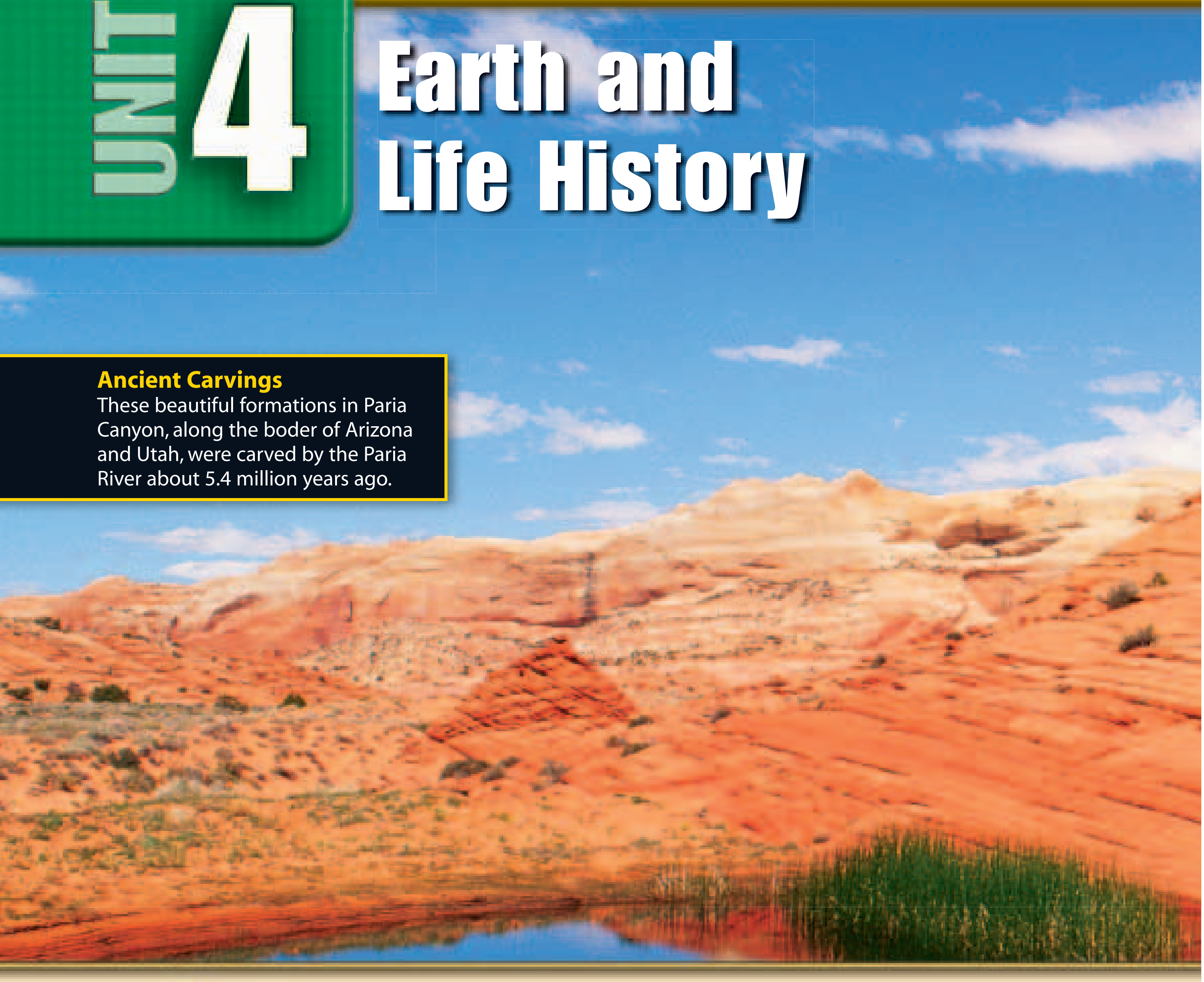
UNIT 4

Earth and Life History



Ancient Carvings
These beautiful formations in Paria Canyon, along the boder of Arizona and Utah, were carved by the Paria River about 5.4 million years ago.

West Coast Events

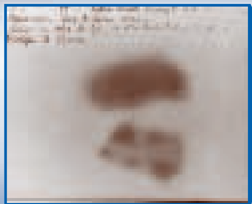
40,000–12,000 Years Ago
Organisms are trapped in tar pits found at La Brea (Los Angeles, California).

1875
Henry Hancock discovers that a tooth more than 23 cm long and 9 cm wide may be from a saber-tooth cat; realizes the bones at La Brea could be ancient.

A.D. 1 | 1750 | 1800 | 1850 | 1900

World Events

1795
James Hutton proposes idea that natural processes forming rock layers occur uniformly throughout time.



1896
Henri Becquerel discovers radioactivity of uranium salts not long after Wilhelm Conrad Roentgen discovers the X ray in 1895.

Science Online

To learn more about geologists and paleontologists and their work, visit ca7.msscience.com.

Concepts In Motion

Interactive Time Line To learn more about these events and others, visit ca7.msscience.com.

c. 1910–1915
First scientific digs of the La Brea Tar Pits are made by scientists from the University of California; about 170,000 fossils found.

1980
Luis and Walter Alvarez from UC Berkeley propose that an asteroid crashed into Earth 65 million years ago, causing the sudden extinction of dinosaurs and many other living things.

1990
NASA researchers Kevin Pope, Adriana Ocampo, and Charles Duller, identify a huge crater in the Yucatan, Mexico, that they think is the site of the asteroid crash.

1900 1920 1940 1960 1980 2000 2020

1913
First numeric time scale of geologic ages is proposed by Arthur Holmes of Great Britain; he used radioactive means to measure the age of Earth (about 4 billion years old).

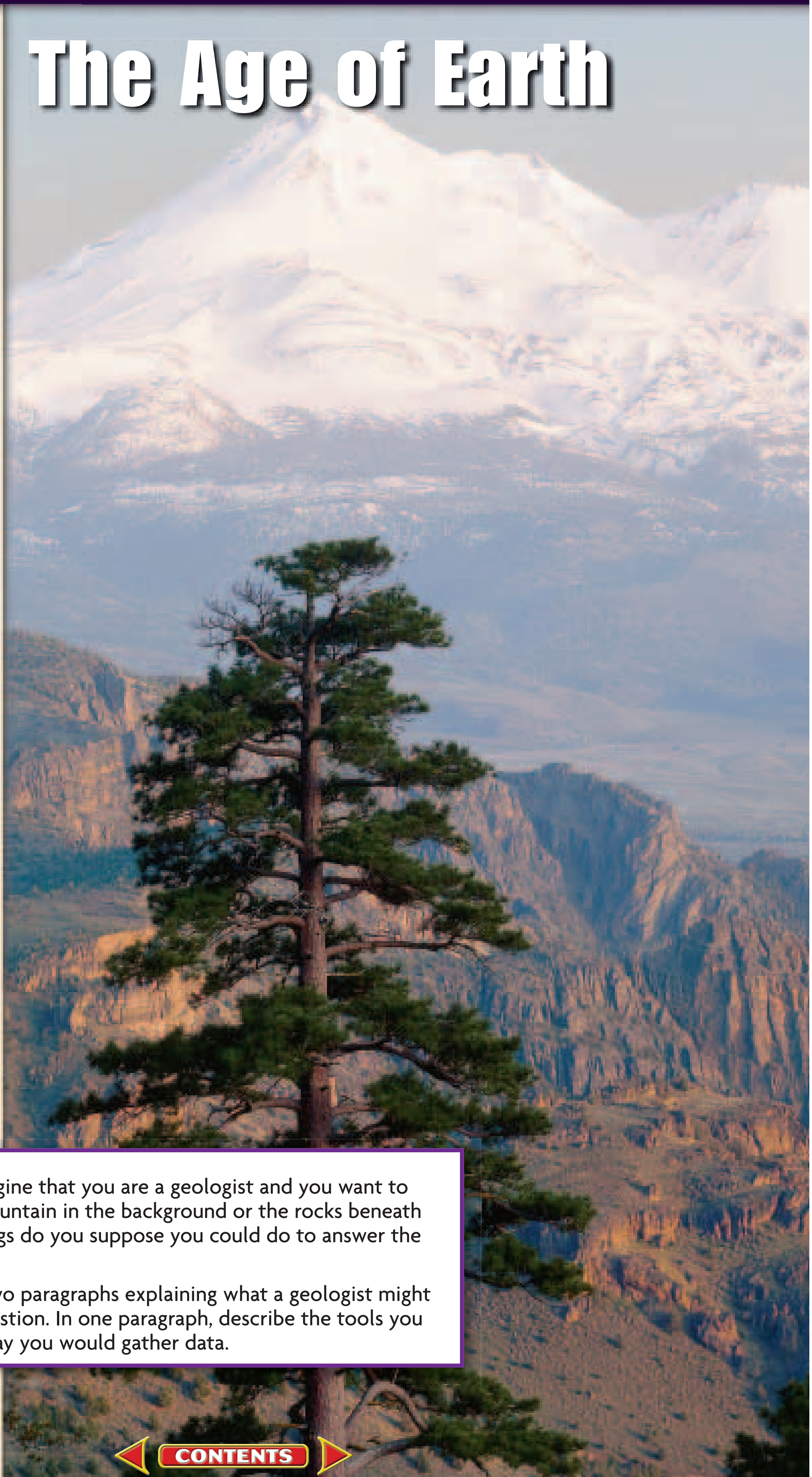
1967
Richard Leakey finds two skulls and uses new technology to date objects more accurately; one is 195,000 years old, the oldest for a fully modern human skull.

November 2002
The National Science Foundation launches a program, scientists from around the world will verify dates and class of old specimens and analyze new ones to find connections.

D. Parker/Photo Researchers

CHAPTER 7

The Age of Earth



The BIG Idea

Geologists use a variety of methods to estimate and determine the age of Earth.

LESSON 1 4.a, 4.c, 7.d

Relative Ages of Rocks

Main Idea Geologists can determine the relative ages of rocks by studying the order of rock layers, fossils, and geologic processes that are occurring today.

LESSON 2 4.d, 7.c, 7.d

Absolute Ages of Rocks

Main Idea Unstable parent isotopes change to stable daughter isotopes at a constant rate. Geologists measure the amounts of these isotopes in minerals to determine how long ago the minerals formed.

Which is older?

Imagine that you are a geologist and you want to know which is older—the mountain in the background or the rocks beneath your feet. What kinds of things do you suppose you could do to answer the question?

Science Journal Write two paragraphs explaining what a geologist might have to do to answer the question. In one paragraph, describe the tools you might need to use and the way you would gather data.

David Muench/CORBIS

CONTENTS

Start-Up Activities

Launch Lab

00:10 minutes

What is Earth's surface like?

How did the soil under you form? You can answer this question by observing what the soil around you is like.

