Chapter 12 Geologic Time

Section 1 Discovering Earth’s History

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
- unconformity
- correlation

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.

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.

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.

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.

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 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?

**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.

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 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.
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.

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

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.

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

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.

**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.

**Section 2  Fossils: Evidence of Past Life**

Key Concepts

- What are fossils?
- What determines if an organism will become a fossil?
- What is the principle of fossil succession?

Vocabulary

- fossil
- index fossil

Fossils are important tools for interpreting the geologic past. Fossils are the remains or traces of prehistoric life. They are important components of sediment and sedimentary rocks. Knowing the nature of the life forms that existed at a particular time helps researchers understand past environmental conditions. Further, fossils are important time indicators. They play a key role in correlating rocks of similar ages that are from different places.

**Fossil Formation**

There are many types of fossils. The type of fossil that is formed is determined by the conditions under which an organism died and how it was buried.

**Unaltered Remains**

Some remains of organisms—such as teeth, bones, and shells—may not have been altered, or changed, hardly at all over time. It is far less common to find the remains of an entire animal, including flesh. In Siberia, archaeologists recently found a fully preserved, frozen mammoth, shown in Figure 9. This is an excellent example of unaltered remains.
Altered Remains

The remains of an organism are likely to be changed over time. Fossils often become petrified, or “turned into stone.” When a fossil is petrified, mineral-rich water soaks into the small cavities and pores of the original organism. The minerals precipitate from the water and fill the spaces. The log of petrified wood in Figure 10E shows the result. In other instances, the cell walls or other solid material of an organism are replaced with mineral matter. Sometimes the microscopic details of the replaced structure are preserved.

Molds and casts are another common type of fossil. A fossil mold is created when a shell or other structure is buried in sediment and then dissolved by underground water. The mold accurately reflects only the shape and surface markings of the organism. It doesn’t reveal any information about its internal structure. Cast fossils (Figure 10F) are created if the hollow spaces of a mold are later filled with mineral matter.

A type of fossilization called carbonization is particularly effective in preserving leaves and delicate animal forms. Carbonization occurs when an organism is buried under fine sediment. As time passes, pressure squeezes out the liquid and gaseous components of an organism and leaves behind a thin residue of carbon, like that shown in Figure 10A. Black shale often contains abundant carbonized remains. If the carbon film is lost from a fossil preserved in fine-grain sediment, a replica of the surface, or an impression, may remain. The impression may still show considerable detail. An impression is shown in Figure 10B.
Delicate organisms, such as insects, are difficult to preserve, so they are relatively rare in the fossil record. For a fossil of an insect to form, the insect must be protected from any pressure that would crush it. Some insects have been preserved in amber—the hardened resin of ancient trees. The fly in Figure 10C was preserved after being trapped in a drop of the sticky resin.

**Indirect Evidence**

Trace fossils are indirect evidence of prehistoric life. Tracks, like those in Figure 10D, are animal footprints made in soft sediment that was later compacted and cemented. Burrows are holes made by an animal in sediment, wood, or rock that were later filled with mineral matter and preserved. Some of the oldest known fossils are believed to be worm burrows. Coprolites are fossils of dung and stomach contents. These can often provide useful information regarding the food habits of organisms. Gastroliths are highly polished stomach stones that were used in the grinding of food by some extinct reptiles.

**Conditions Favoring Preservation**

Two conditions are important for preservation: rapid burial and the possession of hard parts. The soft parts of a dead animal are usually eaten by scavengers or decomposed by bacteria. However, if the remains are buried quickly by sediment, they are protected from the environment. Then there is a chance that the organism will become a fossil. In addition, organisms have a better chance of being preserved if they have hard parts such as shells, bones, and teeth. Fossils of hard parts dominate the fossil record even though fossils of soft-bodied animals such as jellyfish and worms do exist.

**Fossils and Correlation**

In the late 18th century, William Smith, an English engineer and canal builder, demonstrated the usefulness of fossils to geology. He found that fossils weren’t randomly distributed throughout the rock layers he cut through. Instead, each layer contained a distinct assortment of fossils that did not occur in the layers above or below it. Smith also noted that sedimentary rock layers in distant areas could be identified and correlated by the distinct fossils they contained.

Based on Smith’s observations and the findings of many geologists who followed, one of the most important principles in historical geology was formulated. The principle of fossil succession states that fossil organisms succeed one another in a definite and determinable order. Therefore, any time period can be recognized by its fossil content.

