GLOBAL EDITION

Earth

An Introduction to Physical Geology

TWELFTH EDITION

Tarbuck • Lutgens • Illustrated by Tasa

Pearson

Earth

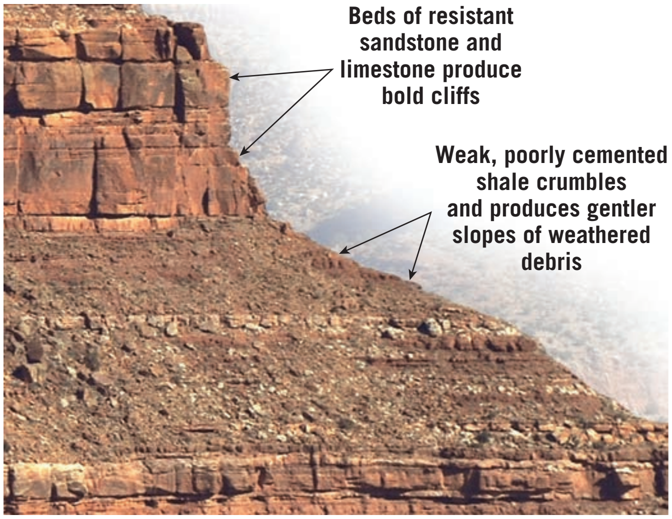


Figure 7.5
Shale crumbles easily This image was taken in the Grand Canyon. Hikers soon notice that the trail is usually gentler when layers of shale are encountered. (Photo by Dennis Tasa)

arrangement leaves a high percentage of open space (called *pore space*) that is filled with water. However, this situation usually changes over time as additional layers of sediment pile up and compact the sediment below.

During this phase, the clay and silt particles take on a more nearly parallel alignment and become tightly packed. This rearrangement of grains reduces the size of the pore spaces and forces out much of the water. Once the grains are pressed closely together, the tiny spaces between particles do not readily permit solutions containing cementing material to circulate. Therefore, geologists often describe shales as being weak because they are poorly cemented and therefore not well lithified.

The inability of water to penetrate shale's microscopic pore spaces explains why this rock often forms barriers to the subsurface movement of water and petroleum. Indeed, rock layers that contain groundwater are commonly underlain by shale beds that block further downward movement. The opposite is true for underground reservoirs of petroleum. They are often capped by shale beds that effectively prevent oil and gas from escaping to the surface.*

Shale, Mudstone, or Siltstone? It is common to apply the term *shale* to all fine-grained sedimentary rocks, especially in a nontechnical context. However, be aware that there is a more restricted use of the term. In this narrower usage, shale must exhibit the ability to split into thin layers along well-developed, closely spaced planes. This property is termed **fissility** (*fissilis* = that which can be cleft or split). If the rock breaks into chunks or blocks, the name *mudstone* is applied. Another fine-grained sedimentary rock that, like mudstone, is often grouped with shale but lacks fissility is *siltstone* (see Figure 7.3). As its name implies, siltstone is composed largely of silt-size particles and contains less clay-size material than shale and mudstone.

Gentle Slopes Although shale is far more common than other sedimentary rocks, it does not usually attract as much notice as other, less abundant, members of this group. The reason is that shale does not form prominent outcrops, as sandstone and limestone often do. Rather, shale crumbles easily and usually forms a cover of soil that hides the unweathered rock below. This is illustrated nicely in the Grand Canyon, where the gentler slopes of weathered shale are quite inconspicuous and overgrown with vegetation, in sharp contrast with the bold cliffs produced by more durable rocks (**Figure 7.5**).

Although shale beds may not form striking cliffs and prominent outcrops, some deposits have economic value. Certain shales are quarried to obtain raw material for pottery, brick, tile, and china. Moreover, when mixed with limestone, shale is used to make Portland cement. In the future, one type of shale, called oil shale, may become a valuable energy resource. Oil shale potential is discussed in Chapter 23.