Procedure

1. Walk through your neighborhood or through a nearby park. What natural land features do you see? Make simple sketches of your observations.
2. List your observations. Be sure to consider the Think About This questions when making your observations.

Think About This

- **Describe** the soil type. Is it filled with clay, sandy, or black and filled with plant matter? What sizes are any rocks and grains?
- **Identify** clues that tell you what the area might have been like in the past. Explain the clues and describe any evidence of river or stream erosion.

4.a, 7.e

Science Online

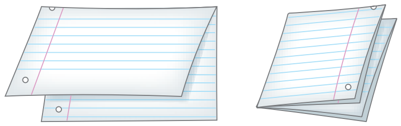
Visit ca7.msscience.com to:

- view Concepts in Motion
- explore Virtual Labs
- access content-related Web links
- take the Standards Check

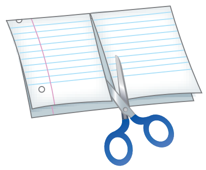
FOLDABLES™ Study Organizer

The Age of Earth Make the following Foldable to summarize the ways the age of Earth can be determined.

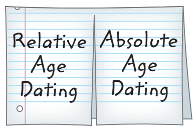
STEP 1 **Fold** a sheet of paper in half from top to bottom and then in half from side to side.



STEP 2 **Unfold** the paper once. **Cut** along the fold of the top flap to make two flaps.



STEP 3 **Label** the flaps as shown.



Reading Skill

Comparing and Contrasting
As you read this chapter, record information to compare relative age dating to absolute age dating.

mediacolor's/Alamy Images

Get Ready to Read

Make Predictions

1 Learn It! A prediction is an educated guess based on what you already know. One way to predict while reading is to guess what you believe the author will tell you next. As you are reading, each new topic should make sense because it is related to the previous paragraph or passage.

2 Practice It! Read the excerpt below from Lesson 1. Based on what you have read, make predictions about what you will read in the rest of the lesson. After you read Lesson 1, go back to your predictions to see if they were correct.

Predict how rocks are broken into pieces.

Predict at which step the pieces are changed into rock again.

Predict how rock pieces are transported most often.

Sedimentary rocks form from **pieces** of preexisting rocks. There are four steps in the process that forms sedimentary rock: **weathering, transportation, deposition, and lithification.** These four steps occur simultaneously everywhere on Earth's surface.

—*from page 287*

3 Apply It! Before you read, skim the questions in the Chapter Assessment. Choose three questions and predict the answers.

Reading Tip

As you read, check the predictions you made to see if they were correct.

Target Your Reading

Use this to focus on the main ideas as you read the chapter.

1. **Before you read** the chapter, respond to the statements below on your worksheet or on a numbered sheet of paper.
   - Write an **A** if you **agree** with the statement.
   - Write a **D** if you **disagree** with the statement.

2. **After you read** the chapter, look back to this page to see if you've changed your mind about any of the statements.
   - If any of your answers changed, explain why.
   - Change any false statements into true statements.
   - Use your revised statements as a study guide.

Before You Read A or D	Statement	After You Read A or D
	1 The processes that are at work on Earth today work at a faster rate than they did a million years ago.	
	2 Moving water is able to carry large rocks, sand, and soil downstream.	
	3 Sand particles can be pressed by layers of sand above them and cemented by minerals in the groundwater to become sandstone.	
	4 Layers of rock that are tilted at an angle because they have been eroded by glaciers.	
	5 Unless they have been folded or turned over, rock layers on the bottom are older than rock layers above them.	
	6 All the atoms of one kind of element are the same and never change.	
	7 We can use the position of rock layers to determine exact dates for the history of Earth's geologic events.	
	8 Igneous rocks are the best rocks to use for finding out how old Earth is.	

Science Online

Print a worksheet of this page at ca7.msscience.com.

LESSON 1

Relative Ages of Rocks

Science Content Standards

4.a Students know Earth processes today are similar to those that occurred in the past and slow geologic processes have large cumulative effects over long periods of time.

4.c Students know that the rock cycle includes the formation of new sediment and rocks and that rocks are often found in layers, with the oldest generally on the bottom.

Also covers: 7.d

Reading Guide

What *You'll* Learn

- **Explain** how geologists identify past events by studying rocks.
- **Recognize** the geologic history of an area.
- **Describe** how early geologists estimated Earth's age.

Why *It's* Important

Identifying the processes that have been at work on Earth will guide scientists in predicting what will happen on Earth in the future.

Vocabulary

uninformitarianism
rock cycle
clast
lithification
stratum
superposition
relative age

Review Vocabulary

fossil: remains, trace, or imprint of a plant or animal preserved in Earth's crust (p. 244)

Main Idea Geologists can determine the relative ages of rocks by studying the order of rock layers, fossils, and geologic processes that are occurring today.

Real-World Reading Connection When detectives go to the scene of a crime, they look for clues. After recording their observations, they try to determine what happened. Geologists search for clues in the rocks that can provide information about events that occurred millions of years ago.

The Beginning of Modern Geology

Before the late 1700's most scientists believed that rocks formed by evaporation of minerals dissolved in sea water. By observing rock features and the movement of sediments in streams, a Scotsman named James Hutton first realized there were two processes at work on Earth. One process formed rock and the other tore it down again. **Figure 1** shows one of these destructive processes.

Figure 1 These rocks look different from when they first formed.

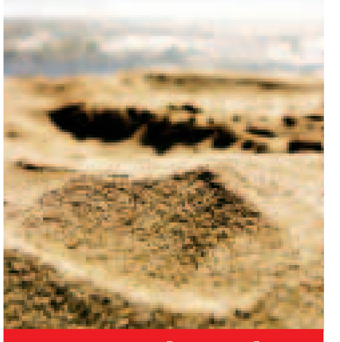
Infer What changes do you think the rock layers in the mountain experienced?

Martin Bond/Photo Researchers

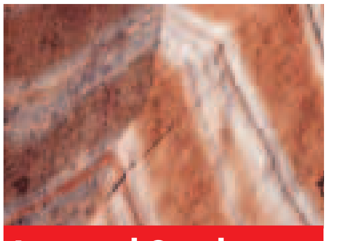
The Principle of Uniformitarianism

Geologists, like all scientists, search for ideas to explain how Earth's processes work. Hutton had an idea that "the present is the key to the past." His principle of **uniformitarianism** states that the processes that are at work today are the same processes that have been at work in Earth's past. Another way to say this is that the same Earth processes have been at work for a very long time. Therefore, scientists can observe the processes that are active on Earth today, and use them to interpret what happened in the past. So when scientists observe soil layers being put down during annual flooding, they can compare that to how layering in rocks might have occurred. **Figure 2** shows what might have happened to a sand beach.

Figure 2 The beach sand and the sand grains in the sandstone share similar characteristics. This suggests that the sandstone formed from the same processes that the beach sand is experiencing now.



Sorted Sand

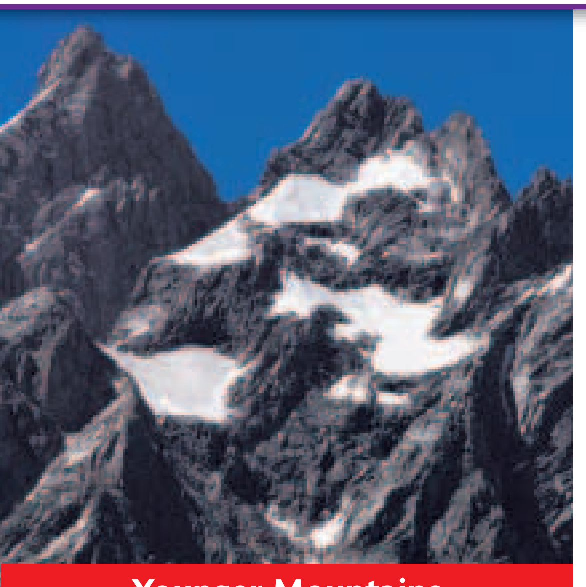


Layered Sandstone

Change is Slow

No one has ever directly observed a mountain forming or a steep river valley becoming wider and less steep. Yet we know these things happen. The process is so slow that direct observation is not possible. James Hutton realized this. He reasoned that if erosion occurred for a long time, it could greatly change Earth's surface. In fact, with enough time, erosion could wear down mountain ranges. **Figure 3** shows a young, rugged mountain range and an older, smoother range. How might time and erosion change the rugged mountains?

Figure 3 Young mountains have not been exposed to the effects of erosion for very long. Their peaks are jagged and angular. Tops of older mountains that have been eroding for millions of years are more rounded.



Younger Mountains

Older Mountains

The Rock Cycle

James Hutton had begun to recognize what geologists now call the rock cycle, shown in **Figure 4.** The **rock cycle** is the series of processes that make and change rocks through heating, melting, cooling, uplift, weathering, burial, and increasing pressure. You can trace the formation of the three major types of rocks—igneous, sedimentary, and metamorphic—on the figure.

Igneous, Metamorphic, and Sedimentary

Geologists divide rocks into three groups determined by how a rock is formed. Igneous rocks are produced when magma solidifies. Different kinds of igneous rock are identified by the size of the crystals that they contain. Large crystals form when magma cools very slowly underground. Smaller crystals form in igneous rock that cools rapidly at the surface. Some igneous rocks have no crystals because they cool very rapidly, perhaps in the ocean water.

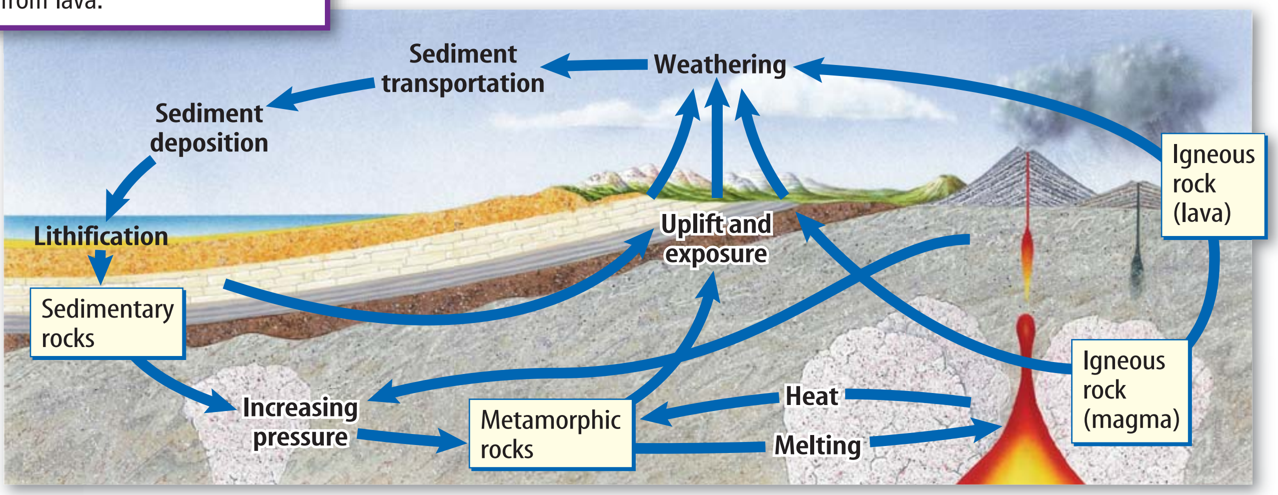
Metamorphic rock is any rock that is put under extreme pressure or heat short of melting. The rocks that are most affected are those that come in contact with hot fluids and magma moving through fractures toward the surface. Pressure may cause the mineral spaces to collapse and become more closely packed. Temperature may cause the minerals to recrystallize and form a new rock mineral.