Based on the rock record from around the world, geologists have identified an order of fossils: an Age of Trilobites, an Age of Fishes, an Age of Coal Swamps, an Age of Reptiles, and an Age of Mammals. These “ages” correspond to particular time periods and are characterized by distinct and abundant fossils. This same order of dominant organisms is found on every continent.

Once fossils were recognized as time indicators, they became the most useful means of correlating rocks of similar age in different regions. Geologists pay particular attention to index fossils. Index fossils are widespread geographically, are limited to a short span of geologic time, and occur in large numbers. Their presence provides an important method of matching rocks of the same age. Rock formations, however, do not always contain a specific index fossil. Then groups of fossils are used to establish the age of a rock layer. Figure 11 shows how an assemblage of fossils can be used to date rocks more precisely than using only one kind of fossil.
Figure 11 Overlapping ranges of fossils help date rocks more exactly than using a single fossil. The fossils contained in rock unit A all have overlapping age ranges in time 4. The fossils in rock unit B have overlapping age ranges in time 2.

Interpreting Environments

Fossils can also be used to interpret and describe ancient environments. For example, geologists can conclude that a region was once covered by a shallow sea when the remains of certain clam shells are found in the limestone of that region. The geologists might also be able to conclude the approximate position of the ancient shoreline by observing the types and locations of fossils. For instance, fossil animals with thick shells capable of withstanding pounding waves must have lived near shorelines.

Fossils can also indicate the former temperature of the water. Certain present-day corals require warm and shallow tropical seas—like those around Florida and the Bahamas. When similar corals are found in ancient limestones, they indicate that a Florida-like marine environment must have existed when the corals were alive. These examples illustrate how fossils can help unravel the complex story of Earth history.

Section 3 Dating with Radioactivity

Key Concepts

- What is radioactivity?
- What is half-life?
- What is radiometric dating?
- How is carbon-14 used in radiometric dating?

Vocabulary

- radioactivity
- half-life
- radiometric dating
- radiocarbon dating

Today, it is possible to obtain reliable numerical dates for events in the geologic past. For example, we know that Earth is about 4.56 billion years old and that the last dinosaurs became extinct about 65 million years ago. Although these great spans of time are hard to imagine, the vast expanse of geologic time is a reality. In this section you will learn how scientists measure time using radioactivity and radiometric dating.
Basic Atomic Structure

Recall from Chapter 2 that each atom has a nucleus containing protons and neutrons and that the nucleus is orbited by electrons. Electrons have a negative electrical charge and protons have a positive charge. A neutron has no charge. The atomic number of an element is the number of protons in its nucleus. Different elements have different atomic numbers, but atoms of the same element always have the same atomic number. An atom’s mass number is the number of protons and neutrons in an atom’s nucleus. The number of neutrons can vary, and these variants, or isotopes, have different mass numbers.

Radioactivity

The forces that bind protons and neutrons together in the nucleus are usually strong. However, in some isotopes, the forces binding the protons and neutrons together are not sufficiently strong and the nuclei are unstable. When nuclei are unstable, they spontaneously break apart, or decay, in a process called radioactivity. An unstable or radioactive isotope of an element is called the parent. The isotopes that result from the decay of the parent are called the daughter products.

What happens when unstable nuclei break apart? Radioactive decay continues until a stable or non-radioactive isotope is formed. A well-documented decay series is uranium-238, which decays over time to form the stable isotope lead-206. Three common types of radioactive decay are shown in Figure 12 on page 347.

![Common Types of Radioactive Decay](image)

Figure 12 Common Types of Radioactive Decay in each case, the number of protons (atomic number) in the nucleus changes, thus producing a different element.

Half-Life

A half-life is a common way of expressing the rate of radioactive decay. A half-life is the amount of time necessary for one half of the nuclei in a sample to decay to its stable isotope. Figure 13 illustrates what occurs when a radioactive parent decays directly into its stable daughter product. If the half-life of a radioactive isotope is known and the parent/daughter ratio can be measured, the age of the sample can be calculated. For example, if the half-life of an unstable isotope is 1 million years, and the parent/daughter ratio is 1:16, the ratio indicates that four half-lives have passed. The sample must be 4 million years old.
Figure 13 The Half-Life Decay Curve The radioactive decay curve shows change that is exponential. Half of the radioactive parent remains after one half-life. After a second half-life, one quarter of the parent remains, and so forth. Interpreting Graphs If 1/32 of the parent material remains, how many half-lives have passed?