Figure 7.6
Quartz sandstone After shale, sandstone is the next most abundant sedimentary rock. (Photos by Dennis Tasa)

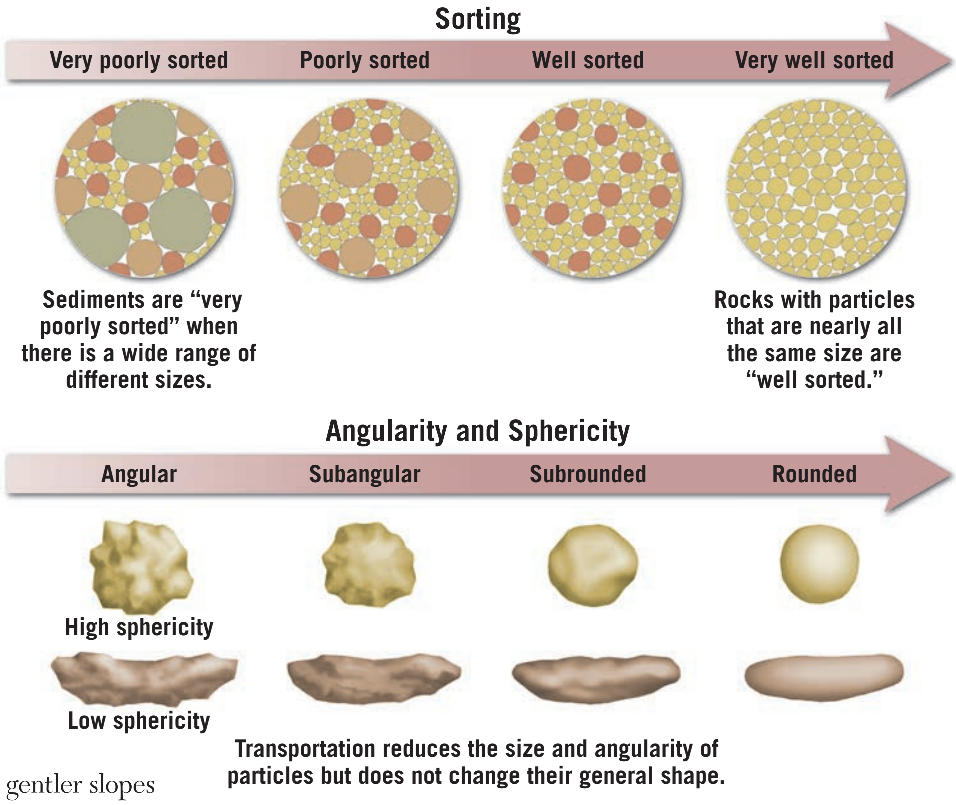
Sandstone

Sandstone is the name given to rocks in which sand-size grains predominate (**Figure 7.6**). After shale, sandstone is the next most abundant sedimentary rock, accounting for approximately 20 percent of the entire group. Sandstones form in a variety of environments and often contain significant clues about their origin, including sorting, particle shape, and composition.

Sorting All the particles in sandstone are not necessarily identical in size. **Sorting** refers to the degree of similarity in particle size in a sedimentary rock. For example, if all the grains in a sample of sandstone are

* The relationship between impermeable beds and the occurrence and movement of groundwater is examined in Chapter 17. Shale beds can be cap rocks in oil traps and are discussed in Chapter 23.

about the same size, the sand is considered *well sorted*. Conversely, if the rock contains mixed large and small particles, the sand is said to be *poorly sorted* (**Figure 7.7**). By studying the degree of sorting, we can learn much about the depositing current. Deposits of wind-blown sand are usually better sorted than deposits sorted by wave activity (**Figure 7.8**). Particles washed by waves are commonly better sorted than materials deposited by streams. Sediment accumulations that exhibit poor sorting usually result when particles are transported for only a relatively short time and then rapidly deposited. For example, when a turbulent stream reaches the gentler slopes at the base of a steep mountain, its velocity is quickly reduced, and poorly sorted sands and gravels are deposited.



SmartFigure 7.7
Sorting and particle shape *Sorting* refers to the range of particle sizes present in a rock. Geologists describe a particle's shape in terms of its *angularity* (the degree to which edges and corners are rounded) and *sphericity* (how close the shape is to a sphere).
(https://goo.gl/hcKMT3)

