9.1 Creating a Time Scale: Relative Dating Principles

Distinguish between numerical and relative dating and apply relative dating principles to determine a time sequence of geologic events.

Figure 9.1 shows a hiker resting atop the Permian-age Kaibab Formation at Cape Royal, on the Grand Canyon's North Rim. Beneath him are thousands of meters of sedimentary strata that go as far back as Cambrian time, more than 540 million years ago. These strata rest atop even older sedimentary, metamorphic, and igneous rocks from a span known as the Precambrian. Some of these rocks are 2 billion years old. Although the Grand Canyon's rock record has numerous interruptions, the rocks beneath the hiker contain clues to great spans of Earth history.

The Importance of a Time Scale

Like the pages in a long and complicated history book, rocks record the geologic events and changing life-forms of the past. The book, however, is not complete. Many pages, especially in the early chapters, are missing. Others are tattered, torn, or smudged. Yet enough of the book remains to allow much of the story to be deciphered.

Interpreting Earth history is an important goal of the science of geology. Like a modern-day sleuth, a geologist must interpret the clues found preserved in the rocks. By studying rocks, especially sedimentary rocks, and the features they contain, geologists can unravel the complexities of the past.

Geologic events by themselves, however, have little meaning until they are put into a time perspective. Studying history, whether it is the Civil War or the age of dinosaurs, requires a calendar. Among geology's major contributions to human knowledge are the geologic time scale and the discovery that Earth history is exceedingly long.

Numerical and Relative Dates

The geologists who developed the geologic time scale revolutionized the way people think about time and perceive our planet. They learned that Earth is much older than anyone had previously imagined, and they learned that its surface and interior have been changed over and over again by the same geologic processes that operate today.

Numerical Dates

During the late 1800s and early 1900s, attempts were made to determine Earth's age. Although some of the methods appeared promising at the time, none of those early efforts proved to be reliable. What those scientists were seeking was a numerical date. Such dates specify the actual number of years that have passed since an event occurred. Today, our understanding of radioactivity allows us to accurately determine numerical dates for rocks that represent important events in Earth's distant past. We will study radioactivity later in this chapter. Prior to the discovery of radioactivity, geologists had no reliable method of carrying out numerical dating and had to rely solely on relative dating.

Relative Dates

When we place rocks in their proper sequence of formation—indicating which formed first, second, third, and so on—we are establishing relative dates. Such dates cannot tell us how long ago something took place, only that it followed one event and preceded another. The relative dating techniques that were developed are valuable and still widely used. Numerical dating methods did not replace those techniques but supplemented them. To establish a relative time scale, a few basic principles had to be discovered and applied. They were major breakthroughs in thinking at the time, and their discovery was an important scientific achievement.

Figure 9.1 Contemplating geologic time
This hiker is resting atop the Kaibab Formation, the uppermost layer in the Grand Canyon.
(Photo by Michael Collier)

Principle of Superposition

Nicolas Steno (1638–1686), a Danish anatomist, geologist, and priest, was the first to recognize a sequence of historical events in an outcrop of sedimentary rock layers. Working in the mountains of western Italy, Steno applied a very simple rule that has become the most basic principle of relativedating—the principle of superposition (super = above; positum = to place). This principle simply states that in an undeformed sequence of sedimentary rocks, each bed is older than the one above and younger than the one below. Although it may seem obvious that a rock layer could not be deposited with nothing beneath it for support, it was not until 1669 that Steno clearly stated this 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, we can easily place the layers in their proper order. Among those pictured in Figure 9.2, the sedimentary rocks in the Supai Group are the oldest, followed in order by the Hermit Shale, Coconino Sandstone, Toroweap Formation, and Kaibab Limestone.

