1 FOCUS

Section Objectives

12.1 **Explain** how rocks allow geologists to interpret Earth's history.

12.2 **Recognize** how uniformitarianism helps explain Earth's features.

12.3 **List** the key principles of relative dating and **describe** how geologists use relative dating in their work.

12.4 **Describe** the importance of unconformities in unraveling Earth's history.

Reading Focus

Build Vocabulary L2

Word Forms Point out that the word *uniform* is closely tied to this section's vocabulary term *uniformitarianism*. Ask students to state the meaning of *uniform* in their own words. *(Sample answer: always the same)* Tell them that the meaning of *uniform* can help them to remember the meaning of *uniformitarianism*, which refers to processes that have operated in a similar manner throughout Earth's history.

Reading Strategy L2

Sample answers: **a.** rock record; **b.** clues to geological events and changing life forms; **c.** uniformitarianism; **d.** today's processes mimic those of the past; **e.** relative dating; **f.** the relative order of events

2 INSTRUCT

Rocks Record Earth History

Build Science Skills L2

Using Analogies Have students create analogies that describe the following key concept: "Rocks record geological events and changing life forms of the past." A sample analogy might be that rocks are like a long and complicated well-worn novel. Even though some of the pages might be missing or torn, enough of the book remains for the story to be understood.
Verbal

12.1 Discovering Earth's History

Reading Focus

Key Concepts

- How do rocks allow geologists to interpret Earth's history?
- How does uniformitarianism help explain Earth's features?
- How do geologists use relative dating in their work?
- What are the key principles of relative dating?
- What do unconformities represent?

Vocabulary

- uniformitarianism
- relative dating
- law of superposition
- principle of original horizontality
- principle of cross-cutting relationships
- unconformity
- correlation

Reading Strategy

Identifying Main Ideas Copy and expand the table below. As you read, fill in the first column with a main idea and add details that support it in the second column.

Main Idea	Details
1. a. ?	b. ?
2. c. ?	d. ?
3. e. ?	f. ?


A

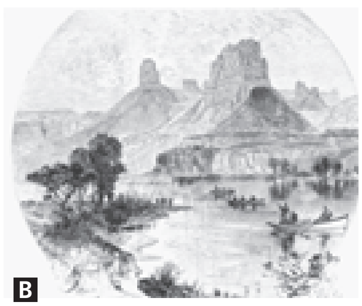
B

Figure 1 Exploring the Grand Canyon A John Wesley Powell, pioneering geologist and the second director of the U.S. Geological Survey. **B** Start of the expedition from Green River station.

In the 18th and 19th centuries, scientists recognized that Earth had a very long history and that Earth's physical features must have taken a long time to form. But they had no way of knowing Earth's true age. A geologic time scale was developed that showed the sequence, or order, of events based on several principles of relative dating. What are these principles? What part do fossils play? In this chapter you will learn the answers to these questions.

Rocks Record Earth History

In 1869, Major John Wesley Powell, shown in Figure 1A, led an expedition down the Colorado River and through the Grand Canyon, shown in Figure 1B. Powell realized that the evidence for an ancient Earth was concealed in its rocks. Powell was impressed with the record of Earth's history contained in the rocks exposed along the walls of the Grand Canyon.

Rocks record geological events and changing life forms of the past. Erosion has removed a lot of Earth's rock record but enough of it remains to allow much of the story to be studied and interpreted.

Geological events by themselves, however, have little meaning until they are put into a time perspective. The geologic time scale revolutionized the way people think about time and how they perceive our planet. **We have learned that Earth is much older than anyone had previously imagined and that its surface and interior have been changed by the same geological processes that continue today.**

A Brief History of Geology

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

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

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

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

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

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

Relative Dating—Key Principles

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

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

Customize for English Language Learners

Use a cloze strategy to extract information from the text about the key principles of relative time. For example, after reading pp. 336–337, have ELL students fill in the blanks in the following paragraph: **Rocks record _______ events and changing _______ of the past. Uniformitarianism means that the _______ and processes that operate _______ have been at work for a very long time.** *(geological, life forms, forces, today)* Use student answers to pinpoint misunderstandings and clarify key concepts.