Sedimentary rocks are those that form from sediments. Sediments are the tiny particles that come from the erosion of various types of rocks. The particles eventually become compacted and cemented into rocks.

Estimating the age of each type of rock is a challenge geologists encounter as they observe these rock formation processes. The most important ideas in determining the ages of rocks are related to sedimentary rock formation.

Figure 4 The rock cycle traces the recycling pathways of Earth materials.

Identify Trace the complete path through the rock cycle of a mineral crystal formed from lava.



Sediment Formation and Layering

Sedimentary rocks form from pieces of preexisting rocks. There are four steps in the process that forms sedimentary rock: weathering, transportation, deposition, and lithification. These four steps occur simultaneously everywhere on Earth's surface.

Weathering The first step in the formation of sedimentary rocks is weathering. Weathering is the physical or chemical breakdown of rocks into smaller pieces. Physical weathering breaks down rocks without changing the mineral composition. Frost wedging, the weathering process that occurs when water freezes and expands in cracks, can force rocks to break apart. This process is illustrated in the top photo of **Figure 5.**

Chemical weathering changes the mineral composition of rocks. When minerals that are holding a rock together change to new minerals, the rock often falls apart. This crumbling increases the surface area of the rock. As surface area increases, the rate of chemical weathering increases. Chemical weathering usually involves water. Rainwater can combine with carbon dioxide in the atmosphere to form carbonic acid. Acidic rainwater can dissolve limestone. The cave shown in **Figure 5** was formed when acidic rainwater dissolved limestone under Earth's surface.

Figure 5 Physical and chemical weathering result in formation of sediment that may eventually become a sedimentary rock.

Reading Check How does physical weathering change rocks?

Transportation The next step in sedimentary rock formation is transportation. It occurs when sediments move downhill to lower areas where they come to rest. Sediments are moved by running water, wind, moving ice, and gravity.

Sediments vary in size from large boulders to microscopic bits of rock. These different-sized pieces of rock are called **clasts.** Different amounts of force are needed to move them. The force is applied by gravity as the slope of the landscape changes. When the slope of the landscape is steep, more force can be applied to the clast. The more force that is applied to the clast, the larger the clast that can be moved.

Gravity pulling on water, air, and ice can also move the clasts. Fast-moving water can move larger clasts than slowly moving water. You can understand how wind might move large clasts during large storms while sand and smaller clasts are commonly blown across the landscape. Clasts of all sizes can be moved by glaciers because of the glacier's mass and size, but they move very slowly. During the process of being transported, clasts may change size and shape. They become rounded as they knock into each other and chips are broken off. This reduces their size at the same time.

WORD ORIGIN
clast
from Greek *klastos;* means *broken*

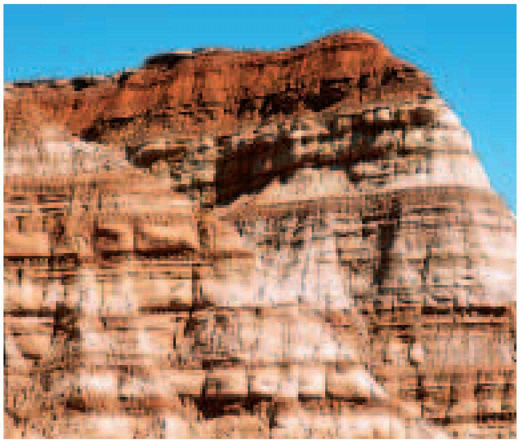


Figure 6 This stack of sedimentary rock strata is in Utah. Slight differences in grain size and composition produce the distinct layering.

Deposition The third step in the formation of sedimentary rocks is depostion (deh puh ZIH shun). It occurs when sediment being transported by water, wind, or a glacier slows down or stops. This usually happens in low areas on the landscape called depositional environments. As the sediments are dropped, gravity causes them to form **parallel,** horizontal layers. Distinct layering is a common feature in sedimentary rocks, as shown in **Figure 6.** Another characteristic of deposition is sorting. As the carrier of the sediment slows down, heavier objects are dropped first. Lighter and lighter objects are carried farther and deposited later. **Figure 7** shows how different materials may be sorted.

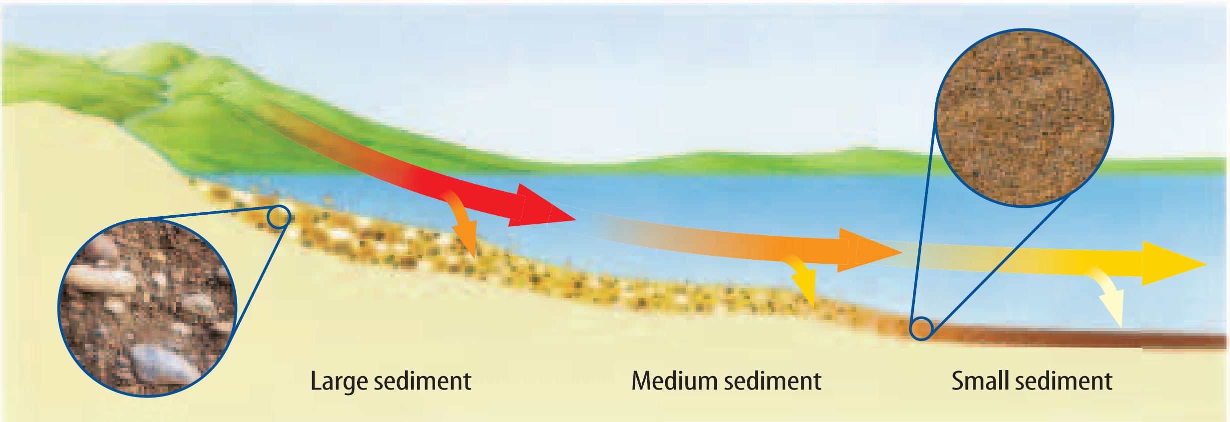
Reading Check Why are river deposits well sorted?

Lithification The final step in the formation of sedimentary rock is **lithification** (lih thuh fuh KAY shun). As older sediment layers become buried beneath layers of younger sediments, the weight of the younger sediments squeezes the older sediments together. This is called compaction. Mineral-rich liquids are still able to seep into the pore spaces between the sediment grains. Evaporation of the water and the weight of the layers cause the minerals in the pore spaces to turn to cement. This compaction and cementation changes the sediments into rock. The sediments have become lithified.

ACADEMIC VOCABULARY

parallel (PAYR uh lel)
(adj) extending in the same direction without meeting and everywhere equidistant
The lanes of traffic ran parallel for many blocks.

Figure 7 These diagrams illustrate the different grades of sediment sorting. Sediment that has been deposited by glacial ice or mass wasting is very poorly sorted. Beach sand is commonly very well sorted.



Superposition and the Fossil Record

Layers of rocks are called **strata** (singular, stratum). In 1669, Nicolas Steno, a Danish physician, presented four principles that helped geologists study strata and interpret the rocks' history. They are the principles of superposition, original horizontality, original lateral continuity, and cross-cutting relationships.

Principle of Superposition

The principle of **superposition** states that in a stack of undisturbed sedimentary rock layers, the layers on the bottom were deposited before the layers on the top. This means that the rocks on the bottom are older than the rocks on the top. **Figure 8** shows this relationship. The exact ages of the rocks are not known, but their relative age is known. **Relative age** tells you how old something is when compared to something else. For example you know that the middle strata are younger than the bottom stratum, but are older than the top stratum.

The principle of superposition is perhaps the most important of Steno's four principles. Once the relationship between strata and age was understood, geologists could study the rock layers and determine the geologic events that resulted in their deposition.

The remaining three Steno's principles are:

- Rock layers are originally deposited in horizontal, or nearly horizontal, layers.
- These rock layers usually do not end suddenly.
- A rock layer or feature that cuts across other rock layers is younger than the layer(s) being cut.

Table 1 on the next page more fully explains these three principles.

Fossils and Relative Age

You have read that the fossil record provides information on changes in life throughout Earth's history. By keeping track of which fossils came from which strata, and by applying the principle of superposition, geologists use the fossil occurrences in layers to confirm or assign relative ages to rock strata. **Figure 9** show how the superposition has helped date the layers.

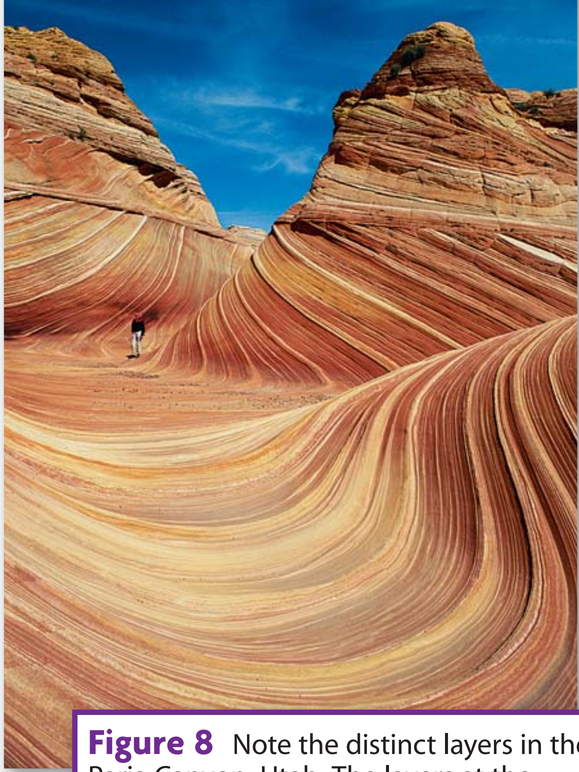
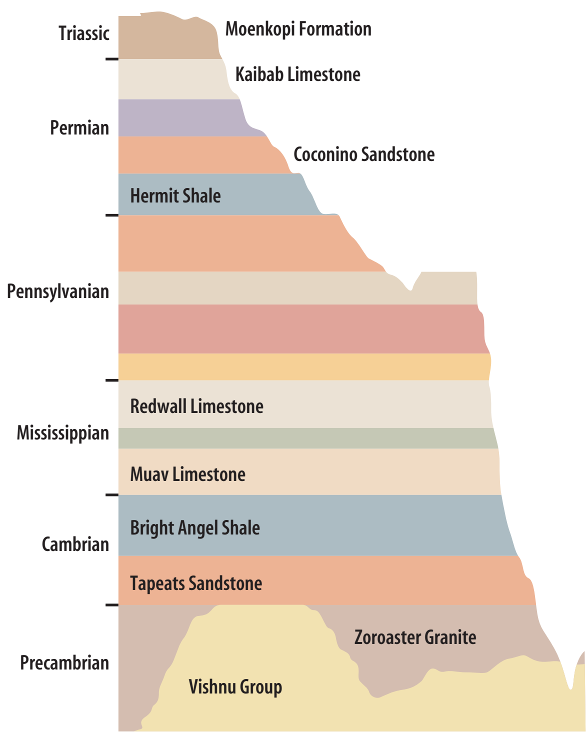


Figure 8 Note the distinct layers in the Paria Canyon, Utah. The layers at the bottom were deposited first, so they are older than the layers on the top.