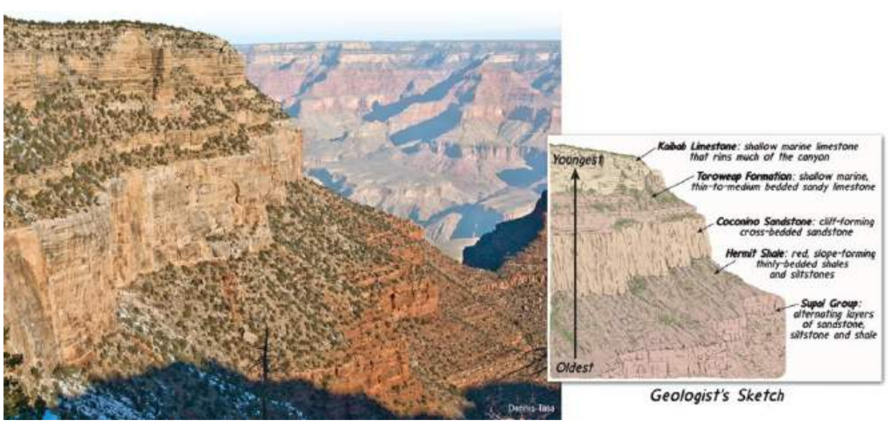


Figure 9.2 Superposition
Applying the principle of superposition to these layers in the upper portion of the Grand Canyon, the Supai Group is oldest, and the Kaibab Limestone is youngest.

Figure 9.3 Original horizontality

Most layers of sediment are deposited in a nearly horizontal position. When we see strata that are folded or tilted, we can assume that they were moved into that position by crustal disturbances after their deposition.

(Photo by Marco Simoni/Robert Harding World Imagery)

Principle of Original Horizontality

Steno is also credited with recognizing the importance of another basic rule, the principle of original horizontality, which says that layers of sediment are generally deposited in a horizontal position. Thus, if we observe rock layers that are flat, it means they have not been disturbed and still have their original horizontality. The layers in the Grand Canyon illustrate this in Figures 9.1 and 9.2. But if they are folded or inclined at a steep angle (discussed in detail in Chapter 10), they must have been moved into that position by crustal disturbances sometime after their deposition (Figure 9.3).

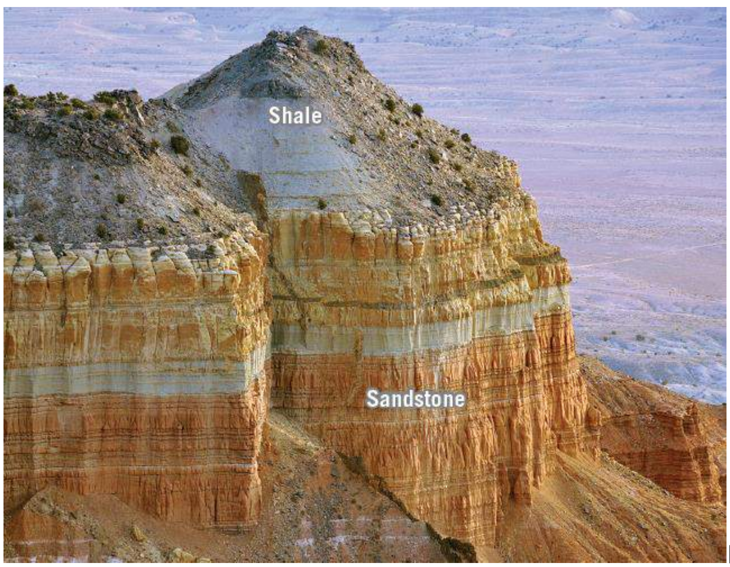
Principle of Lateral Continuity

The principle of lateral continuity refers to the fact that sedimentary beds originate as continuous layers that extend in all directions until they eventually grade into a different type of sediment or until they thin out at the edge of the basin of deposition (Figure 9.4A). For example, when a river creates a canyon, we can assume that identical or similar strata on opposite sides once spanned the canyon (Figure 9.4B). Although rock outcrops may be separated by a considerable distance, the principle of lateral continuity tells us those outcrops once formed a continuous layer (Figure 9.4C). This principle allows geologists to relate rocks in isolated outcrops to one another. Combining the principles of lateral continuity and superposition lets us extend relative age relationships over broad areas. This process, called correlation, is examined in Section 9.3.

