Section 12.1

1 FOCUS

Section Objectives

12.1 **List** three main ideas that geologists use in studying Earth's history.

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

12.3 **Describe** how geologists use inclusions, unconformities, and correlation of rock layers to interpret the rock record.

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.** Earth's age; **f.** Earth is very old and has changed over time.

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

- What are three main ideas of the science of geology?
- What are the key principles of relative dating?
- How do geologists interpret the rock record?

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. ?

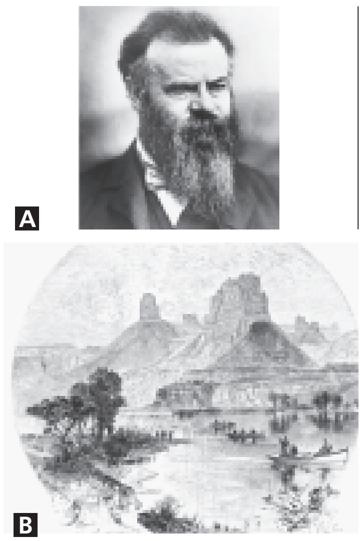


Figure 1 Exploring the Grand Canyon A John Wesley Powell, pioneering geologist and the second director of the U.S. Geological Survey **B** Start of the expedition from Green River station

In 1869, Major John Wesley Powell led a scientific expedition down the Colorado River and through the Grand Canyon. Powell and his crew traveled by boat through the canyon. They marveled at the canyon's huge walls made up of colorful sedimentary rocks. A veteran of the Civil War, Powell was also a geologist. To him, the walls of the Grand Canyon provided evidence of Earth's long history.

Before the 1800s, most scientists thought that Earth was only a few thousand years old. By John Wesley Powell's time, developments in the science of geology had led many scientists to change their ideas about Earth's age and history. Geologic time grew from thousands to many millions of years.

Studying Earth's History

For John Wesley Powell, and for geologists today, one goal of geology is to interpret Earth's history. Geologists do this by studying the rocks of the crust–especially sedimentary rocks. Together, these rocks make up the rock record of Earth's past. **In studying Earth's history, geologists make use of three main ideas:**

- **the rock record provides evidence of geological events and life forms of the past;**
- **processes observed on Earth in the present also acted in the past;**
- **Earth is very old and has changed over geologic time.**

Facts and Figures

Horizontality The fact that sediments appear on land as broad horizontal layers may seem puzzling. After all, sedimentary rocks are mostly made at shorelines. The shore sand becomes sandstone, reefs become limestone, and mud becomes shale. However, because sea level goes up and down significantly with changes in climate (as ice caps freeze and then melt) and the continents are mostly low and flat, shorelines go back and forth great distances. For instance, the fact that the many different sedimentary layers shown in Figure 8 reach from the Grand Canyon in Arizona to the canyons of Utah means that the ocean shoreline passed back and forth over these locations many, many times.

Scientists in Europe and the British Isles began to develop these ideas during the 1700s, as they observed the landscapes around them. They wondered about the processes that formed mountains and the rock beneath the land surface. They noticed that sedimentary rocks were laid down in layers, and thought about how much time it must have taken for these layers to form.

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 *What is uniformitarianism?*

Relative Dating—Key Principles

During the 1800s, the geologists that followed William Hutton worked to interpret Earth's rock record. By studying layers of rock exposed at the surface, they inferred the order in which the layers had formed. The method that geologists used to place rocks in chronological order is called **relative dating**. Relative dating identifies which rock units formed first, second, third, and so on.

In relative dating, geologists follow several principles: the law of superposition, the principle of original horizontality, and the principle of cross-cutting relationships. These principles help geologists determine the sequence in which events occurred, but not how long ago they occurred.

Go Online SCI LINKS NSTA

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

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

Go Online NSTA SCI LINKS

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

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.

Answer to . . .

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

Section 12.1 (continued)

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. 339–341 to see if their predictions were correct.
Verbal, Logical

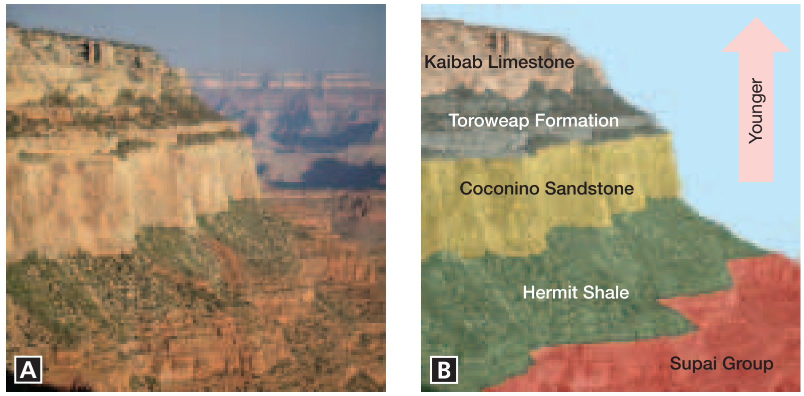


Figure 2 Ordering the Grand Canyon's History The law of superposition can be applied to the layers exposed in the Grand Canyon. **Interpreting Illustrations** *Which layer is the oldest? The youngest?*