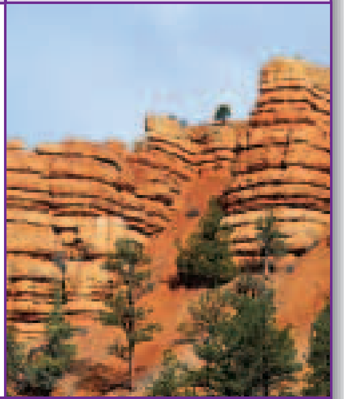
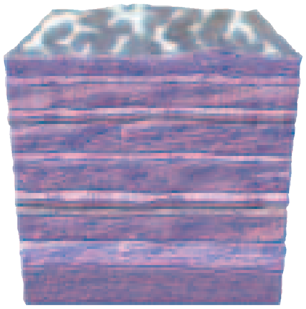
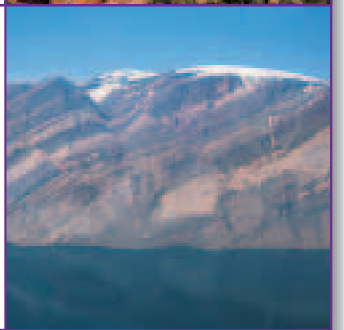
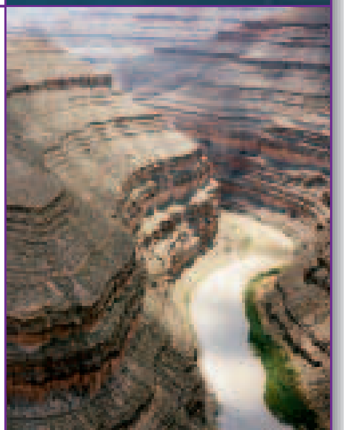
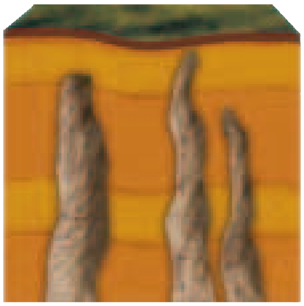
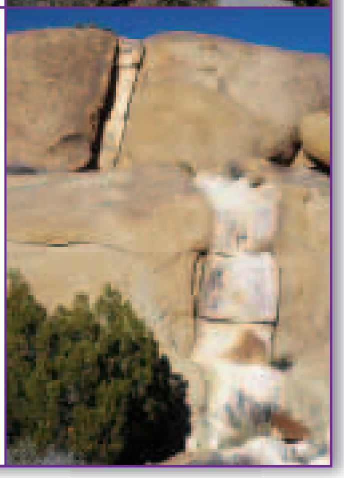
Figure 9 The relative ages of these layers have been found using superposition.

Interpret Data Which layer is oldest?



Concepts In Motion
Interactive Table Organize information about Steno's principles at ca7.msscience.com.

Table 1 Steno's Principles

Principle	Definition		
Principle of superposition	**In a stack of undisturbed sedimentary rock layers, the layers on the bottom were deposited before the layers on the top.** They are the oldest in the sequence. Fossils in the rocks also follow this principle. They are oldest at the bottom and are younger toward the top.		
Principle of original horizontality	**Rock layers are originally deposited in horizontal, or nearly horizontal, layers.** This principle explains that rock strata that are now at an angle must have been tilted after the rocks formed.		
Principle of original lateral continuity	**Sedimentary rocks form layers that cover large areas.** Imagine a trench being cut in the ground to bury a wire. Now the ground is divided, with the once-continuous grass on either side. Rock strata are affected the same way. The river valley in the picture is like the trench and the strata are like the grass.		
Principle of cross-cutting relationships	**A rock layer or feature that cuts across other rock layers is younger than the layers being cut.** Imagine magma getting injected into and across a sequence of strata and then cooling to granite. Because the strata had to be there in order for the granite to cut across them, the strata are necessarily older than the dike is.		

(t)Ed Reschke/Peter Arnold, Inc., (tc)Keith Mann/Boreal Ltd, (bc)John Crossley, (b)Doug Sokell/Visuals Unlimited

Using Rocks to Determine Relative Age

Estimating when a rock layer formed or the age of certain fossils in those layers is one of the tasks of a geologist. James Hutton explained the process of uniformitarianism. Scientists can use geologic processes observed today to interpret geologic events of the past. Nicolas Steno stated four principles that help scientists determine the order, or the relative ages, of these geologic events. The rock cycle outlines the formation processes of the three main types of rock. Following the four steps in the formation of sedimentary rocks helps scientists understand how Earth formed. Layering and fossils are common in sedimentary rocks. Fossils can also be used to determine or confirm the relative ages of rock strata.

WORD ORIGIN
stratum
from Latin *stratere;* means *to spread out*

LESSON 1 Review

Summarize

Create your own lesson summary as you design a **visual aid.**

1. **Write** the lesson title, number, and page numbers at the top of your poster.
2. **Scan** the lesson to find the **red** main headings. Organize these headings on your poster, leaving space between each.
3. **Design** an information box beneath each **red** heading. In the box, list 2–3 details, key terms, and definitions from each **blue** subheading.
4. **Illustrate** your poster with diagrams of important structures or processes next to each information box.

ELA7: W 2.5

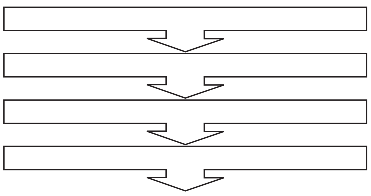
Standards Check

Using Vocabulary

1. Explain the relationship between the following terms: *superposition, strata.* 4.a
2. Using your own words, define *relative age.* 4.c
3. Describe the principle of uniformitarianism. 4.a

Understanding Main Ideas

4. **List** the four processes involved in the formation of sedimentary rocks. 4.a
5. **Complete** the graphic organizer to summarize how Hutton came to realize that Earth is old. Add more arrows if needed. 4.a



6. Which of Steno's principles is illustrated below? 4.a

7. **Contrast** the formation of igneous rocks and the formation of metamorphic rocks. 4.a

Applying Science

8. **Explain** how scientists use fossils and rock strata to determine the relative age of rocks. 4.a
9. **Summarize** Hutton's reasoning that allowed him to conclude that Earth's processes are cyclic. 4.c

Science Online
For more practice, visit **Standards Check** at ca7.msscience.com.

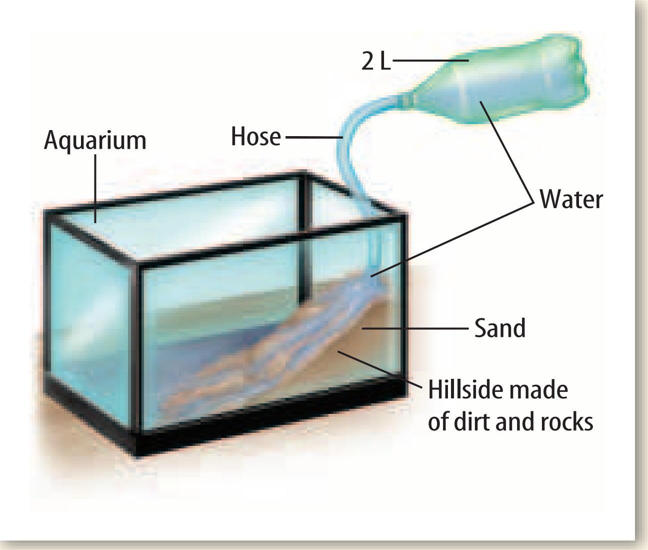
MiniLab

Try at Home

00:30 minutes

How does Earth change over time?

Earth has changed over time by slow geologic processes, and by catastrophic events. Create a mini-world to show changes that are happening to a landscape over time.



Procedure

1. Read and complete the lab safety form.
2. Choose one of the following geologic environments to model: beach, mountains, glacier-covered mountains, or river valley.
3. Think about the geologic processes you have read about in this chapter. Make a list of the ways landscapes change over time and the forces and processes that cause the changes.
4. Create a model showing some of these processes. Materials you might use include **modeling clay, water, rocks, sand, dirt and rocks, an aquarium,** and any other materials you think will work well.

Analysis

1. **Describe** the types of rock and the processes you have modeled. Be specific.
2. **Analyze** your model. How does your model compare to real life?

Science Content Standards

4.c Students know that the rock cycle includes the formation of new sediment and rocks and that rocks are often found in layers, with the oldest generally on the bottom.

7.d Construct scale models, maps, and appropriately labeled diagrams to communicate scientific knowledge (e.g., motion of Earth's plates and cell structure).

Español

LESSON 2

Science Content Standards

4.d Students know that evidence from geologic layers and radioactive dating indicates Earth is approximately 4.6 billion years old and that life on this planet has existed for more than 3 billion years.

7.c Communicate the logical connection among hypotheses, science concepts, tests conducted, data collected, and conclusions drawn from the scientific evidence.

7.d Construct scale models, maps, and appropriately labeled diagrams to communicate scientific knowledge (e.g., motion of Earth's plates and cell structure).

Reading Guide

What *You'll Learn*

- **Describe** the different types of radioactive decay.
- **Determine** the age of a mineral given the relative amounts of parent and daughter isotopes and the half-life of the parent.
- **Explain** how sedimentary rocks are dated.

Why *It's Important*

Knowing the absolute age of Earth helps scientists predict how the universe formed and when.

Vocabulary

isotope
radioactive decay
half-life

Review Vocabulary

radiation: thermal energy transferred by electromagnetic waves (Grade 6)

Absolute Ages of Rocks

Main Idea Unstable parent isotopes change to stable daughter isotopes at a constant rate. Geologists measure the amounts of these isotopes in minerals to determine how long ago the minerals formed.

Real-World Reading Connection Bog bodies are well-preserved human remains found in peat bogs. They range in age from hundreds to thousands of years old. Their clothes and hairstyles have allowed researchers to infer about when these people lived. What dating methods allow researchers to confirm their inferences and more closely pinpoint when these people lived?