A Brief History of Geology

Use Community Resources L2

Arrange for students to visit a local museum or historical society to view artifacts that relate to important events in your community's geologic history.
Kinesthetic

Relative Dating—Key Principles

Address Misconceptions L2

As students read about the law of superposition, make sure they clearly distinguish between theories and laws. Some students mistakenly think that when theories gain enough supporting evidence, they automatically become laws. In reality, a theory never becomes a law. A scientific law simply describes the behavior of an event or process in nature. A theory attempts to explain this behavior.
Verbal

Answer to . . .

Reading Checkpoint *The same laws that operated in the past still operate today.*

Use Visuals L1

Figure 2 Have students state the law of superposition in their own words. *(Unless layers of sedimentary rock are disturbed, the oldest rocks will be on the bottom. The rocks get younger from bottom to top.)* Then have students sequence the layers of rock from oldest to youngest. *(Supai Group, Hermit Shale, Coconino Sandstone, Toroweap Formation, Kaibab Limestone)*
Visual

Build Reading Literacy L1

Refer to the Build Reading Literacy strategy for **Chapter 1**, which provides the guidelines for an anticipation guide.

Anticipation Guide Before students read about the principle of cross-cutting relationships and unconformities, have them review the law of superposition. Point out that this law only pertains to an undisturbed sequence of sedimentary rocks. Ask: **What might happen if the rocks were disturbed?** *(Sample answer: The youngest rocks might not necessarily be on top.)* Have students read the text on pp. 339–342 to see if their predictions were correct.
Verbal, Logical

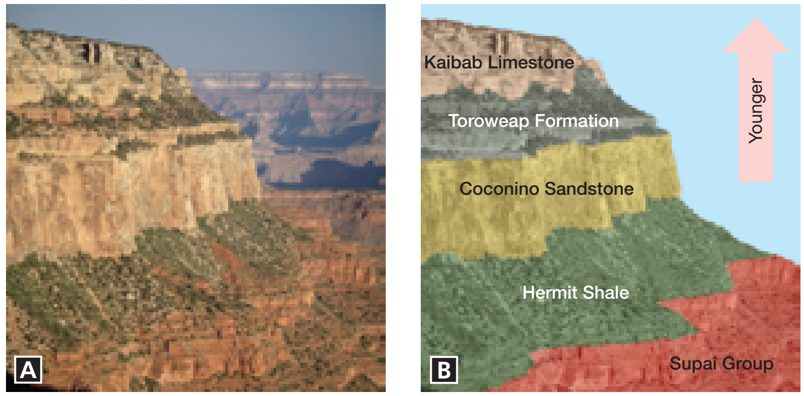

Figure 2 Ordering the Grand Canyon's History The law of superposition can be applied to the layers exposed in the Grand Canyon. **Interpreting Illustrations** *Which layer is the oldest? youngest?*

Law of Superposition Nicolaus Steno, a Danish anatomist, geologist, and priest (1636–1686), is credited with describing a set of geologic observations that are the basis of relative dating. The first observation is the **law of superposition.** **The law of superposition states that in an undeformed sequence of sedimentary rocks, each bed is older than the one above it and younger than the one below it.** Although it may seem obvious that a rock layer could not be deposited unless it had something older beneath it for support, it was not until 1669 that Steno stated the principle. This rule also applies to other surface-deposited materials, such as lava flows and beds of ash from volcanic eruptions. Applying the law of superposition to the beds exposed in the upper portion of the Grand Canyon, shown in Figure 2, you can easily place the layers in their proper order.

Figure 3 Disturbed Rock Layers Rock layers that are folded or tilted must have been moved into that position by crustal disturbances after their deposition. These folded layers are exposed in the Namib Desert (southwestern Africa).

Principle of Original Horizontality

Another of Steno's observations is called the **principle of original horizontality.** **The principle of original horizontality means that layers of sediment are generally deposited in a horizontal position.** If you see rock layers that are flat, it means they haven't been disturbed and they still are in their original horizontal position. The layers in the Grand Canyon shown on pages 334–335 and in Figure 2 clearly demonstrate this. However, the rock layers shown in Figure 3 have been tilted and bent. This tilting means they must have been moved into this position sometime after their deposition.