Q: In radioactive decay, is there ever a time when all of the parent material is converted into the daughter product?

A: Theoretically, no. During a half-life, half of the parent material is converted into the daughter product. Then half of the remaining parent material is converted to the daughter product in another half life, and so on. By converting only half of the parent material with each half-life, there is never a time when all the parent material would be converted. However, after many half-lives, the parent material can exist in such small amounts that it is essentially undetectable.

Radiometric Dating

One of the most important results of the discovery of radioactivity is that it provides a way to calculate the ages of rocks and minerals that contain certain radioactive isotopes. The procedure is called radiometric dating. The rates of decay for many isotopes have been precisely measured and do not vary under the physical conditions that exist in Earth’s outer layers. Each radioactive isotope has been decaying at a constant rate since the formation of the rocks in which it occurs. The products of decay have also been accumulating at a constant rate. For example, when uranium is incorporated into a mineral that crystallizes from magma, lead isn’t present from previous decay. The radiometric “clock” starts at this point. As the uranium decays, atoms of the daughter product are formed, and measurable amounts of lead eventually accumulate.

Of the many radioactive isotopes that exist in nature, five have proved particularly useful in providing radiometric ages for ancient rocks. The five radioactive isotopes are listed in Table 1.

<table>
<thead>
<tr>
<th>Radioactive Parent</th>
<th>Stable Daughter Product</th>
<th>Currently Accepted Half-Life Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranium-238</td>
<td>Lead-206</td>
<td>4.5 billion years</td>
</tr>
<tr>
<td>Uranium-235</td>
<td>Lead-207</td>
<td>713 million years</td>
</tr>
<tr>
<td>Thorium-232</td>
<td>Lead-208</td>
<td>14.1 billion years</td>
</tr>
<tr>
<td>Rubidium-87</td>
<td>Strontium-87</td>
<td>47.0 billion years</td>
</tr>
<tr>
<td>Potassium-40</td>
<td>Argon-40</td>
<td>1.3 billion years</td>
</tr>
</tbody>
</table>
An accurate radiometric date can be obtained only if the mineral remained in a closed system during the entire period since its formation. If the addition or loss of either parent or daughter isotopes occurs, then it is not possible to calculate a correct date. For example, an important limitation of the potassium-argon method stems from the fact that argon is a gas. Argon may leak from minerals and throw off measurements. Cross-checking of samples, using two different radiometric methods, is done where possible to ensure accuracy. Although the basic principle of radiometric dating is simple, the actual procedure is quite complex. The analysis that determines the quantities of parent and daughter must be painstakingly precise. In addition, some radioactive materials do not decay directly into the stable daughter product. Uranium-238, for example, produces thirteen intermediate unstable daughter products before the fourteenth and final daughter product, the stable isotope lead-206, is produced.

**Dating with Carbon-14**

To date recent events, carbon-14 is used in a method called radiocarbon (carbon-14) dating. Carbon-14 is the radioactive isotope of carbon. Carbon-14 is continuously produced in the upper atmosphere. It quickly becomes incorporated into carbon dioxide, which circulates in the atmosphere and is absorbed by living matter. As a result, all organisms—including you—contain a small amount of carbon-14.

While an organism is alive, the decaying radiocarbon is continually replaced. Thus, the ratio of carbon-14 to carbon-12—the stable isotope of carbon—remains constant. When an organism dies, the amount of carbon-14 gradually decreases as it decays. By comparing the ratio of carbon-14 to carbon-12 in a sample, radiocarbon dates can be determined.

Because the half-life of carbon-14 is only 5730 years, it can be used to date recent geologic events up to about 75,000 years ago. The age of the object shown in Figure 14 was determined using radiocarbon dating. Carbon-14 has become a valuable tool for anthropologists, archaeologists, and historians, as well as for geologists who study recent Earth history.
Importance of Radiometric Dating

Radiometric dating methods have produced thousands of dates for events in Earth’s history. Rocks formed on Earth have been dated to be as much as 4 billion years old. Meteorites have been dated at 4.6 billion years old.

Radiometric dating has supported the ideas of James Hutton, Charles Darwin, and others who inferred that geologic time must be immense. Modern dating methods have proved that there has been enough time for the processes we observe to have accomplished tremendous tasks.

Section 4 The Geologic Time Scale

Key Concepts

- What is the geologic time scale?
- How is the geologic time scale constructed?
- What are some complications in dating rocks?

