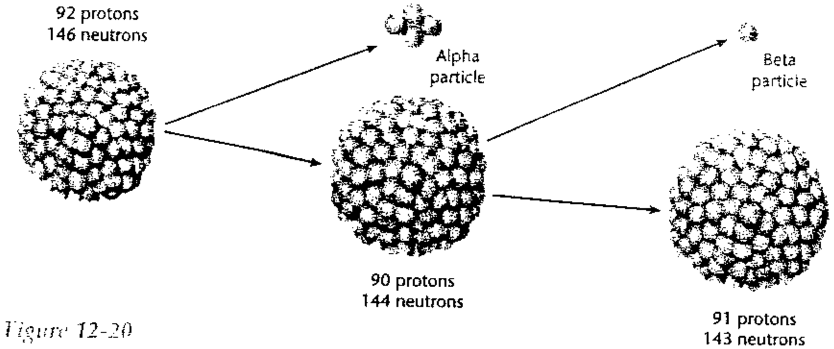


Figure 12-20

Uranium-238 decays by emitting alpha particles (two protons and two neutrons) and beta particles (one electron). A beta particle is produced when a neutron decays and becomes a proton. *Is any energy released during this process? If so, what?*

Half-Life

The **half-life** of an isotope is the time it takes for half of the atoms in the isotope to decay. For example, the half-life of carbon-14 is 5730 years. So it will take 5730 years for half of the carbon-14 atoms in an object to decay to nitrogen-14. You might guess that in another 5730 years, all of the remaining carbon-14 atoms will have decayed to nitrogen-14. However, this is not the case. Only half of the atoms of carbon-14 remaining after the first 5730 years will decay during the second 5730 years. So, after two half-lives, one-fourth of the original carbon-14 atoms still remain. Half of them will decay during another 5730 years. After three half-lives, one-eighth of the original carbon-14 atoms still remain. After many half-lives, such a small amount of the parent material remains that it may not be measurable.

Radiometric Dating

To a geologist, the decay of radioactive isotopes is like a clock ticking away, keeping track of time that's passed since rocks have formed. As time passes, the concentration of parent material in a rock decreases as the concentration of daughter product increases, as seen in **Figure 12-21** on the next page. By measuring the amounts of parent and daughter materials in a rock and by knowing the half-life of the parent, a geologist can calculate the absolute age of the rock. This process is called **radiometric dating.**

MiniLAB

What are the dates of some events in Earth's history?

Procedure

1. Sequence these events in Earth's history in relative order: Earth forms, first many-celled organisms, first land plants, first mammals, dinosaurs become extinct, first amphibians, first human ancestors, oldest known fossils.
2. Make a time line using these dates: 4.6 billion years, 3.5 billion years, 1.0 billion years, 630 million years, 408 million years, 225 million years, 66 million years, and 5 million years ago.
3. Match each event with the absolute date on your time line.

Analysis

1. Check your time line with your teacher.
2. Did you correctly list the events in relative order?
3. How does the age of Earth compare with the presence of humans on the time line?

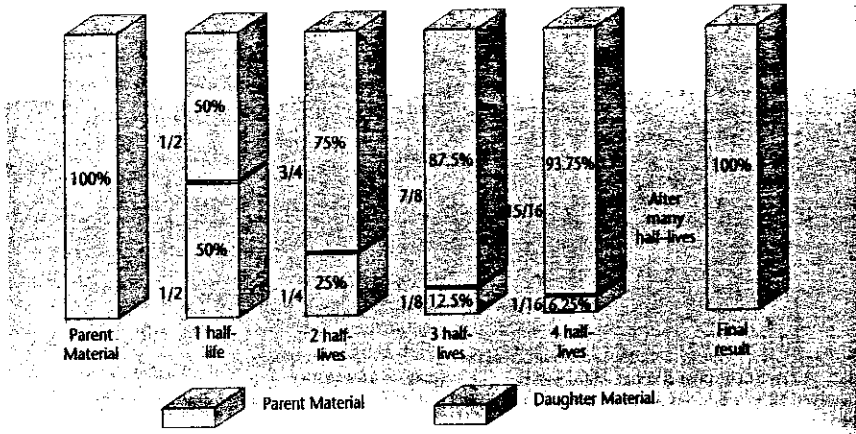


Figure 12-21

After each half-life, one-half the amount of parent material remains. Eventually, such a small amount of the parent material is left that it may not be measurable.

A scientist must decide which parent and daughter materials to measure when dating a rock or fossil. If the object to be dated is very old, then an isotope with a long half-life must be used. For example, if a fossil is 1 billion years old, there would be no carbon-14 left to measure. However, the half-life of uranium-238 is 4.5 billion years. Enough of the parent and daughter material would still be present to measure.

Radiocarbon Dating

Carbon-14 is useful for dating fossils, bones, and wood up to 50 000 years old. Organisms take in carbon from the environment to build tissues in their bodies. After the organism dies, the carbon-14 slowly decays and escapes as nitrogen-14 gas. The amount of carbon-14 remaining can be measured to determine the age of the fossil or when humans used a fire site, as in **Figure 12-22**.

Other than for carbon-14 dating, rocks that can be radiometrically dated are mostly igneous and some recrystallized metamorphic rocks. Sedimentary rocks cannot be dated by this method because the absolute age of only the sediment grains in the rock can be determined, not the rock itself. Radiometric dating has been used to date the oldest rocks found on Earth. These rocks are 3.96 billion years old. Scientists have estimated the age of Earth at 4.6 billion years.

Figure 12-22

Human activity can also be dated with carbon-14. Things like this campfire or other types of charcoal can be dated. *What other events could leave charcoal behind and provide radiocarbon dates?*

Uniformitarianism

Before radiometric dating was available, many people had estimated the age of Earth to be only a few thousand years old. But in the 1700s, Scottish scientist James Hutton estimated that Earth was much older. He used the principle of **uniformitarianism**. This principle states that Earth processes occurring today are similar to those that occurred in the past. He observed that the processes that changed the rocks and land around him were very slow, and he inferred that they had been just as slow throughout Earth's history. Hutton hypothesized that it took much longer than a few thousand years to form the layers of rock around him and to erode mountains that once towered kilometers high. John Playfair advanced Hutton's theories, but an English geologist, Sir Charles Lyell, is given the most credit for advancing uniformitarianism.

USING MATH

The half-life of radium-226 is 1600 years. How old is an object in which 1/32 of the original radium-226 is present?

Section Wrap-up

Review

1. You discover three rock layers that have not been overturned. The absolute age of the middle layer is 120 million years. What can you say about the ages of the layers above and below it?
2. How old would a fossil be if it had only one-eighth of its original carbon-14 content remaining?
3. Think Critically: Suppose you radiometrically date an igneous dike running through only the bottom two layers in question 1. The dike is cut off by the upper rock layer. The dike is 70 million years old. What can you say about the absolute age of the upper layer?

Skill Builder

Making and Using Tables

Make a table that shows the amounts of parent and daughter materials left of a radioactive element after four half-lives if the original parent material had a mass of 100 g. If you need help, refer to Making and Using Tables in the **Skill Handbook**.

Science Journal

Research John Playfair and Sir Charles Lyell in a geology book. In your Science Journal, write about their contributions to uniformitarianism.