Reading Checkpoint *To what rock type can the law of superposition and the principle of original horizontality be best applied?*

Facts and Figures

The work of Swiss scientist Louis Agassiz provides an excellent example of the application of the principle of uniformitarianism. In 1821, Agassiz heard another scientist present a paper stating that glacial features occurred in places that were far from existing glaciers in the Alps. The hypothesis implied that these glaciers had once been much larger in size. Agassiz doubted the hypothesis and set out to prove it wrong. Ironically, he was the one who was wrong. In the Alps, Agassiz found the same unique deposits and features that could be seen forming with active glaciers far beyond the limits of the ice in the Alps. Subsequent work led Agassiz to hypothesize that a great ice age had occurred in response to a period of worldwide climate change. Agassiz's ideas eventually developed into our present-day glacial theory.

Principle of Cross-Cutting Relationships

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

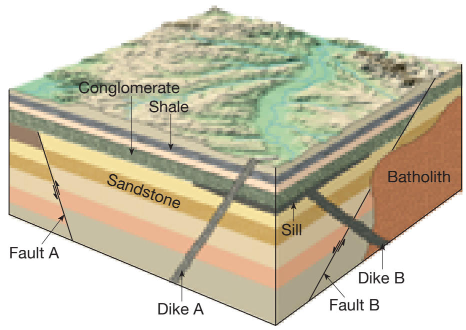

Figure 4 Applying Steno's Principles Cross-cutting relationships are an important principle used in relative dating. An intrusive rock body is younger than the rocks it intrudes. A fault is younger than the rock layers it cuts.
Interpreting Diagrams ***What is the age relationship between the batholith,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

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

Formation of Inclusions

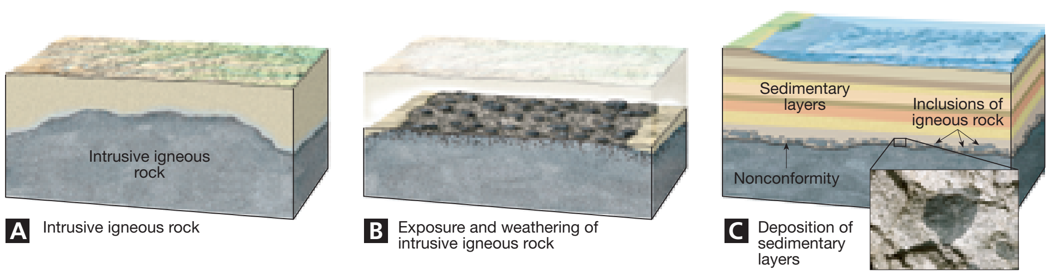

Figure 5 A A mass of igneous rock formed from magma that intruded an older rock body. **B** The older rock erodes and exposes the igneous rock to weathering. **C** Sedimentary rock layers form on top of the weathered igneous rock.

Teacher Demo

Cross-Cutting Relationships L2

Purpose Students will observe how cross-cutting relationships can be used in relative dating.

Materials wooden stick, piece of foam

Procedure To represent a dike, insert a wooden stick into a corner of the foam from underneath. Then break off that corner and realign the pieces so that the foam and stick are close to their original positions. Ask students to explain what each element represents, and the relative ages of those elements.

Expected Outcomes Students will recognize that the foam represents the oldest layer of rock. The wooden stick represents a younger intrusion. The broken foam represents a fault; it is the youngest element.
Visual

Answer to . . .

Figure 2 *The oldest layer is the Supai Group. The youngest layer is the Kaibab Limestone.*

Figure 4 *The batholith is oldest. The sill and dike B are the same unit. Dike A is the youngest.*

Reading Checkpoint *undisturbed sedimentary rocks*

Geologic Time 339

Build Reading Literacy L1

Refer to **p. 530D** in **Chapter 19,** which provides the guidelines for making inferences.