Principle of Cross-Cutting Relationships

Figure 9.5 shows layers of rock that have been offset by a fault, a fracture in rock along which displacement occurs. It is clear that the strata must be older than the fault that broke them. The principle of cross-cutting relationships states that geologic features that cut across rocks must form after the rocks they cut through. Igneous intrusions (see Chapter 4) provide another example. The dikes shown in Figure 9.6 are tabular masses of igneous rock that cut through the surrounding rock. The magmatic heat from igneous intrusions often creates a narrow “baked” zone of contact metamorphism on the adjacent rock, also indicating that the intrusion occurred after the surrounding rocks were in place.

EYE on Earth 9.1



Michael Collier

This image shows West Cedar Mountain in southern Utah. The gray rocks are shale that originated as muddy river delta deposits. The sediments composing the orange sandstone were deposited by a river.

QUESTION 1 Place the events related to the geologic history of this area in proper sequence. Explain your logic. Include the following: uplift, sandstone, erosion, and shale.

QUESTION 2 What term is applied to the type of dates you established for this site?

Principle of Inclusions

Sometimes inclusions can aid in the relative dating process. Inclusions are fragments of one rock unit that have been enclosed within another. The basic principle of inclusions is logical and straightforward. The rock mass adjacent to the one containing the inclusions must have been there first in order to provide the rock fragments. Therefore, the rock mass that contains inclusions is the younger of the two. For example, when magma intrudes into surrounding rock, blocks of the surrounding rock may become dislodged and incorporated into the magma. If these pieces do not melt, they remain as inclusions known as xenoliths (see Chapter 4). In another example, when sediment is deposited atop a weathered mass of bedrock, pieces of the weathered rock become incorporated into the younger sedimentary layer (Figure 9.7).

Figure 9.4 Lateral continuity
A. Sediments are deposited over a large area in a continuous sheet. Sedimentary strata extend continuously in all directions until they thin out at the edge of a depositional basin or grade into a different type of sediment.
B. Although rock exposures are separated by many miles, we can infer that they were once continuous.
C. The idea depicted in B is illustrated in this image of the Grand Canyon.
(Photo by bcampbell65/Shutterstock)

SmartFigure 9.5 Cross-cutting fault
The rocks are older than the fault that displaced them.
(Morley Read/Alamy)
(https://goo.gl/BiFVHa)

Unconformities

When we observe layers of rock that have been deposited essentially without interruption, we call them conformable. Particular sites exhibit conformable beds representing certain spans of geologic time. However, no place on Earth has a complete set of conformable strata.

Throughout Earth history, the deposition of sediment has been interrupted over and over again. All such breaks in the rock record are termed unconformities. An unconformity represents a long period during which deposition ceased, erosion removed previously formed rocks, and then deposition resumed. In each case, uplift and erosion were followed by subsidence and renewed sedimentation. Unconformities are important features because they represent significant geologic events in Earth history. There are three basic types of unconformities, and geologists can use them to identify what intervals of time are not represented by strata and thus are missing from the geologic record.