Vocabulary

- geologic time scale
- eon
- era
- period
- epoch

Historians divide human history into certain periods, such as the Renaissance and the Industrial Revolution, based on human events. Thus you can produce a timeline of human history. Geologists have done something similar. Based on their interpretations of the rock record, geologists have divided Earth’s 4.56-billion-year history into units that represent specific amounts of time. Taken together, these time spans make up the geologic time scale. The geologic time scale is shown in Figure 17. The major units of the time scale were described during the nineteenth century, principally by scientists working in Western Europe and Great Britain. Because radiometric dating was unavailable at that time, the entire time scale was created using methods of relative dating. It was only in the twentieth century that radiometric dating permitted numerical dates to be added.

Structure of the Time Scale

As shown in Figure 17, the geologic time scale is divided into eons, eras, periods, and epochs. Eons represent the greatest expanses of time. Eons are divided into eras. Each era is subdivided into periods. Finally, periods are divided into still smaller units called epochs. The eon that began about 540 million years ago is the Phanerozoic, a term derived from Greek words meaning “visible life.” It is an appropriate description because the rocks and deposits of the Phanerozoic Eon contain abundant fossils that document major changes in life-forms over time.

There are three eras within the Phanerozoic. The Paleozoic, which means “ancient life,” the Mesozoic, which means “middle life,” and the Cenozoic, which means “recent life.” As the names imply, the eras are bounded by profound worldwide changes in life forms. Each era is subdivided into periods, each of which is characterized by a somewhat less profound change in life forms as compared with the eras.

The periods of the Cenozoic are divided into still smaller units called epochs. The epochs of other periods, however, are not usually referred to by specific names. Instead, the terms early, middle, and late are generally applied to the epochs of these earlier periods.
Precambrian Time

Notice that the detail of the geologic time scale doesn’t begin until the start of the Cambrian Period, about 540 million years ago. The more than 4 billion years prior to the Cambrian is divided into eons, as shown in Figure 17. The common name for this huge expanse of time is the Precambrian. The view of the time scale on page 357 gives you a better idea of the expanse of time represented by the Precambrian.

Although it represents about 88 percent of Earth history, the Precambrian is not divided into nearly as many smaller time units as is the Phanerozoic eon. The reason is simple. Precambrian history is not known in great enough detail. The amount of information that geologists have acquired about Earth’s past decreases substantially the farther back in time you go. During Precambrian time, there were fewer life forms. These life forms are more difficult to identify and the rocks have been disturbed often.
Difficulties With the Geologic Time Scale

Although reasonably accurate numerical dates have been determined for the periods of the geologic time scale, the task is not easy. The basic problem comes from the fact that not all rocks can be dated by radiometric methods. For a radiometric date to be useful, all minerals in the rock must have formed at about the same time. For this reason, radioactive isotopes can be used to determine when minerals in an igneous rock crystallized and when pressure and heat made new minerals in a metamorphic rock.

However, samples of sedimentary rock can rarely be dated directly by radiometric means. A sedimentary rock may contain particles that contain radioactive isotopes, but these particles are not the same age as the rock in which they occur. The sediments that are eventually cemented together into a sedimentary rock have been weathered from older rocks. Radiometric dating would not be accurate since sedimentary rock forms from so many older rock particles.

Radiometric dating of metamorphic rocks may also be difficult. The age of a particular mineral in a metamorphic rock does not necessarily represent the time when the rock first formed. Instead, the date may indicate when the rock was metamorphosed.

If samples of sedimentary rocks rarely produce reliable radiometric ages, how can numerical dates be assigned to sedimentary layers? Usually geologists must relate sedimentary rocks to datable igneous masses, as shown in Figure 18. In this example, radiometric dating has determined the ages of the volcanic ash bed within the Morrison Formation and the dike cutting the Mancos Shale and Mesaverde Formation. Both formations are igneous rock. The area covered by the Morrison Formation includes the following states: Montana, North and South Dakota, Nebraska, Kansas, Oklahoma, Texas, New Mexico, Arizona, Colorado, Utah, Wyoming, and Idaho. Using the principle of superposition, you can tell that the sedimentary beds below the ash are older than the ash, and all the layers above the ash are younger. Using the principle of cross-cutting relationships, you can see that the dike is younger than the Mancos Shale and the Mesaverde Formation. But the dike is older than the Wasatch Formation because the dike does not intrude the Tertiary rocks.

The Morrison Formation is one example of literally thousands that illustrates how datable materials are used to bracket the various episodes in Earth history within specific time periods. It shows the necessity of combining laboratory methods with field observations of rocks.