Make Inferences Have students draw on their prior knowledge to infer why sedimentary rocks in particular help scientists learn about Earth's past. Ask: **How would heat, pressure, and melting affect fossils?** *(They would destroy fossils.)* **What type of rock likely contains most fossils? Explain your answer.** *(Sedimentary rock likely contains most fossils because it has not been affected by melting, heat, or pressure.)*
Verbal, Logical

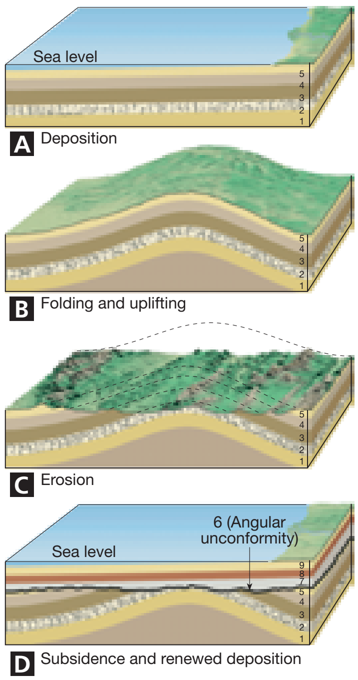

Figure 6 Formation of an Angular Conformity An angular unconformity represents an extended period during which deformation and erosion occurred.

Unconformities Casual observation of layers of rock may look like they represent a complete geologic history of an area. However, no place on Earth is geologically complete. Throughout Earth's history, the deposition of sediment has been interrupted again and again. All such breaks in the rock record are termed **unconformities.** **An unconformity represents a long period during which deposition stopped, erosion removed previously formed rocks, and then deposition resumed.** In each case uplift and erosion are followed by subsidence and renewed sedimentation, as shown in Figure 6. Unconformities are important features because they represent significant geologic events in Earth history. Moreover, their recognition helps us identify what intervals of time are not represented in the rock record.

A geologic cross section of the Grand Canyon is shown in Figure 7. It shows the three basic types of unconformities: angular unconformities, disconformities, and nonconformities. Perhaps the most easily recognized unconformity is an angular unconformity. It appears as tilted or folded sedimentary rocks that are overlain by younger, more flat-lying strata. **An angular unconformity indicates that during the pause in deposition, a period of deformation (folding or tilting) and erosion occurred.**

Two sedimentary rock layers that are separated by an erosional surface are called a disconformity. Disconformities are more common than angular unconformities, but they are more difficult to recognize. The third basic type of unconformity is a nonconformity. Nonconformities mean the erosional surface separates older metamorphic or intrusive igneous rocks from younger sedimentary rocks.

Reading Checkpoint *What are the three basic types of unconformities?*

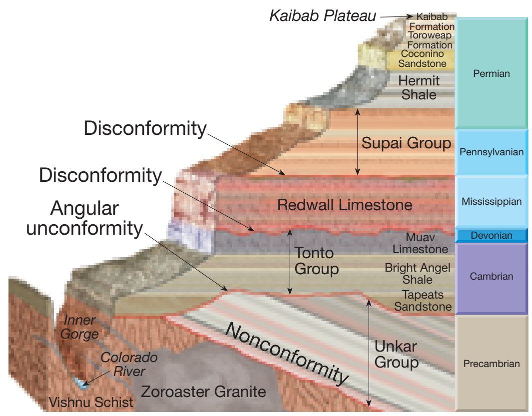

Figure 7 A Record of Uplift, Erosion, and Deposition This cross section through the Grand Canyon illustrates the three basic types of unconformities.

Facts and Figures

Although Earth processes vary in intensity, they still take a very long time to create or destroy major landscape features. For example, geologists have established that mountains once existed in portions of present-day Minnesota, Wisconsin, and Michigan. Today the region consists of low hills and plains. Erosion gradually wore down these peaks. Scientists estimate that the North American continent is eroding at a rate of about 3 cm every 1000 years.

