As you read this section, keep these questions in mind:

• Why can’t scientists use rates of erosion and deposition as the only ways of determining absolute age?
• How do varves form?
• How can scientists use radioactive decay to determine the absolute age of rocks?

What Is Absolute Age?
Remember that relative dating indicates only that one rock is older or younger than another. To learn more about Earth’s history, scientists often need to learn a rock’s absolute age, or age in years. Scientists use a variety of methods to measure absolute age. Some methods require scientists to observe and measure geologic processes over time. Other methods involve the chemical composition of materials in rocks.

RATES OF EROSION

Studying rates of erosion is one way scientists estimate the absolute age of rocks. For example, scientists may measure the rate at which a stream erodes, or wears away, its stream bed. They can use that measurement to estimate the absolute age of the stream.

Scientists cannot use rates of erosion in all cases. This method is useful only for geologic features that formed within the past 10,000 to 20,000 years. For features such as the Grand Canyon that formed over millions of years, the method is less useful. Rates of erosion vary greatly over millions of years. Therefore, estimates based on recent erosion rates are not dependable.

The rocky ledge that forms Niagara Falls has been eroding at a rate of 1.3 m per year for almost 9,900 years.

Looking Closer
2. Calculate How many kilometers has the ledge been eroded in the last 9,900 years?
RATES OF DEPOSITION

Rivers can carry sediment, and then deposit it. Calculating rates of deposition is another way scientists can estimate absolute age. Scientists can estimate the average rate of deposition of common sedimentary rocks. These common rocks include limestone, shale, and sandstone. Scientists have found that, in general, about 30 cm of sedimentary rock are deposited over a period of 1,000 years.

However, a given sediment layer might not have been deposited at the average rate. For example, a flood may deposit many meters of sediment in just one day. Therefore, this method for determining absolute age is not always accurate.

VARVE COUNT

You may know that you can estimate a tree’s age by counting the growth rings in the tree’s trunk. Scientists use a similar method to estimate the age of certain sedimentary rocks. Some sedimentary rocks show layers called varves. In general, varves are annual, or yearly, layers. They have a light band of coarse particles and a dark band of fine particles.

Most varves form in glacial lakes. During summer, snow and ice melt quickly. The water carries large amounts of sediment into the lake. Most of the coarser (larger) sediment particles settle quickly to the bottom and form a layer. When winter comes, the lake starts to freeze. Finer clay particles that stayed mixed in the water settle slowly on top of the layer of coarse particles.

A coarse summer layer and a fine winter layer make up one varve. By counting the varves, scientists can estimate the age of the sediments in years.
What Is Radiometric Dating?

Remember that all atoms of an element have the same number of protons. Atoms of the same element may, however, have different numbers of neutrons. Atoms of the same element with different numbers of neutrons are called isotopes. Radioactive isotopes have nuclei that emit, or give off, particles and energy at a constant rate. This process is called radioactive decay. The figure below shows two forms of radioactive decay.

Beta Decay

Neutron breaks down into proton and electron; electron is emitted

Alpha Decay

Alpha particle (two protons and two neutrons) emitted by nucleus

Beta decay and alpha decay are two forms of radioactive decay. In both forms of decay, an atom emits particles and energy.

Scientists can use the rates of decay of radioactive isotopes to measure absolute age. This method of finding absolute age is called radiometric dating.

As a radioactive isotope decays, it may change to a different isotope of the same element. It may even change to an isotope of a different element. Scientists can measure the concentrations of the original radioactive isotope and the newly formed isotopes in a sample. The original radioactive isotopes are called parent isotopes. The newly formed isotopes are called daughter isotopes.

Scientists determine the ratio of parent and daughter isotopes in a sample of rock. Using this ratio and the known decay rate, scientists can determine the absolute age of the rock.
HALF-LIFE

Radioactive decay happens at a constant rate. Temperature, pressure, and other environmental conditions do not change the decay rate. Scientists have found that the time needed for a certain radioactive isotope to decay is always the same. Scientists typically talk about the half-life of a radioactive isotope. **Half-life** is the time it takes for half the mass of a parent isotope to decay into daughter isotopes.

For example, suppose you begin with 10 g of a parent isotope. After one half-life, you would have half, or 5 g, of that isotope. At the end of the second half-life, you would have one-fourth, or 2.5 g, of the original isotope. Three-fourths of the sample would now be made up of daughter isotopes. The figure below shows the ratios of parent and daughter isotopes through four half-lives.

![Image of radioactive isotopes through four half-lives]

RADIOACTIVE ISOTOPES

Scientists can choose from a variety of radioactive isotopes for radiometric dating. The method they use depends mainly on how long ago the rock probably formed. If too little time has passed since the rock formed, the amount of daughter isotope will be too small. Scientists will be unable to determine age accurately. If too much time has passed since a rock formed, the amount of parent isotope will be too small.