What is Earth's age?

How would you go about finding out how old Earth is? In the past, scientists have tried measuring rates of erosion to see how long it would take mountains to erode. They tried calculating the time it would take Earth to cool from a molten mass to its present temperature. Each attempt was unsuccessful at predicting Earth's age. Finally, scientists discovered a natural "clock" that ticked away with great accuracy. This new clock allowed geologists to date the age of Earth, meteorites, and the Moon. In this lesson, you will read about natural clocks and how they work. **Figure 10** shows a bog body. Since bog bodies are well preserved by the acid conditions of the bog, scientists used the natural clock to determine their age.

Reading Check Why was the discovery of a natural clock so important?

Figure 10 Found in peat bogs in Great Britain and Northern Europe, bog bodies are human remains preserved by the acidic bog conditions.

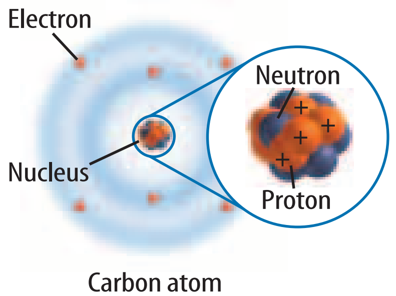


Figure 11 The carbon-12 atom has 6 protons, 6 neutrons, and 6 electrons.

WORD ORIGIN

isotope
from Greek *iso–*; means *the same*
from Greek *–topos;* means *place*

Atoms and Isotopes

Atoms are the building blocks of all matter. Atoms are made of protons, neutrons, and electrons. Protons and neutrons are located in the center of an atom called the nucleus. Electrons are located outside the nucleus. **Figure 11** shows a representation of a carbon atom.

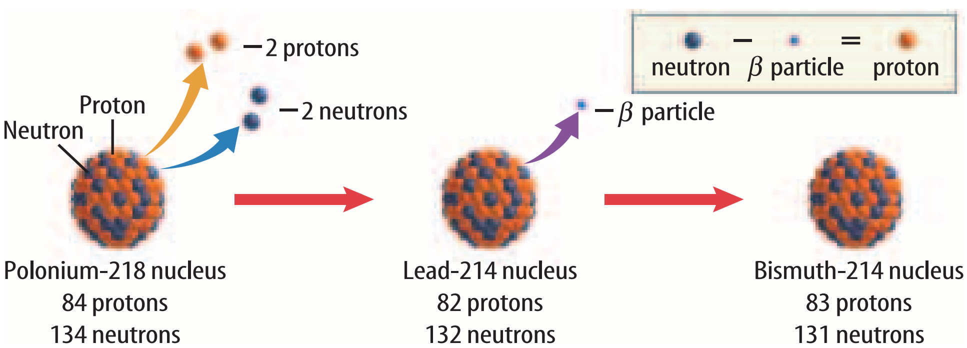
Carbon is one of more than 100 known chemical elements that exist on Earth. An element is defined by the number of protons in its atoms. For example, a carbon atom contains six protons while an oxygen atom contains eight protons. Although the number of protons in an atom of any given element is always the same, the number of neutrons in that element can vary. **Isotope** is the term for atoms of a given element that have the same number of protons, but a differing number of neutrons. Isotopes of carbon atoms can have six, seven, or eight neutrons. The isotopes are written as carbon-12, carbon-13 and carbon-14. The carbon isotope numbers are found by adding the number of protons and neutrons. Carbon-12 has six protons and six neutrons. Carbon-13 has six protons and seven neutrons. Carbon-14 has six protons and eight neutrons.

Radioactive Decay

Isotopes of an element may be stable or unstable. Carbon has two stable isotopes and one unstable, or radioactive, isotope. An isotope that has an unstable nucleus emits particles and energy. A more stable nucleus is formed through a process called radioactive decay. **Radioactive decay** occurs when an unstable atomic nucleus changes into another nucleus by emitting particles and energy. A nucleus that is unstable and undergoes radioactive decay is called radioactive. This decay is the natural clock that scientists use to find the ages of Earth's rocks. **Figure 12** illustrates the radioactive decay process for the element polonium. Radioactive decay is useful for finding the age of objects that are very old. **Figure 13** shows a method for dating things only a few thousand years old.

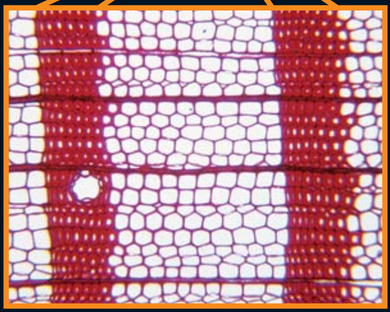
Figure 12 The nucleus of this polonium atom has lost two protons and two neutrons.

Explain Why does the atomic number change when polonium decays to bismuth?



Visualizing Accurate Dating with Tree Rings

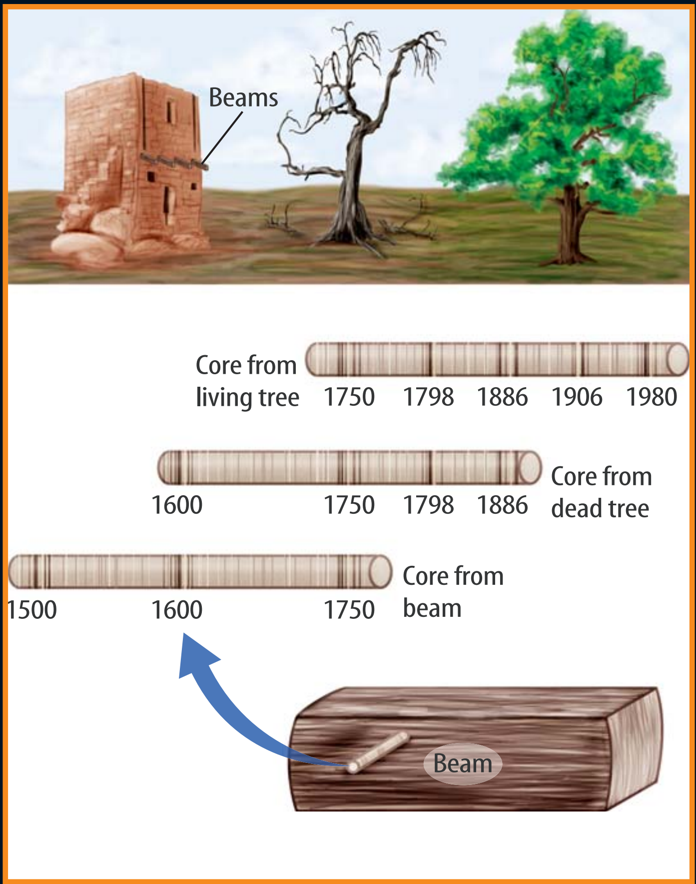
Figure 13 The science of dendrochronology compares annual tree-ring growth in trees to date events and changes in past environments.



A tree ring is a layer of wood cells produced by a tree or a shrub in one year. As seen in the photo on the left, a ring is composed of thin-walled earlywood cells and thicker-walled latewood cells. The start of the earlywood and the end of the latewood makes one annual ring. The width of a tree ring in any one year is influenced by many factors including rainfall, temperature, sunlight, and disease.

Use these steps to date the age of the Pueblo beams.

1. Core samples are taken from living trees. This provides the common starting point for all the living trees in the area.
2. Core samples are taken from dead trees that are still standing. There will be a point that will match in the living trees and in the standing, dead trees.
3. Core samples are taken from the beams. A correlation between the beams and the dead trees will allow us to find the age of the tree the beam was made from. This will tell us the age of the building. The cores are all cross-dated by comparing patterns of rings in all the core samples.



Contributed by National Geographic

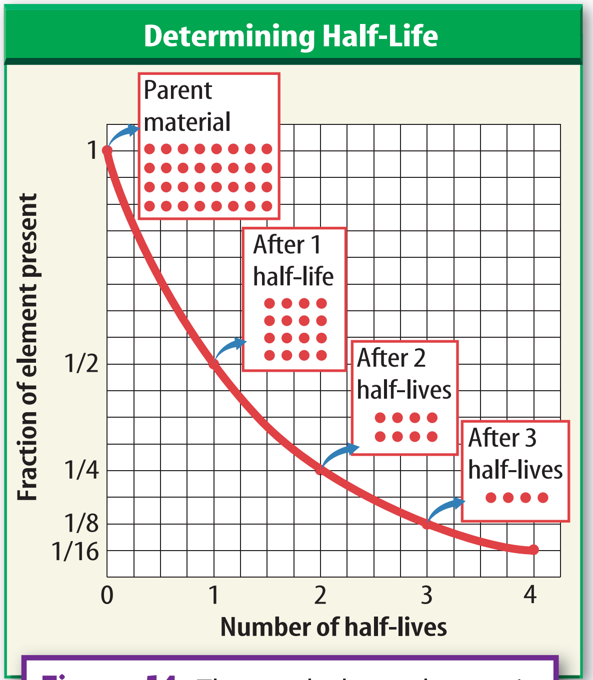


Figure 14 The graph shows the way in which all radioactive elements decay.

Calculate How many half-lives have elapsed if a sample has 25 percent of a parent isotope and 75 percent of the daughter isotope?

Parent and Daughter Isotopes Scientists call the isotope that undergoes radioactive decay the parent isotope. The stable form of the element that forms is called the daughter isotope. Recall that carbon has two stable isotopes and one radioactive isotope. Uranium-238 goes through fourteen steps as it decays to a stable isotope of lead. Uranium decay is the process behind nuclear fission and nuclear power.

Half-Life

In 1902, Ernest Rutherford and Frederick Soddy discovered that parent isotopes decay into daughter isotopes at a constant rate. This rate is the decay rate. **Table 2** lists the decay rates of some common radioactive isotopes. To measure decay rates, scientists must compare the amount of parent and daughter isotopes in a material. They then measure the rate at which the radioactive element gives off energy and particles. The time it takes for a sample of a radioactive isotope to decay to half its original mass is called **half-life.** Geologists can determine the absolute age of a piece of the Earth's crust by calculating the absolute age of the minerals that compose it. They do this by measuring the parent-to-daughter ratio of an isotope in the minerals. The method for calculating half-lives and age is illustrated in **Figure 14.**

Reading Check What is the half-life of an isotope?

Table 2 Half-Lives of Selected Radioactive Isotopes

Radioactive Isotope	Approximate Half-Life	Decay Product
Rubidium-87	48.6 billion years	strontium-87
Thorium-232	14.0 billion years	lead-208
Potassium-40	1.3 billion years	argon-40
Uranium-238	4.5 billion years	lead-206
Uranium-235	0.7 billion years	lead-207
Carbon-14	5,730 years	nitrogen-14

Determining Earth's Age

When scientists discovered that radioactive isotopes decay at a constant rate, they knew they had found a "natural clock." Then they turned their attention to the age of Earth. If they could find a way to use this "clock," would they be able determine the age of Earth's oldest rocks?