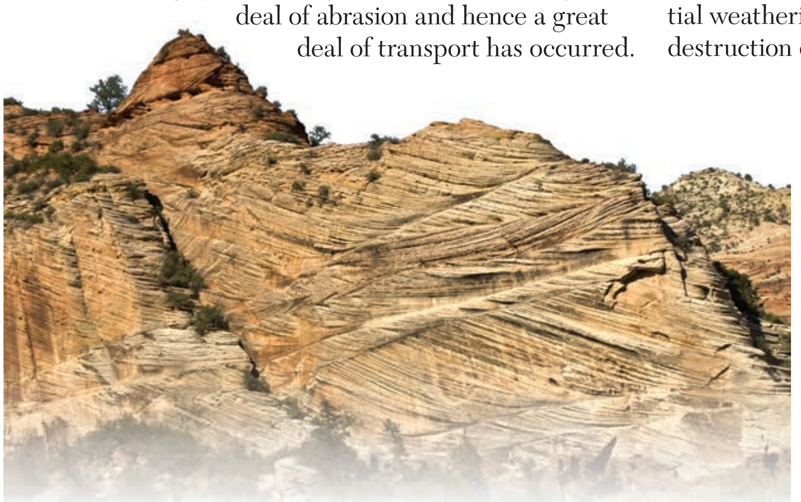
Tutorial

Particle Shape The shapes of sand grains can also help decipher the history of a sandstone (see Figure 7.7). When streams, winds, or waves move sand and other larger sedimentary particles, the grains lose their sharp edges and corners and become more rounded as they collide with other particles during transport. Thus, rounded grains likely have been airborne or waterborne. Further, the degree of rounding indicates the distance or time involved in the transportation of sediment by currents of air or water. Highly rounded grains indicate that a great deal of abrasion and hence a great deal of transport has occurred.

Very angular grains, on the other hand, imply two things: that the rock materials were transported only a short distance before they were deposited or that some other medium may have transported them. For example, when glaciers move sediment, the particles are usually made more irregular by the crushing and grinding action of the ice.

Transport Affects Mineral Composition In addition to affecting the degree of rounding and the amount of sorting that particles undergo, the length of transport by turbulent air and water currents also influences the mineral composition of a sedimentary deposit. Substantial weathering and long transport lead to the gradual destruction of weaker and less stable minerals, including

Figure 7.8
Sand dunes consist of well-sorted sediment
A. The Navajo Sandstone represents a vast area of ancient sand dunes that once covered an area the size of California. **B.** These modern dunes are among the highest in North America. (Photo A by Dennis Tasa; photo B by George H. H. Huey/Alamy Images)



A. The orange and yellow cliffs of Utah's Zion National Park expose thousands of feet of Jurassic-age Navajo Sandstone.

B. The quartz grains composing the Navajo Sandstone were deposited by wind as dunes similar to these in Colorado's Great Sand Dunes National Park. The sand is well sorted because all of the particles are practically the same size.

Figure 7.9
Conglomerate The gravel-size particles in this rock are rounded. (Photo by E. J. Tarbuck)

the feldspars and ferromagnesians. Because quartz is very durable, it is usually the mineral that survives a long trip in a turbulent environment.

To summarize, the origin and history of sandstone can often be deduced by examining the sorting, roundness, and mineral composition of its constituent grains. Knowing this information allows us to infer that a well-sorted, quartz-rich sandstone consisting of highly rounded grains must be the result of a great deal of transport. Such a rock, in fact, may represent several cycles of weathering, transport, and deposition. We may also conclude that a sandstone containing significant amounts of feldspar and angular grains of ferromagnesian minerals underwent little chemical weathering and transport and was probably deposited close to the source area of the rock particles.

Figure 7.10
Poorly sorted sediments
Gravel deposits along Carbon Creek in Grand Canyon National Park are poorly sorted. (Photo by Michael Collier)

Varieties of Sandstone Due to its durability, quartz is the predominant mineral in most sandstones. Such rock is often simply called *quartz sandstone* (see Figure 7.6). When a sandstone contains appreciable quantities of feldspar (25 percent or more), the rock is called *arkose*. In addition to feldspar, arkose usually contains quartz and sparkling bits of mica. The mineral composition of arkose indicates that the grains were derived from granitic source rocks. The particles are generally poorly sorted and angular, which suggests short-distance transport, minimal chemical weathering in a relatively dry climate, and rapid deposition and burial.

A third variety of sandstone is known as *graywacke*. Along with quartz and feldspar, this dark-colored rock contains abundant rock fragments and matrix—finer-grained material in which the fragments are embedded. More than 15 percent of graywacke's volume is matrix. The poor sorting and angular grains characteristic of graywacke suggest that the particles were transported only a relatively short distance from their source area and were then rapidly deposited. Before the sediment could be reworked and sorted further, it was buried by additional layers of material. Graywacke is frequently associated with submarine deposits made by dense sediment-choked torrents called *turbidity currents*.