Law of Superposition Nicolaus Steno, a Danish anatomist, geologist, and priest (1636–1686), made observations that are the basis of relative dating. Based on his observations, Steno developed the **law of superposition.** The law of superposition states that in an undeformed sequence of sedimentary rocks, each layer 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 layers of ash from volcanic eruptions. Applying the law of superposition to the layers 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 Steno also developed the **principle of original horizontality.** The principle of original horizontality states 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 are still 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

Later geologists developed another principle used in relative dating. The **principle of cross-cutting relationships** states that when a fault cuts through rock layers, or when magma intrudes other rocks and hardens, then the fault or intrusion is younger than the rocks around it. 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 surrounding layers, the faults and dikes must have formed after those layers were deposited.

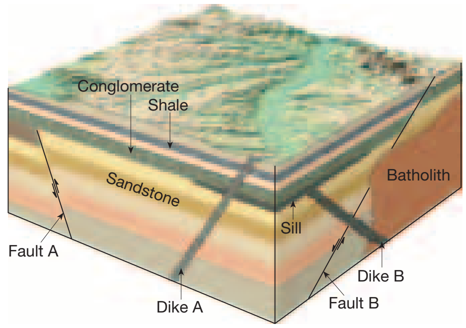


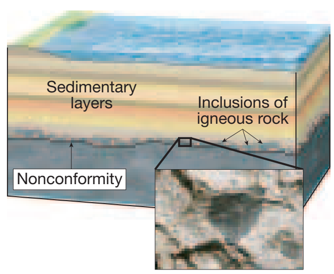
Figure 4 Cross-cutting Relationships An intrusive rock body is younger than the rocks it intrudes. A fault is younger than the rock layers it cuts. **Interpreting Diagrams** ***What are the relative ages of the batholith, dike B, dike A, and the sill?***

Reading the Rock Record

As they apply Steno's principles, geologists interpret, or "read," other geologic features to reconstruct Earth's history. Geologists also determine how the rocks in one area are related to similar rocks in other places. **Methods that geologists use to interpret the rock record include the study of inclusions and unconformities. Geologists also correlate rock layers at different locations.** By studying rocks from many different places worldwide, geologists can construct a model of the rock record. Such a model is called a *geologic column*. It is made up of rocks arranged according to their relative ages. The oldest rocks are at the bottom of the column, while the youngest rocks are at the top.

Inclusions Sometimes the study of 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 5 shows inclusions of igneous rock within a layer of sedimentary rock. How did the inclusions get there? The inclusions indicate that the sedimentary layer was deposited on top of a 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 hardened, because the igneous rock shows signs of weathering.

Figure 5 Inclusions Inclusions made of older igneous rock can be found within younger sedimentary rock layers 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

Facts and Figures

Hutton's Unconformity James Hutton got some of his ideas about Uniformitarianism from looking at an angular unconformity at Jedburgh, Scotland. He noticed that the underlying layers were tilted and eroded, and reconstructed the geologic history from them. Old sedimentary rock must have been made from shorelines advancing back and forth over the land many times, stacking up the sediments. The land was then lifted, rotated, eroded, and put back under water to receive more sediments that became the horizontal sedimentary rocks on top of the unconformity. Now the land is above water again, and eroding back down to the depth of the unconformity. Hutton surmised that this cyclic process of erosion and deposition had gone on countless times before, and would continue to do so in the future.

Answers 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*

Section 12.1 (continued)

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

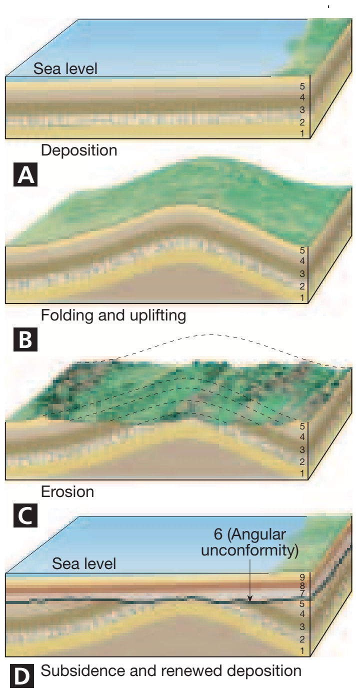


Figure 6 Formation of an Angular Unconformity An angular unconformity, (labeled as "6" in the diagram above) represents an extended period during which deformation and erosion occurred. The numbers show the sequence of geologic events.

Unconformities Throughout Earth's history, the deposition of sediment has been interrupted again and again. Nowhere is Earth's rock record complete. A surface that represents a break in the rock record is termed an **unconformity**. An unconformity indicates a long period during which deposition stopped, erosion removed previously formed rocks, and then deposition resumed. Unconformities help geologists identify what intervals of time are not represented in the rock record. There are three basic types of unconformities: angular unconformities, disconformities, and nonconformities.