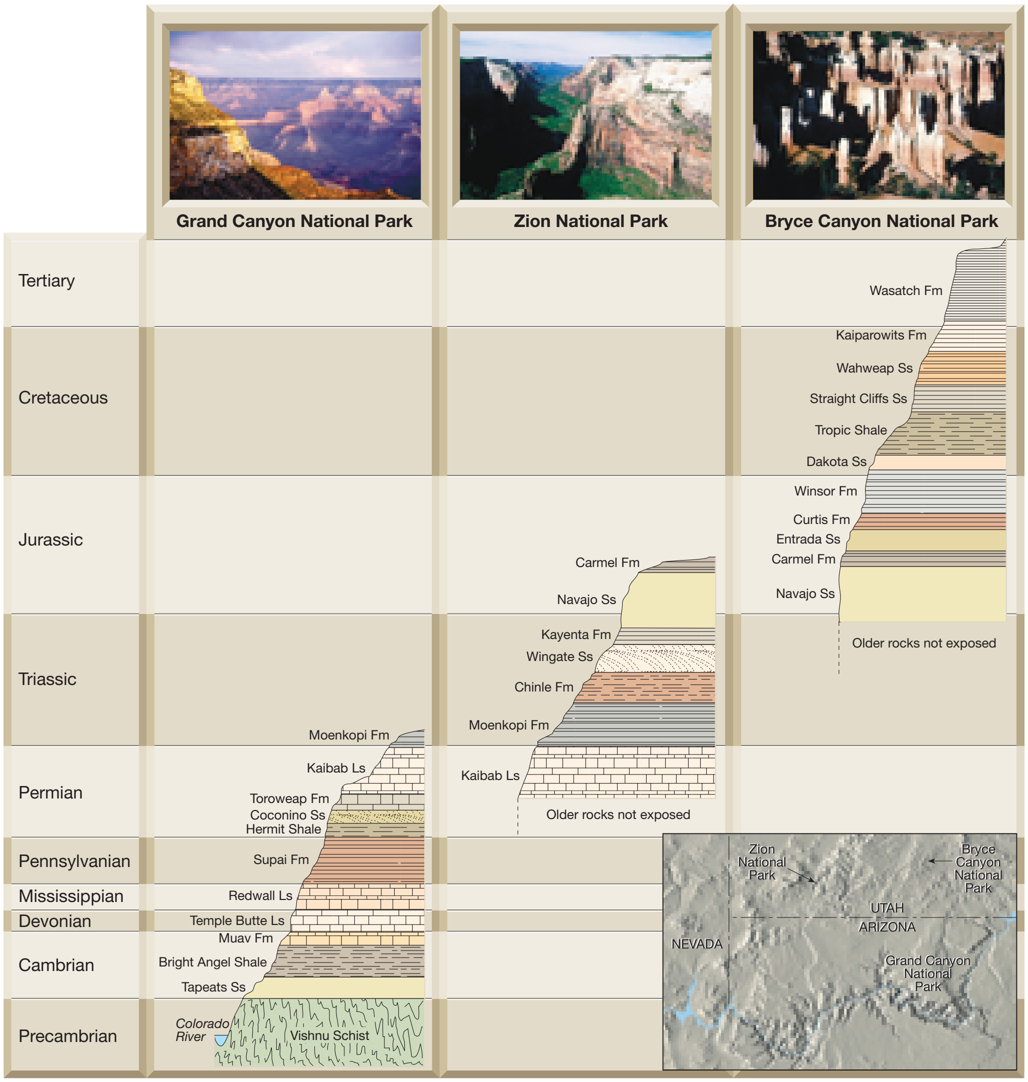

Figure 8 Correlation of strata at three locations on the Colorado Plateau reveals a more complete view of the extent of sedimentary rocks in the region.

Use Visuals L1

Figure 8 To fully understand this diagram, which includes geologic subdivisions, students will need to examine a copy of the geologic time scale. Either obtain a copy or refer students to Figure 17 on p. 353. Ask: **Which site has the oldest exposed rocks?** *(Grand Canyon National Park)*
Visual

Build Science Skills L2

Making Judgments Build on prior knowledge to ensure that students understand the concept of relative dating. Ask: **If you were told that a person has an older sister and a younger brother, what can you determine about their ages?** *(You can determine the relative ages of the three siblings. You would need additional information, however, to determine the actual ages.)*
Logical

Answer to . . .