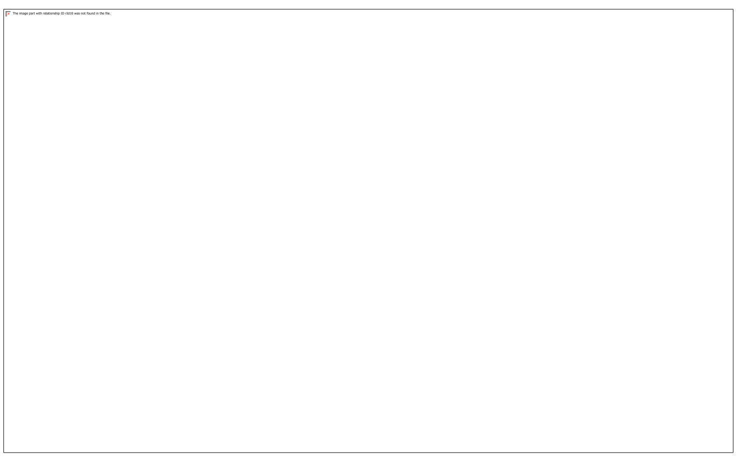
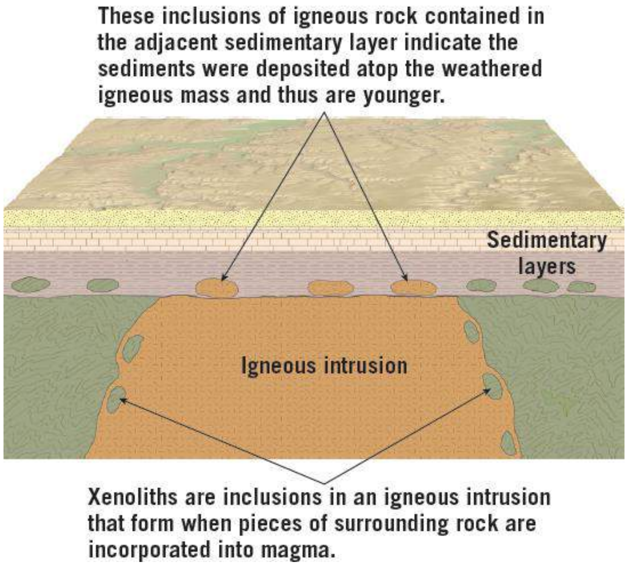


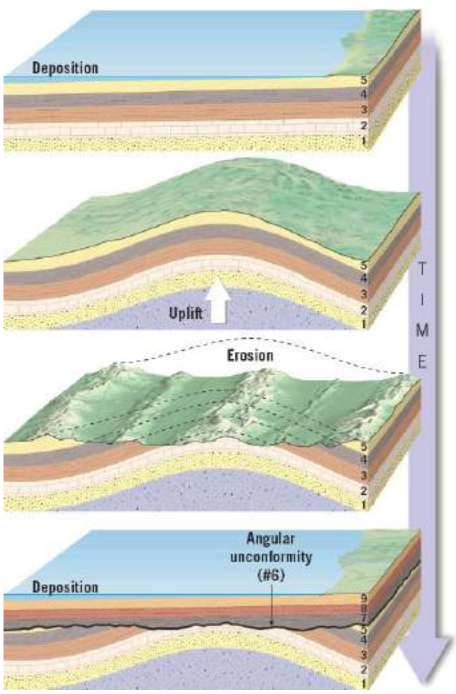
Figure 9.6 Cross-cutting dikes
This igneous intrusion is younger than the rocks that are intruded.
(Photo by Jonathan.Skt)

Angular Unconformity

Perhaps the most easily recognized unconformity is an angular unconformity. It consists of 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 (Figure 9.8).



SmartFigure 9.7 Inclusions
The rock containing inclusions is younger than the inclusions.
(https://goo.gl/Okfrm6)



SmartFigure 9.8 Formation of an angular unconformity
An angular unconformity represents an extended period during which deformation and erosion occurred.
(https://goo.gl/arrwhC)

Figure 9.9 Siccar Point, Scotland
James Hutton studied this famous unconformity in the late 1700s.
(Photo by Marli Miller)

When James Hutton studied an angular unconformity in Scotland more than 200 years ago,* he understood that it represented a major episode of geologic activity (Figure 9.9). He and his colleagues also appreciated the immense time span implied by such relationships; a companion later wrote of their visit to this site, "the mind seemed to grow giddy by looking so far into the abyss of time."

*This pioneering geologist is discussed in the section on the birth of modern geology in Chapter 1.