In an angular unconformity, layers of sedimentary rock form over older sedimentary rock layers that are tilted or folded. Figure 6 shows the process that produces an angular unconformity.

In a disconformity, two sedimentary rock layers are separated by an erosional surface. Because the rocks on both sides of the unconformity are of the same type, disconformities can be difficult to recognize. Figure 7 shows disconformities in the Grand Canyon.

In a nonconformity, an erosional surface separates older metamorphic or igneous rocks from younger sedimentary rocks. Figure 7 shows a nonconformity in the Grand Canyon.

Correlating Rock Layers Interpreting unconformities helps geologists read the rock record in one location. Geologists use **correlation** to match rocks of similar age in different locations. Geologists often correlate layers by noting the position of a distinctive rock layer in a sequence of layers. They may find the distinctive layer in another location. If they do, then they can infer that the same layer once covered both locations.

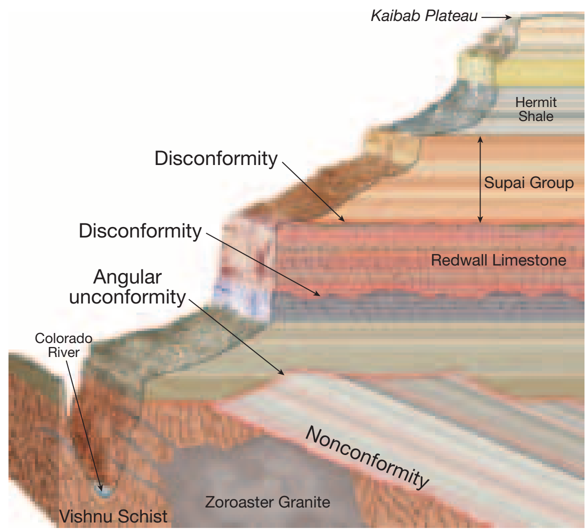


Figure 7 Unconformities in the Grand Canyon This cross section through the Grand Canyon illustrates the three basic types of unconformities.

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.

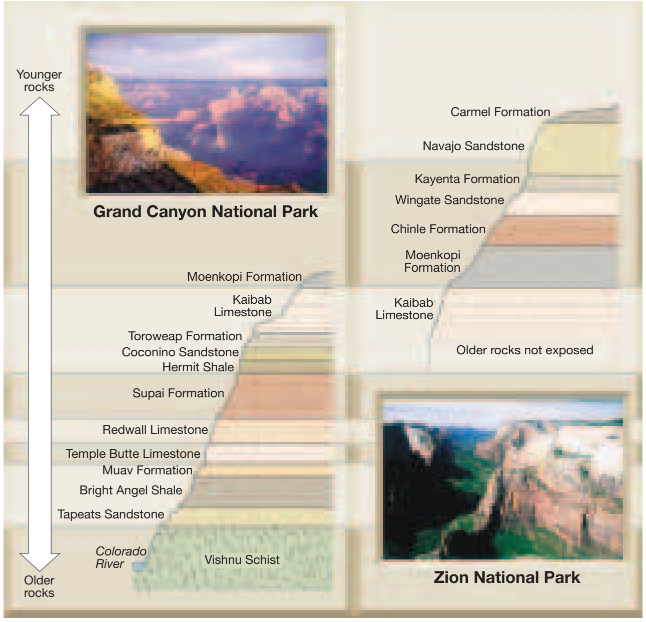


Figure 8 Correlation of rock layers at two locations on the Colorado Plateau: the Grand Canyon and Zion National Park. **Interpreting Diagrams** *Which rock layers are found in both canyons?*

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, for example, shows the correlation of strata at two 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.

Section 12.1 Assessment

Reviewing Concepts

1. List three main ideas of the science of geology.
2. List and briefly describe Steno's principles.
3. In your own words, write definitions of inclusion, unconformity, and correlation.
4. What is the geologic column?

Critical Thinking

5. **Applying Concepts** How did the acceptance of uniformitarianism change the way scientists viewed Earth?
6. **Inferring** What can you infer about the age of sedimentary rock layers relative to the age of a sill intruded into those layers?
7. **Classifying** A geologist finds layers of sedimentary rocks immediately above an eroded anticline. What type of unconformity is this? Explain.
8. **Relating Cause and Effect** Why is the rock record for any given location on Earth incomplete?

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.

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: Folding 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.

Answer to . . .

Figure 8 *The Moenkopi formation and Kaibab limestone are exposed in both canyons.*

Section 12.1 Assessment

1. The rock record provides evidence of Earth's history; processes at work today were also at work in the past; Earth is very old and has changed over time.
2. 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.
3. Inclusion: piece of one kind of rock contained in another rock; unconformity: surface that represents a break in the rock record; correlation: way of determining that two separated rock units are the same
4. All the rocks in the rock record arranged in order of relative age
5. 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.
6. The sedimentary rock layers are older than the sill.
7. It is an angular unconformity because sedimentary rock layers overlie the eroded surface of tilted sedimentary layers in the anticline.
8. Because erosion leads to the formation of unconformities representing breaks in the rock record