For example, uranium-238 has a half-life of 4.5 billion years. Uranium-238 is most useful for dating rock samples that contain uranium and that are more than 10 million years old. For younger rocks, the sample would have too few daughter isotopes for scientists to find an accurate age.
Radiometric Dating Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Parent Isotope</th>
<th>Daughter Isotope</th>
<th>Half-Life (years)</th>
<th>Dating Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiocarbon dating</td>
<td>carbon-14, $^{14}$C</td>
<td>nitrogen-14, $^{14}$N</td>
<td>5,730</td>
<td>organic matter, less than 70,000 years</td>
</tr>
<tr>
<td>Argon-argon dating</td>
<td>argon-39, $^{39}$Ar</td>
<td>argon-40, $^{40}$Ar</td>
<td>1.25 billion</td>
<td>10,000 to 4.6 billion years</td>
</tr>
<tr>
<td>Potassium-argon dating</td>
<td>potassium-40, $^{40}$K</td>
<td>argon-40, $^{40}$Ar</td>
<td>1.25 billion</td>
<td>50,000 to 4.6 billion years</td>
</tr>
<tr>
<td>Rubidium-strontium dating</td>
<td>rubidium-87, $^{87}$Rb</td>
<td>strontium-87, $^{87}$Sr</td>
<td>48.1 billion</td>
<td>10 million to 4.6 billion years</td>
</tr>
<tr>
<td>Uranium-lead dating</td>
<td>uranium-235, $^{235}$U</td>
<td>lead-207, $^{207}$Pb</td>
<td>704 billion</td>
<td>10 million to 4.6 billion years</td>
</tr>
<tr>
<td>Uranium-lead dating</td>
<td>uranium-238, $^{238}$U</td>
<td>lead-206, $^{206}$Pb</td>
<td>4.5 billion</td>
<td>10 million to 4.6 billion years</td>
</tr>
<tr>
<td>Thorium-lead dating</td>
<td>thorium-232, $^{232}$Th</td>
<td>lead-208, $^{208}$Pb</td>
<td>14.0 billion</td>
<td>more than 200 million years</td>
</tr>
</tbody>
</table>

How Do Scientists Use Carbon Dating?

Scientists can date some younger sediments indirectly. They can date organic material, such as wood and bones, found in sediment layers. Scientists can use carbon-14 dating to find the age of organic material that is less than about 70,000 years old. Another term for carbon-14 dating is radiocarbon dating.

Carbon-14, $^{14}$C, is a radioactive isotope. It is far less common than the carbon-12, $^{12}$C, isotope. Both $^{14}$C and $^{12}$C combine with oxygen to form carbon dioxide (CO$_2$). Plants take CO$_2$ into their bodies during photosynthesis. The carbon becomes part of the bodies of the plants. When animals eat the plants or other animals, the carbon becomes part of their bodies.

After an organism dies, it stops taking in carbon. Like all radioactive isotopes, $^{14}$C decays at a constant rate. The amount of $^{14}$C in a sample decreases as the $^{14}$C decays. Therefore, to find the age of a sample of organic material, scientists find the ratio of $^{14}$C to $^{12}$C. They compare the ratio with the ratio they know is found in a living organism. The higher the ratio is, the younger the sample is.

LOOKING CLOSER

10. Apply Concepts Scientists find a rock that they think is about 250 million years old. Name three radiometric dating methods they could use to date the rock.

Talk About It

Connect to Prior Knowledge In a small group, talk about situations you have read or heard about in which scientists use radiocarbon dating. For example, scientists use radiocarbon dating to find the ages of mummies, such as those from Egypt.
Section 2 Review

SECTION VOCABULARY

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>absolute age</td>
<td>the numeric age of an object or event, often stated in years before the present, as established by an absolute-dating process, such as radiometric dating</td>
</tr>
<tr>
<td>half-life</td>
<td>the time required for half of a sample of radioactive isotope to break down by radioactive decay to form a daughter isotope</td>
</tr>
<tr>
<td>radiometric dating</td>
<td>a method of determining the absolute age of an object by comparing the relative percentages of a radioactive (parent) isotope and a stable (daughter) isotope</td>
</tr>
<tr>
<td>varve</td>
<td>a pair of sedimentary layers (one coarse, one fine) that is deposited in an annual cycle, commonly in glacial lakes, and that can be used to determine absolute age</td>
</tr>
</tbody>
</table>

1. Define  In your own words, define half-life.

   _____________________________________________________________

2. Explain  Why can’t scientists use only rates of erosion and deposition to determine the absolute ages of rocks?

   _____________________________________________________________
   _____________________________________________________________
   _____________________________________________________________

3. Describe  Where and how do varves form?

   _____________________________________________________________
   _____________________________________________________________
   _____________________________________________________________

4. Compare  How are varves like tree rings?

   _____________________________________________________________
   _____________________________________________________________
   _____________________________________________________________

5. Apply Concepts  Suppose you have a shark’s tooth that you think is about 15,000 years old. Would you use uranium-238 or carbon-14 to date the tooth? Explain your answer.

   _____________________________________________________________
   _____________________________________________________________
   _____________________________________________________________