Disconformity

A disconformity is a gap in the rock record that represents a period of erosion rather than deposition. Imagine that a series of sedimentary layers is deposited in a shallow marine setting. Following this period of deposition, sea level falls or the land rises, exposing some the sedimentary layers. During this span, when the sedimentary beds are above sea level, no new sediment accumulates, and some of the existing layers are eroded away. Later, sea level rises or the land subsides, submerging the landscape. Now the surface is again below sea level, and a new series of sedimentary beds is deposited. The boundary separating the two sets of beds is a disconformity—a span for which there is no rock record (Figure 9.10). Because the layers above and below a disconformity are parallel, these features are sometimes difficult to identify unless you notice evidence of erosion such as a buried stream channel.

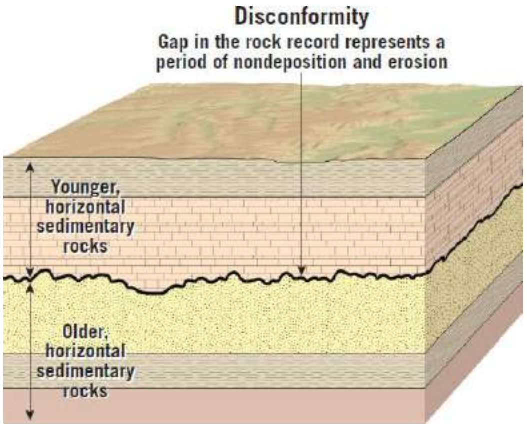


Figure 9.10 Disconformity
The layers on both sides of this gap in the rock record are essentially parallel.

Nonconformity

The third basic type of unconformity is a nonconformity, in which younger sedimentary strata overlie older metamorphic or intrusive igneous rocks (Figure 9.11). Just as angular unconformities and some disconformities imply crustal movements, so too do nonconformities. Intrusive igneous masses and metamorphic rocks originate far below the surface. Thus, for a nonconformity to develop, there must be a period of uplift and erosion of overlying rocks. Once exposed at the surface, the igneous or metamorphic rocks are subjected to weathering and erosion, then undergo subsidence and renewed sedimentation.

Unconformities in the Grand Canyon

The rocks exposed in the Grand Canyon of the Colorado River represent a tremendous span of geologic history. It is a wonderful place to take a trip through time. The canyon's colorful strata record a long history of sedimentation in a variety of environments—advancing seas, rivers and deltas, tidal flats and sand dunes. But the record is not

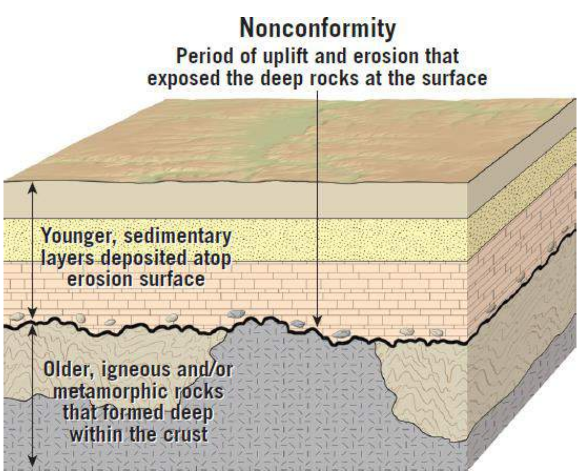


Figure 9.11 Nonconformity: Younger sedimentary rocks rest atop older metamorphic or igneous rocks.