Radiometric Dating

The procedure that scientists use to calculate absolute ages of rocks and minerals is called radiometric dating. By measuring the amount of parent material and comparing it to the daughter material in a rock, the number of half-lives the material has been through can be counted. Igneous rocks are the most common rocks used for radiometric dating. They usually contain only parent isotopes when they formed. Dates calculated from minerals in igneous rocks indicate when the mineral crystallized from magma.

Determining the age of metamorphic rocks can be difficult. The increase in temperature and pressure during metamorphism can cause a rock to partially melt. When rocks melt, they become igneous and their radiometric clock gets reset. Decay begins again. Geologists rarely use radiometric dating for sedimentary rocks. This is because the dates from sedimentary rocks indicate when the minerals in the rock formed, not when the sedimentary rock itself formed. The lab shown in **Figure 15** is one that does radiometric dating of rocks.

Reading Check Why are igneous rocks most often used in radiometric dating?

SCIENCE USE V. COMMON USE

dating

Science Use to determine the period of time to which something belongs. *Radioactive decay is used in dating rocks billions of years in age.*

Common Use an ongoing romantic social engagement between two people. *Kei and Mai Lin have been dating for two months.*

Figure 15 Radiometric dating is done in a lab using sophisticated equipment.

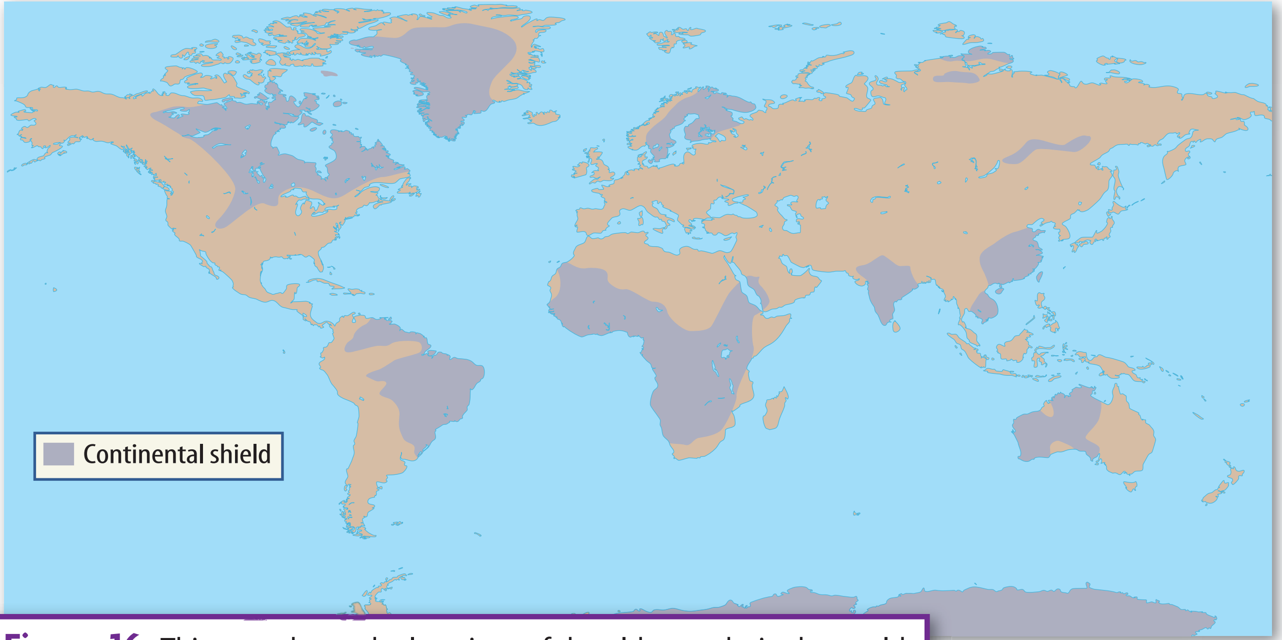


Figure 16 This map shows the locations of the oldest rocks in the world.

Academic Vocabulary
confirm (kun FURM)
(verb) to give approval
It was confirmed by a vote of 9 to 1.

The Absolute Age of Earth

As you have read, Earth's material constantly moves through the rock cycle. Geologists feared this recycling would have destroyed Earth's oldest rocks.

In 1989, scientists made an important discovery. **Figure 16** shows that the oldest rocks on Earth are part of areas called continental shields. Continental shields are areas where exposed rock dates back to Precambrian time—billions of years ago. Grains from sedimentary rock can be dated as if they are an igneous rock sample. The ages reported by different scientists using different isotope pairs ranged between 3.62 and 3.65 billion years. Until 1989, geologists doubted they would find any older rocks from Earth. Then researchers reported a 3.96-billion-year-old age for a zircon grain from a metamorphic rock in Canada.

New technology allowed scientists to date other zircon crystals from rocks in Canada in 1998 and Australia in 2001. The ages they reported were 4.0 and 4.4 billion years.

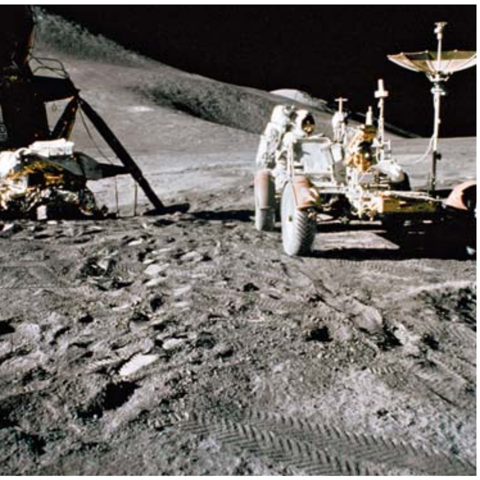


Figure 17 The Moon's surface is covered with broken rock and sediment.

Infer Why do you think the astronaut's footprints are so well preserved?

Meteorites and the Moon Scientists use radiometric dating to determine the age of meteorites and the Moon. The ages of stony meteorites collected in Antarctica have been calculated to be between 4.48 and 4.56 billion years old. As shown in **Figure 17,** the Moon's surface is covered with loose rock material. Rocks brought back from the Moon have been radiometrically dated to be approximately 4.6 billion years old. This closeness of the calculated ages of Earth, the Moon, and meteorites helps to **confirm** the idea that the entire solar system formed at the same time.

Isotopes and Earth's Age

Scientists use radioactive isotopes to measure the percentage of parent to daughter material in a substance. This allows scientists to provide absolute, or numerical ages to the geologic layers and events. Unstable parent isotopes decay into stable daughter isotopes. Measuring the rate at which this occurs provides useful data that can be transformed into a unit called a half-life. Using half-life values of certain isotopes allows scientists to calculate the absolute ages of igneous rocks and some metamorphosed rocks. Earth's age has been calculated to be about 4.55 billion years, the age of its oldest rocks.

In the next chapter you will read how relative and absolute age dating have been used to help explore the history of Earth's life.

LESSON 2 Review

Summarize

Create your own lesson summary as you design a **study web.**

1. **Write** the lesson title, number, and page numbers at the top of a sheet of paper.
2. **Scan** the lesson to find the **red** main headings.
3. **Organize** these headings clockwise on branches around the lesson title.
4. **Review** the information under each **red** heading to design a branch for each **blue** subheading.
5. **List** 2–3 details, key terms, and definitions from each **blue** subheading on branches extending from the main heading branches.

ELA7: W 2.5

Standards Check

Using Vocabulary

1. What process results in the natural breakdown of unstable atoms? 4.d
2. Explain how the terms *isotope* and *half-life* are related. 4.d

Understanding Main Ideas

3. **Determine** the age of a mineral that contains 25 percent of the parent, potassium-40, and 75 percent of the daughter, argon-40. The half-life of potassium-40 is 1.25 billion years. 4.d
4. **Explain** the difference between carbon-12 and carbon-14. 4.d
5. **Construct** a bar graph that demonstrates the decrease in the amount of parent isotope during the first five half-lives. 4.d
6. **Predict** the age of the oldest rocks on Mars. 4.d
7. Fill in the chart with the correct number of protons and neutrons. 4.d

Isotope	Protons	Neutrons
Carbon-12		
Carbon-13		
Carbon-14		

Applying Science

8. **Decide** how to use relative dating and radiometric dating to find and date the oldest rock on a continent. 4.d
9. **Evaluate** the possibility of using radiometric dating methods on a meteorite made of sedimentary rock. 4.d
10. **Explain** how sedimentary rocks are dated. 4.d

Science Online
For more practice, visit **Standards Check** at ca7.msscience.com.

DataLab

00:30 minutes

Try at Home

How long until it's all gone?

Geologists can determine the age of certain types of rock by calculating the amounts of certain radioactive elements in them. You will see how these calculations work as you complete this lab.

- The half-life of uranium-233 is 162,000 years.
- The half-life of plutonium-239 is 24,400 years.
- The half-life of radium-226 is 1,600 years.

Data Collection

1. With a group of two or three classmates, collect 100 pennies. The pennies represent 100 g of one of the elements listed above. Choose one of the elements.
2. Make a data table like the one below.
3. Fill in the data table by repeating these two steps. Divide the amount of pennies in half. Write the number of years that has passed according to the half life of your chosen element.
4. Graph your data.

Data Analysis

1. **Solve** How many half-lives did it take to get to 1 g of your element?
2. **Describe** the shape of your graph.
3. **Interpret data** How accurate can your calculations be once the amount of your element gets below 8 half-lives?

Number of Half-Lives of Element	Number of Pennies Left (equal to mass in grams of substance left over)	Number of Years that Have Passed
0	100	0
1		
2		
3		

Science Content Standards

4.d Students know that evidence from geologic layers and radioactive dating indicates Earth is approximately 4.6 billion years old and that life on this planet has existed for more than 3 billion years.

Also covers: 7.c

MA7: MR 2.5

Applying Math

Measuring Mineral Production in California

4.c

MA7: NS 1.0, AF 1.5

California produces about 8 percent of the minerals produced in the United States each year. The table shows some of the minerals produced in the years 1999, 2000, and 2001.

Mineral Production in California

Mineral	1999 Quantity (short tons)	2000 Quantity (short tons)	2001 Quantity (short tons)
Asbestos	7,900	5,800	5,800
Boron minerals	681,300	602,000	716,600
Cement: masonry	513,800	533,600	521,000
Cement: Portland	11,344,700	12,017,200	11,245,500
Bentonite clay	33,900	23,600	23,700
Common clay	1,017,900	1,067,800	1,068,300
Gypsum	3,561,800	3,534,600	3,197,200
Construction sand and gravel	159,505,300	163,170,000	163,170,000
Industrial sand and gravel	1,972,400	1,992,200	1,934,900
Crushed stone	66,452,100	65,819,200	65,047,500
Dimension stone	32,400	36,700	36,400

Example

What is the total quantity of minerals produced in 2000?