Reading Checkpoint *angular unconformity, disconformity, and nonconformity*

Section 12.1 (continued)

Correlation of Rock Layers

Build Science Skills L2

Applying Concepts Review Steno's principles. Then ask: **Why must the rock layers be undisturbed in order to apply them?** *(Sample answer: Tectonism can cause entire sequences of rock to be overturned, in which case the oldest layers would be on the top.)*
Logical

3 ASSESS

Evaluate Understanding L2

Have students use clay to model the three basic types of unconformities.

Reteach L1

Have students summarize how our views of Earth's age have changed over time. *(People once believed that Earth was only a few thousand years old. We now know that Earth is 4.6 billion years old.)*

Writing in Science

A sample paragraph might use the law of superposition to describe the layers from bottom to top; the principle of original horizontality to describe the rock layers on either side of the canyon and how they match up; and the principle of cross-cutting relationships to explain the relative ages of the dikes toward the bottom of the canyon.

Go Online NSTA SciLinks

Download a worksheet on relative dating for students to complete, and find additional teacher support from NSTA SciLinks.

Correlation of Rock Layers

To develop a geologic time scale that can be applied to the entire Earth, rocks of similar age in different regions must be matched up. This task is called **correlation.**

Within a small area, you can correlate the rocks of one locality with those of another by simply walking along the outcropping edges. However, this might not be possible when the rocks are covered by soil and vegetation. You can correct this problem by noting the position of a distinctive rock layer in a sequence of strata. Or, you might be able to identify a rock layer in another location if it is composed of very distinctive or uncommon minerals.

By correlating the rocks from one place to another, it is possible to create a more complete view of the geologic history of a region. Figure 8 on page 341, for example, shows the correlation of strata at three sites on the Colorado Plateau in southern Utah and northern Arizona. No single location contains the entire sequence. But correlation reveals a more complete picture of the sedimentary rock record.

The methods just described are used to trace a rock formation over a relatively short distance. But they are not adequate for matching rocks that are separated by great distances. The use of fossils comes in to play when trying to correlate rocks separated by great distances.

Go Online SCI LINKS NSTA

For: Links on relative dating
Visit: www.SciLinks.org
Web Code: cjn-4122

Section 12.1 Assessment

Reviewing Concepts

1. What information do rocks provide to geologists?
2. What does uniformitarianism tell us about processes at work on Earth's surface today?
3. How can relative dating be used in geology?
4. List and briefly describe Steno's principles.
5. What is an unconformity?
6. What is the name of the process in which rock layers in different regions are matched?

Critical Thinking

7. **Applying Concepts** How did the acceptance of uniformitarianism change the way scientists viewed Earth?
8. **Comparing and Contrasting** How does Archbishop Ussher's work compare to that of James Hutton? What did each do to back up their ideas?
9. **Summarizing** What features would you look for to correlate rocks from one area to another?

Writing in Science

Descriptive Paragraph Imagine that you are hiking down into the Grand Canyon. Use some of Steno's principles to write a paragraph describing what you see, how old it all is, and how it was deposited.

Section 12.1 Assessment

1. They provide information about geological events and changing life forms of the past.
2. The processes also operated in the geologic past.
3. It helps to identify the order of events, such as which rock layer was deposited first.
4. The law of superposition states that in a sequence of undisturbed rock layers, the oldest layer is on the bottom; the upper layers are progressively younger. The principle of original horizontality states that sedimentary rocks are generally deposited horizontally. The principle of cross-cutting relationships states that features such as faults and intrusions are younger than the features they cut across.
5. a break in the rock record
6. correlation
7. They learned that Earth was very old, that Earth's landscape is always changing, and that the processes they observed had also been at work in the past.
8. Ussher made a timeline of human history and Earth history. He did not consider Earth's physical features. Hutton's ideas came from direct observations of Earth and Earth processes.
9. same rock type, distinctive layers, uncommon minerals, specific fossils