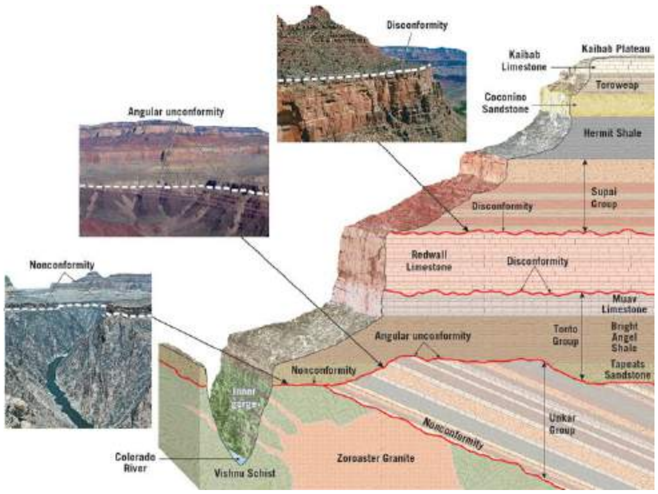


Figure 9.12 Cross section of the Grand Canyon
All three types of unconformities are present.
(Center photo by Marli Miller; other photos by E. J. Tarbuck)

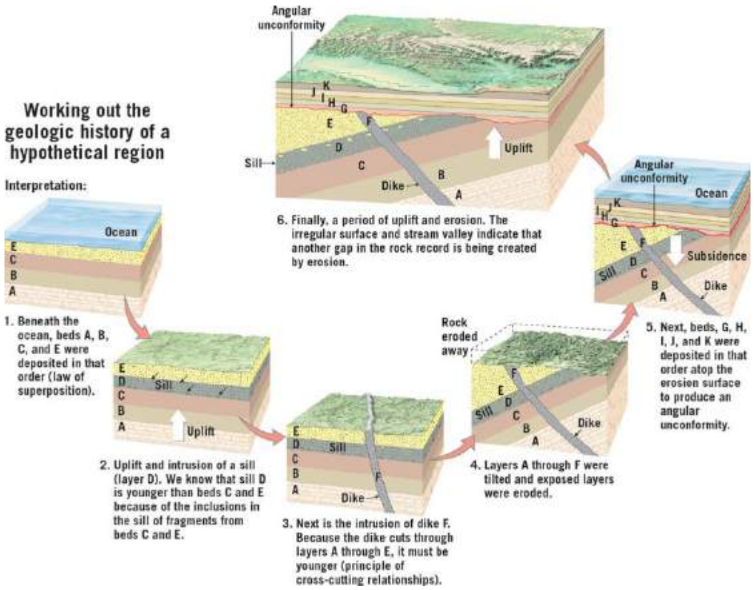
EYE on Earth 9.2

This close-up shows pieces of diorite (darkest rock) in granite. The thin white line is a vein of quartz. Think of a vein as a tiny dike.

QUESTION 1 What term is applied to the pieces of diorite?

QUESTION 2 Place the quartz vein, diorite, and granite in order from oldest to youngest.

Marli Miller



SmartFigure 9.13
Applying principles of relative dating
(https://goo.gl/w4HtAw)

continuous. Unconformities represent vast amounts of time that have not been recorded in the canyon's layers. Figure 9.12 is a geologic cross section of the Grand Canyon. All three types of unconformities can be seen in the canyon walls.

Applying Relative Dating Principles

If you apply the principles of relative dating to the hypothetical geologic cross section in Figure 9.13, you can place in proper sequence the rocks and the events they represent. The statements within the figure summarize the logic used to interpret the cross section.

In this example, we establish a relative time scale for the rocks and events in the area of the cross section. Remember that this method gives us no idea how many years of Earth history are represented, for we have no numerical dates. Nor do we know how this area compares to any other. See GEOgraphics 9.1 for another example of applying relative dating principles.

9.1 Concept Checks

Distinguish between numerical dates and relative dates.

Sketch and label four simple diagrams that illustrate each of the following: superposition, original horizontality, lateral continuity, and cross-cutting relationships.

What is the significance of an unconformity?

Distinguish among angular unconformity, disconformity, and nonconformity.

GEO Graphics 9.1 Dating the Lunar Surface

Question

Notice the two small craters to the right of the large crater in the lower right image. Would cross-cutting relationships be useful in establishing the sequence of their formation? Explain.