What you know: Each quantity of minerals in the year 2000

What you need to find: The total produced

Add the values in the year 2000 column. 248,802,700 short tons

Answer: The total quantity of minerals produced in 2000 is 248,802,700 short tons.

Practice Problems

1. What percent of the total minerals produced in 2000 is gypsum?
2. What percent of the total minerals produced in 2000 is construction sand and gravel?

Science Online
For more math practice, visit **Math Practice** at ca7.msscience.com.

Design Your Own Lab

Model and Invent: Erosion Stoppers

Materials

- stream table
- textbooks or bricks
- sand
- gravel
- water container
- hose or tubing
- clamps
- bucket
- plant matter
- stone
- water

Safety Precautions

Science Content Standards

4.c Students know that the rock cycle includes the formation of new sediment and rocks and that rocks are often found in layers, with the oldest generally on the bottom.

7.c Communicate the logical connection among hypotheses, science concepts, tests conducted, data collected, and conclusions drawn from the scientific evidence.

7.d Conduct scale models, maps, and appropriately labeled diagrams to communicate scientific knowledge (e.g., motion of Earth's plates and cell structure).

Problem

You have learned that water erodes sandy soil. While there are places where the soil is clearly exposed, in most places, the landscape, such as trees and grass, holds the soil in place.

Form a Hypothesis

What happens when landscape elements are added to a model hillside? Will the water follow a predictable path?

Collect Data and Make Observations

1. Read and complete a lab safety form.
2. Decide how many textbooks or bricks you will use to prop up one end of the stream table. Record the final height.
3. Create a hill with the sand and gravel at one end of the stream table.
4. Record the size of the water container in your setup. Fill it with water and attach tubing.
5. Smooth out the slope. Cover the left half with rows of rocks or plant matter. Leave the other half bare.
6. Pour the water out first on one side, then refill the container and repeat on the other half. Be sure to pour with the same pressure and volume.
7. Draw or photograph the results.
8. Change the height of your stream table and repeat steps 5–7.

CONTENTS

Stream Table Results				
	Trial	Height of Stream Table	Sketch of Covered—Before Water	Sketch of Uncovered—Before Water
First Height	1			
	2			
Second Height	1			
	2			

Analyze and Conclude

1. **Summarize** the differences and similarities between your results in step 6.
2. **Compare and contrast** your drawings or photographs with those from other students. Did everyone get the same results? Consider the other heights your classmates choose and the container volumes that were used.
3. **Describe** how different volumes of water affect erosion.
4. **Explain** how the height of the stream table affects erosion.
5. **Infer** from the data you have collected how landscape elements affect erosion.
6. **Think critically** about what you have learned about erosion. What places are most vulnerable to erosion? What could be done to protect such areas? What places would be least affected by erosion?

Communicate

WRITING in **Science** ELA7: W2.3

Write a brief report that explains how landscape affects erosion. Present your findings to your class.

Real World Science

Science & Career

STUDYING THE ROCKS OF EARTH

Some geologists examine rocks formed in or on Earth's crust, such as sedimentary rocks or metamorphic rocks, and igneous rocks from the Earth's interior. They might cut a very thin slice of rock in a laboratory and examine it with a microscope. They determine the mineralogical and chemical composition of rocks, then deduce the conditions of heat and pressure that caused them to be formed. These geologists are called petrologists and geophysicists.

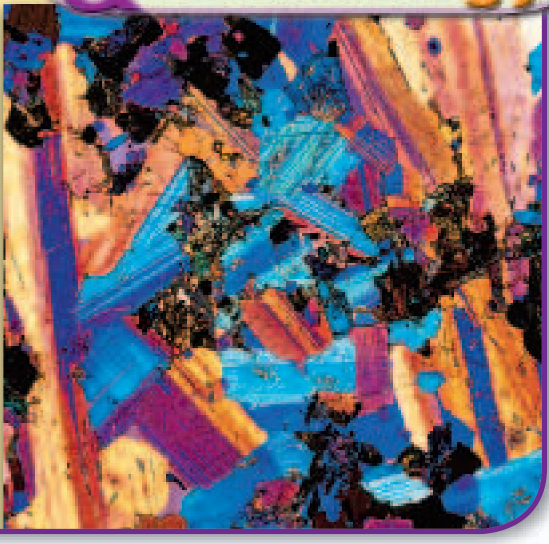
Visit **Careers** at ca7.msscience.com to find out more about how to become a geologist. Why do you think geologists are eager to study the processes involved in creating and changing rock formations?

Science & Technology

It's looking at the small stuff and changing it.

To study rocks at the elemental level, scientists create thin sections. The rock is cut down until it is thin and small enough to see through a microscope. The individual minerals that make up the rock can be seen. Scanning electron microscopes, electron microprobes, and infrared spectrometers are used routinely for study of the experimental samples.

Visit **Technology** at ca7.msscience.com to find out more about spectrometers. Write two paragraphs about how they work and what they are used for.



Science & History

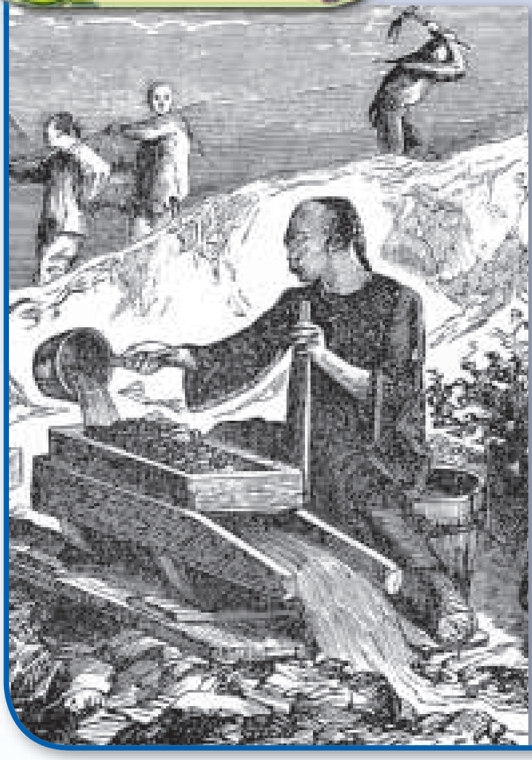
Carving Rocks Through History

Besides being used for building, foraging, and protection, rocks have been used for art through the years. Even before painting cave walls, early humans fashioned shapes from stone. Rocks of many different types have been used for sculpture, including fine marbles used by Michelangelo and compressed volcanic ash used by the ancient inhabitants of Easter Island in the South Pacific. They created these giant sculptures called moai.

Visit **History** at ca7.msscience.com to research several historic works. Select one work and create a brochure. Give the work's history, creator, material, and the material's origin. Use pictures of the work and creator, if possible.

Science & Society

The State Mineral and its History



State legislation signed on April 23, 1965, designated native gold as California's official state mineral. California is ranked fourth in the nation for gold production. In the years 2000–2001 there were 16 significant active gold mines in operation, about half were located in the historic Mother Lode Belt. The California Gold Rush began in 1848 with discovery of gold at Sutter's Mill in Coloma. This started a bonanza that brought California fame and gave it the title of the "Golden State." The Gold Rush of 1849 and the subsequent influx of settlers led to California becoming the thirty-first state in 1850.

Go to **Society** at ca7.msscience.com for more information about the Gold Rush. Divide the class into two groups to represent the Anti-Debris Association (farmers) and the Miners Association. Research the legal activities of both associations and their evidence. Reenact a courtroom scene from the trial that ended with an injunction against the mining companies.

(t)George Holton/Photo Researchers, (b)Bettmann/CORBIS

Standards Study Guide

The BIG Idea Geologists use a variety of methods to estimate and determine the age of Earth.

Lesson 1 Relative Ages of Rocks

4.a, 4.c, 7.d

Main Idea **Geologists can determine the relative ages of rocks by studying the order of rock layers, fossils, and geologic processes that are occurring today.**

- All of Earth's processes are related.
- Uniformitarianism allows scientists to use their observations today to interpret Earth's history.
- The cooling of molten rock forms igneous rocks. Crystal size indicates the rate of cooling.
- Metamorphic rocks form from an increase in temperature and pressure.
- Sedimentary rocks form from pieces of preexisting rock. They are often layered and may contain fossils.
- The processes of weathering, transportation, deposition, and lithification make sedimentary rocks.
- Four principles are used to assign relative ages to rock strata and geologic events. The principle of superposition states that strata at the bottom of a stack of sedimentary rocks are the oldest.
- The principles of original horizontality, original lateral continuity, and cross-cutting relationships are also used to interpret past geologic events.
- Fossils are used to assign relative ages of rocks.

- **clast** (p. 287)
- **lithification** (p. 288)
- **relative age** (p. 289)
- **rock cycle** (p. 286)
- **stratum** (p. 289)
- **superposition** (p. 289)
- **uniformitarianism** (p. 285)

Lesson 2 Absolute Ages of Rocks

4.d, 7.c, 7.d

Main Idea **Unstable parent isotopes change to stable daughter isotopes at a constant rate. Geologists measure the amounts of these isotopes in minerals to determine how long ago the minerals formed.**

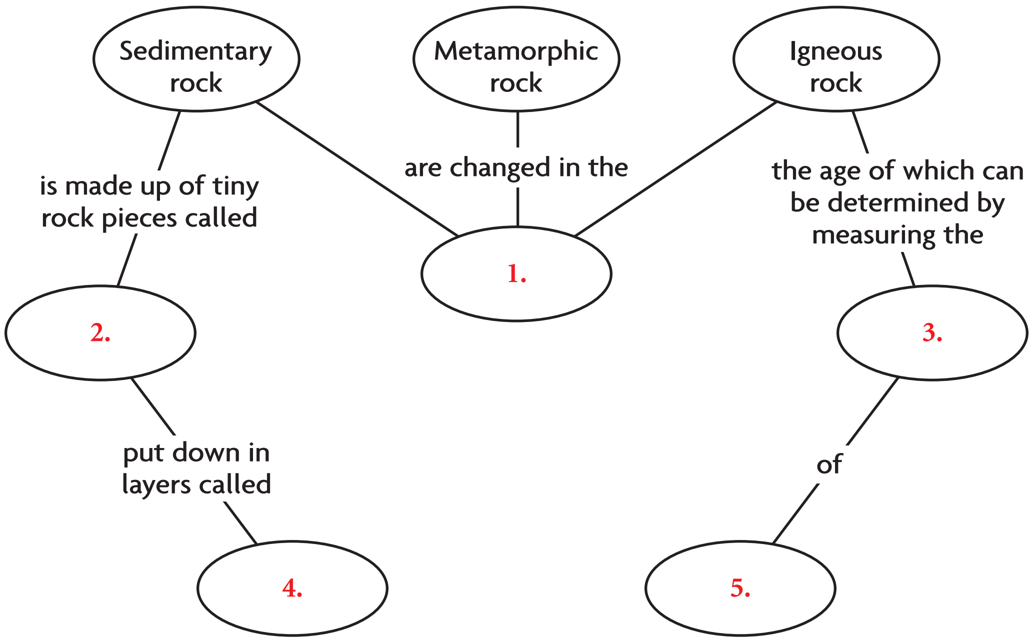
- Radioactive parent isotopes decay into stable daughter isotopes at a constant rate.
- The time it takes for half the amount of the parent isotope to decay into the daughter isotope is called the half-life.
- Using the half-life and the amounts of the parent and daughter isotopes, scientists can determine when a mineral formed.
- The oldest mineral discovered on Earth is 4.4 billion years old.
- The age of the Moon, meteorites, and Earth are calculated to be approximately 4.5 billion years old.