Conglomerate and Breccia

Conglomerate consists largely of rounded gravel-size particles (**Figure 7.9**). As Figure 7.3 indicates, these particles can range in size from large boulders to particles as small as peas. The particles are often large enough to be identified as distinctive rock types; thus, they can be valuable in identifying the source areas of sediments. More often than not, conglomerates are poorly sorted because the openings between the large gravel particles contain sand or mud (**Figure 7.10**).

Gravels accumulate in a variety of environments and usually indicate the existence of steep slopes or very turbulent currents. The coarse particles in a conglomerate

EYE ON EARTH 7.1

This detrital rock consists of angular grains and is rich in potassium feldspar and quartz. (Photo by E. J. Tarbuck)

QUESTION 1 What do the angular grains indicate about the distance the sediment was transported?

QUESTION 2 The source of the sediment in this rock was an igneous mass. Name the likely rock type.

QUESTION 3 Did the sediment in this sample undergo a great deal of chemical weathering? Explain.

may reflect the action of energetic mountain streams or result from strong wave activity along a rapidly eroding coast. Some glacial and landslide deposits also contain plentiful gravel.

If the large particles are angular rather than rounded, the rock is called **breccia** (Figure 7.11). Because large particles abrade and become rounded very rapidly during transport, the pebbles and cobbles in a breccia indicate that they did not travel far from their source area before they were deposited. Thus, as with many other sedimentary rocks, conglomerates and breccias contain clues to their history. Their particle sizes reveal the strength of the currents that transported them, whereas the degree of rounding indicates how far the particles traveled. The fragments within a sample identify the source rocks that supplied them.

Figure 7.11
Breccia The gravel-size sediments in this rock are sharp and angular. (Photo by E. J. Tarbuck)

7.2 Concept Checks

1. What minerals are most abundant in detrital sedimentary rocks? In which rocks do these minerals predominate?
2. What is the primary basis for distinguishing among detrital rocks?
3. Describe how sediments become sorted. What would cause sediments to be poorly sorted?
4. Distinguish between conglomerate and breccia.

7.3 Chemical Sedimentary Rocks

Explain the processes involved in the formation of chemical sedimentary rocks and describe several examples.

In contrast to detrital rocks, which form from the solid products of weathering, chemical sediments derive from ions that are carried *in solution* to lakes and seas. This material does not remain dissolved in the water indefinitely, however. Some of it precipitates to form chemical sediments. These become rocks such as limestone, chert, and rock salt.

This precipitation of material occurs in two ways. *Inorganic* (*in* = not, *organicus* = life) processes such as evaporation and chemical activity can produce chemical sediments. *Organic* (life) processes of water-dwelling organisms also form chemical sediments, said to be of **biochemical** origin.

One example of a deposit resulting from inorganic chemical processes is the dripstone that decorates many caves (Figure 7.12). Another is the salt left behind as a body of seawater evaporates. In contrast, many water-dwelling animals and plants extract dissolved mineral matter to form shells and other hard parts. After the organisms die, their skeletons collect by the millions on the floor of a lake or an ocean as biochemical sediment (Figure 7.13).

Limestone

Representing about 10 percent of the total volume of all sedimentary rocks, **limestone** is the most abundant chemical sedimentary rock, and it has economic significance as well (see GEOgraphics 7.1). It is composed

Delicate calcite crystals forming in a drop of water at the tip of soda straw stalactite. The formation of crystals is triggered when some carbon dioxide escapes from the water drop.