- **half-life** (p. 296)
- **isotope** (p. 294)
- **radioactive decay** (p. 294)

STUDY TO GO Download quizzes, key terms, and flash cards from ca7.msscience.com.

Linking Vocabulary and Main Ideas

Use the vocabulary terms on page 306 to complete the concept map.



Science Online
Visit ca7.msscience.com for:
- Vocabulary PuzzleMaker
- Vocabulary eFlashcards
- Multilingual Glossary

Using Vocabulary

Complete each statement using a term from the vocabulary list.

6. Different ________ of an element have different numbers of neutrons in their nuclei.

7. Layers of rock are called ________.

8. Individual grains of sediment are called ________.

9. The process during which a nucleus gains or loses protons or neutrons is called ________.

10. Watching waves sort sand on a beach and comparing the sand to sandstone is an example of ________.

11. The process that cements grains together to form a rock is called ________.

Standards Review

Understanding Main Ideas

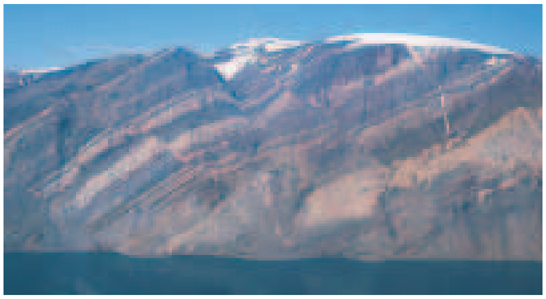
1. The phrase "the present is the key to the past" summarizes which principle?
   A. original time
   B. superposition
   C. unconformities
   D. uniformitarianism
   4.a

2. Why do geologists use the principle of superposition?
   A. to determine the best position to study rocks
   B. to measure the position of continents
   C. to determine the relative ages of rock layers
   D. to predict the position of the plates in the future
   4.a

3. What processes cause metamorphism?
   A. weathering, transportation, and deposition
   B. melting, cooling, and crystallization
   C. erosion, uplift, and nondeposition
   D. pressures, temperatures, and water
   4.a

4. What does the principle of original horizontality state?
   A. Sediments always remain horizontal.
   B. Sediments are always deposited horizontally.
   C. Any sediments that are deposited horizontally will eventually become tilted.
   D. All sediments are deposited in rows.
   4.a

5. Which of Steno's principles explains how we know these rocks were tilted after they were formed?



   A. principle of superposition
   B. principle of original horizontality
   C. principle of original lateral continuity
   D. principle of cross-cutting relationships
   4.a

6. What evidence did James Hutton use to explain that Earth was old?
   A. erosion
   B. glaciers
   C. ocean tides
   D. volcanic eruptions
   4.a

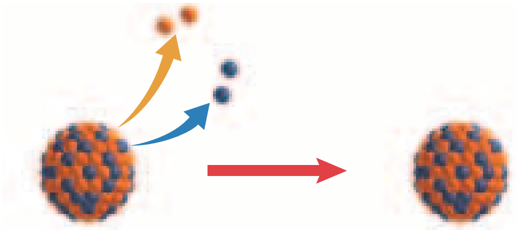
7. Which does not transport sediment?
   A. water
   B. lava
   C. wind
   D. ice
   4.a

8. Which is true about isotopes?
   A. They contain no neutrons.
   B. They have varying numbers of neutrons.
   C. They have very heavy neutrons.
   D. They all have six neutrons.
   4.d

9. How do you identify a daughter isotope?
   A. It forms from the decay of a parent isotope.
   B. It causes parent isotopes to decay.
   C. It is heavier than its parent isotope.
   D. It has two stable forms.
   4.d

10. Which rock types are most commonly used in radiometric dating?
    A. igneous
    B. metamorphic
    C. sedimentary
    D. all three are used
    4.d

11. What process is illustrated below?



    A. daughter-to-parent isotope formation
    B. nuclear fusion
    C. radioactive decay
    D. half-life
    4.d

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Applying Science

12. **Hypothesize** what the crystal size would be in an igneous rock that cooled as soon as the magma reached the surface. 4.a

13. **Describe** how water can provide the cement in sedimentary rocks. 4.a

14. **Determine** the relationship between angular, poorly-sorted sediments and the distance the sediments were transported. 4.c

15. **Construct** a diagram illustrating the concept of half-life. 4.d

16. **Evaluate** the accuracy of a radiometric age date determined from a metamorphic rock. 4.d

17. **Recommend** one of the radioactive isotopes listed below for use in dating an igneous rock estimated to be 1 billion years old. 4.d

Half-Lives of Selected Radioactive Isotopes

Radioactive Isotope	Approximate Half-Life	Decay Product
Rubidium-87	48.6 billion years	strontium-87
Thorium-232	14.0 billion years	lead-208
Potassium-40	1.3 billion years	argon-40
Uranium-238	4.5 billion years	lead-206
Uranium-235	0.7 billion years	lead-207
Carbon-14	5,730 years	nitrogen-14

WRITING in Science

18. **Write** a paragraph explaining the difference in the formation of poorly sorted and well-sorted sediments.

Cumulative Review

19. **Explain** the relationship between fossils and interpreting Earth history. 4.a

20. **Predict** what would happen to a species of birds if the climate in their environment changed very quickly. 4.a

Applying Math

Refer to the table on page 301 to answer questions 21–25.

21. What is the total quantity of minerals produced in 1999? MA7: NS 1.0, AF 1.5

22. What is the total quantity of minerals produced in 2001? MA7: NS 1.0, AF 1.5

23. What percentage of the total minerals produced in 1999 is asbestos? MA7: NS 1.0, AF 1.5

24. What percentage of the total minerals produced in 2000 is asbestos? MA7: NS 1.0, AF 1.5

25. What percentage of the total minerals produced in 1999 is masonry cement? MA7: NS 1.0, AF 1.5

Standards Assessment

1 **Which principle states that the oldest rock layer is found at the bottom in an undisturbed stack of rock layers?** 4.d

- **A** half-life
- **B** absolute dating
- **C** superposition
- **D** uniformitarianism

2 **Which term means matching up rock layers in different places?** 4.a

- **A** superposition
- **B** correlation
- **C** uniformitarianism
- **D** absolute dating

3 **Which isotope is useful for dating wood and charcoal that is less than about 75,000 years old?** 4.d

- **A** carbon-14
- **B** potassium-40
- **C** uranium-238
- **D** argon-40

4 **A substance at 1 half-life has 50 percent of a parent isotope remaining. What percentage of the parent isotope remains at 2 half-lives?** 4.d

- **A** 6.25 percent
- **B** 25 percent
- **C** 3.125 percent
- **D** 1.07 percent

5 **Which principle states that the same processes at work in Earth's past are still at work today?** 4.a

- **A** deposition
- **B** superposition
- **C** unconformity
- **D** uniformitarianism

The table below shows the percent remaining parent isotope per half-life of a radioisotope. Use the table to answer questions 6 and 7.

Number of Half-Lives	Parent Isotope Remaining (%)
1	100
2	X
3	25
4	12.5
5	Y

6 **Which percentage replaces the letter X?** 4.d

- **A** 40
- **B** 50
- **C** 6205
- **D** 75

7 **Which percentage replaces the letter Y in the table above?** 4.d

- **A** 0
- **B** 2.5
- **C** 3.13
- **D** 6.25

8 **While fossil hunting, Ana found fossils of three different types of trilobites in three different rock layers. She sketched the fossils she found in each layer. What principle is represented by the fossils Ana found?**

4.c

- **A** All animals that lived in an ancient sea looked like trilobites.
- **B** Fossils provide a record of all organisms that have lived on Earth.
- **C** Trilobites that lived in the ocean became extinct millions of years ago.
- **D** Evidence that animals have changed over time is found in the fossil record.

9 **Which type of scientist studies fossils?**

4.a

- **A** paleontologist
- **B** meteorologist
- **C** chemist
- **D** astronomer

10 **Which of the following is an igneous rock characteristic?**

4.c

- **A** made of sediments
- **B** changed by pressure
- **C** found in layers
- **D** came from magma

11 **Sedimentary rocks are formed by what process?**

4.c

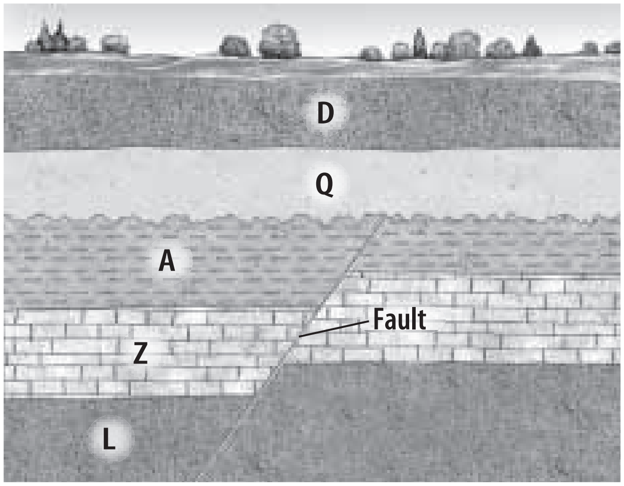
- **A** cementation
- **B** deposition
- **C** weathering
- **D** lithification

12 **Which step of sedimentary rock formation results in sorted clasts?**

4.c

- **A** weathering
- **B** transportation
- **C** deposition
- **D** lithification

Use the illustration below to answer questions 13 and 14.



13 **Which sequence of letters describes the rock layers in the diagram from oldest to youngest?**

4.a

- **A** D, Q, A, Z, L
- **B** L, Z, A, Q, D
- **C** Z, L, A, D, Q
- **D** Q, D, L, Z, A

14 **Which correctly describes the relative age of the fault?**

4.a

- **A** younger than A, but older than Q
- **B** younger than Z, but older than L
- **C** younger than Q, but older than A
- **D** younger than D, but older than Q