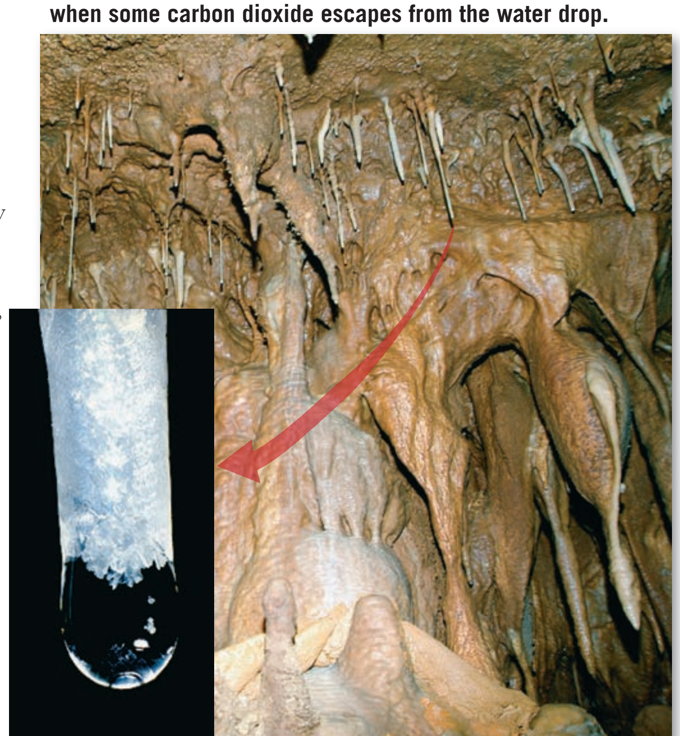


Figure 7.12
Cave deposits An example of a chemical sedimentary rock with an inorganic origin. (Photo by Guillen Photography/Alamy Images; inset photo by Dante Fenolio/Science Source)

GEO GRAPHICS 7.1

Limestone
An Important and Versatile Commodity

Limestone, as defined by the minerals industry, refers to any rock composed mostly of the carbonate minerals calcite and dolomite. The U.S. Geological Survey characterizes limestone as an *"essential mineral commodity of national importance."*

Why is limestone important?

Limestone that has undergone metamorphism is called marble. It is used as floor tile, table and countertops, and as a building stone.

Purified limestone is added to bread and cereal as a source of calcium and is an ingredient in antacid tablets and calcium supplements. It is even used to neutralize acids in wine and beer making!

Limestone is used as a filler and white pigment in many products including paper, plastics, paint, and even toothpaste.

Limestone is a key ingredient in making Portland cement, an essential product to the building industry.

White roofing granules.

USGS

Question:
List at least five different commercial uses for limestone. ?

Huge quantities of limestone are crushed and used as aggregate—the solid base of many roads and an ingredient in concrete. It is the raw material for making lime (CaO), which is used to treat soils, purify water, and smelt copper among many uses.

Martin Bond/Photo Researchers, Inc.

Limestone has been used as a building stone for centuries—from Egypt's ancient pyramids and Europe's medieval castles, to modern buildings such as this.

B. Christopher/Alamy Images

chiefly of the mineral calcite ($CaCO_3$) and forms either by inorganic means or as a result of biochemical processes. Regardless of origin, the mineral composition of all limestone is similar, yet many different types exist. This is true because limestones are produced under a variety of conditions. Forms that have a marine biochemical origin are by far the most common.

Figure 7.13
Coquina This variety of limestone consists of shell fragments; therefore, it has a biochemical origin. (Rock sample photo by E. J. Tarbuck; beach photo by Donald R. Frazier Photolibrary, Inc./Alamy Images)

Carbonate Reefs Corals are one important example of organisms that are capable of creating large quantities of marine limestone. These relatively simple invertebrate animals secrete a calcareous (calcium carbonate) external skeleton. Although they are small, corals are capable of creating massive structures called *reefs* (**Figure 7.14**). Reefs consist of coral colonies made up of great numbers of individuals that live side by side on a calcite structure secreted by the animals. In addition, calcium carbonate–secreting algae live with the corals and help cement the entire structure into a solid mass. A wide variety of other organisms also live in and near the reefs.

Certainly the best-known modern reef is Australia's 2600-kilometer-long (1600-mile-long) Great Barrier Reef, but many lesser reefs also exist. They develop in the shallow, warm waters of the tropics and subtropics equatorward of about 30 degrees latitude. Striking examples exist in The Bahamas, Hawaii, and the Florida Keys.

Modern corals were not the first reef builders. Earth's first reef-building organisms were photosynthesizing bacteria that lived during Precambrian time, more than 2 billion years ago. From fossil remains, it is known that a variety of organisms have constructed reefs, including bivalves (clams and oysters), bryozoans (coral-like animals), and sponges. Corals have been found in fossil reefs as ancient as 500 million years old, but corals

This image in Guadalupe Mountains National Park, Texas, shows a small portion of an ancient (Permian-age) reef complex that once formed a 600-kilometer loop around the margin of the Delaware Basin.

Aerial view showing a small portion of Australia's Great Barrier Reef. Located off the coast of Queensland, it extends for 2600 kilometers and consists of more than 2900 individual reefs.

Figure 7.14
Carbonate reefs Large quantities of biochemical limestone are created by reef-building organisms. (Photos by JC Photo/Shutterstock and Michael Collier)