

Chapter 6

Sedimentary Rocks

Coal is responsible for slightly more than half the electricity generated in the United States.

The Importance of Sedimentary Rocks

Most of solid Earth consists of igneous and metamorphic rocks. Geologists estimate these two categories represent 90 to 95 percent of the outer 16 kilometers (10 miles) of the crust. Nevertheless, most of Earth's solid surface consists of either sediment or sedimentary rock! Across the ocean floor, which represents about 70 percent of Earth's solid surface, virtually everything is covered by sediment. *Igneous rocks are exposed only at the crest of mid-ocean ridges and at some volcanic areas.* Thus, while sediment and sedimentary rocks make up only a small percentage of Earth's crust, they are concentrated at or near the surface—the interface among the geosphere, hydrosphere, atmosphere, and biosphere.

Because of this unique position, sediments and the rock layers that they eventually form contain evidence of past conditions and events at the surface.

Furthermore, *it is sedimentary rocks that contain fossils, which are vital tools in the study of the geologic past.* This group of rocks provides geologists with much of the basic information they need to reconstruct the details of Earth history.

Such study is not only of interest for its own sake but has practical value as well. Coal, which provides a significant portion of our electrical energy, is classified as a sedimentary rock. Moreover, other major energy sources—oil, natural gas, and uranium—are derived from sedimentary rocks.

So are major sources of iron, aluminum, manganese, and phosphate fertilizer, plus numerous materials essential to the construction industry, such as cement and aggregate. Sediments and sedimentary rocks are also the primary reservoir of groundwater. Thus, an understanding of this group of rocks and the processes that form and modify them is basic to locating additional supplies of many important resources.

How does the volume of sedimentary rocks in Earth's crust compare to igneous and metamorphic rocks? Why are sedimentary rocks important?

Origins of Sedimentary Rock

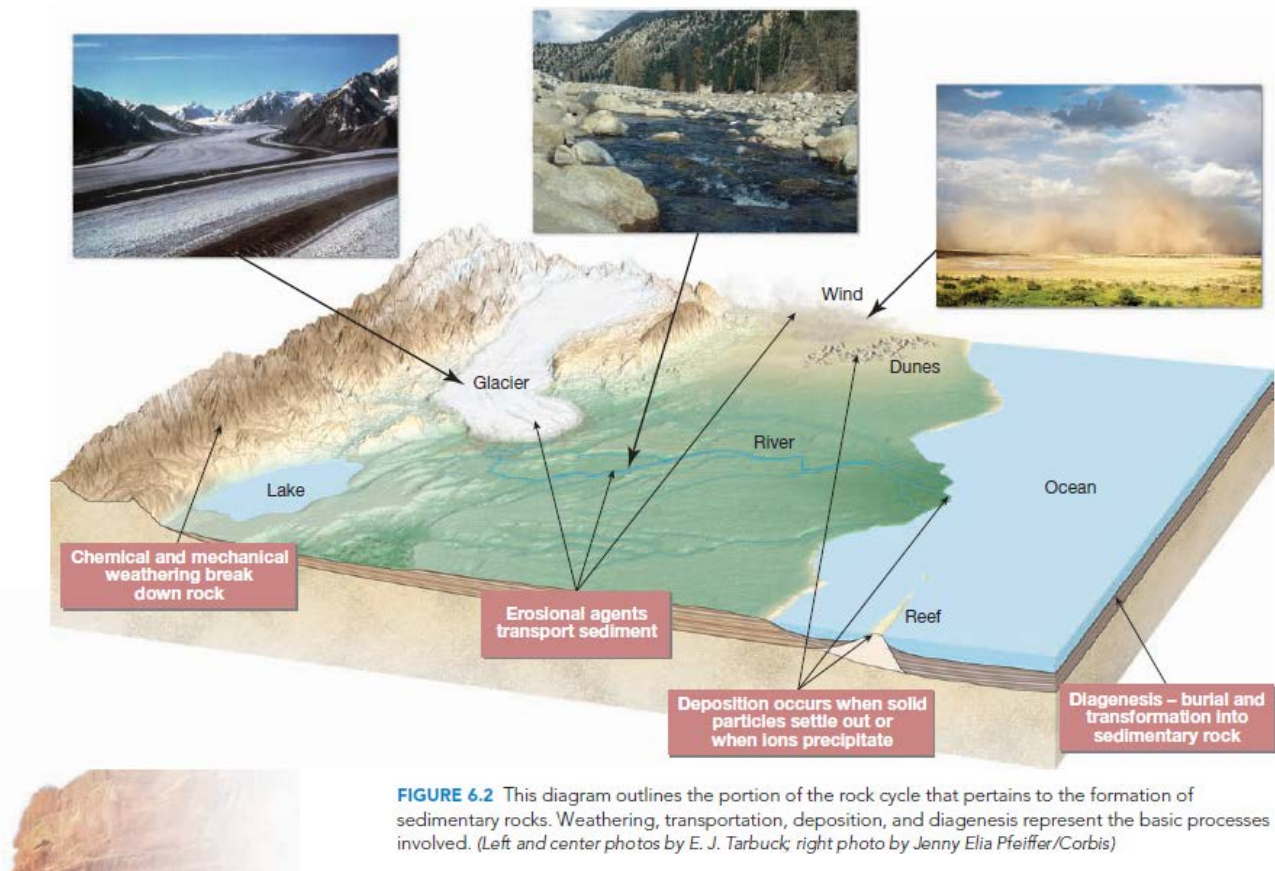
Sedimentary Rocks

FIGURE 6.2 illustrates the portion of the rock cycle that occurs near Earth's surface—the part that pertains to sediments and sedimentary rocks. A brief overview of these processes provides a useful perspective.

- Weathering begins the process. It involves the physical disintegration and chemical decomposition of pre-existing igneous, metamorphic, and sedimentary rocks. Weathering generates a variety of products, including various solid particles and ions in solution. These are the raw materials for sedimentary rocks.
- Soluble constituents are carried away by runoff and groundwater. Solid particles are frequently moved downslope by gravity, a process termed mass wasting, before running water, groundwater, wind, and glacial ice remove them.

Transportation moves these materials from the sites where they originated to locations where they accumulate. The transport of sediment is usually irregular.

For example, during a flood, a rapidly moving river moves large quantities of sand and gravel. As the flood waters recede, particles are temporarily deposited, only to be moved again by a Subsequent flood.



• **Deposition of solid particles occurs** when wind and water currents slow down and as glacial ice melts. The word sedimentary actually refers to this process. It is derived from the Latin *sedimentum*, which means “to settle,” a reference to solid material settling out of a fluid (water or air). The mud on the floor of a lake, a delta at the mouth of a river, a gravel bar in a stream bed, the particles in a desert sand dune, and even household dust are examples. • *The deposition of material dissolved in water is not related to the strength of wind or water currents. Rather, ions in solution are removed when chemical or temperature changes cause material to crystallize and precipitate or when organisms remove dissolved material to build shells.*

• As deposition continues, older sediments are buried beneath younger layers and gradually converted to sedimentary rock (**lithified**) by compaction and cementation. This and other changes are referred to as (**diagenesis** (the physical and chemical changes occurring during the conversion of sediment

to sedimentary rock)), a collective term for all of the changes (short of metamorphism) that take place in texture, composition, and other physical properties after sediments are deposited.

Because there are a variety of ways that the products of weathering are transported, deposited, and transformed into solid rock, three categories of sedimentary rocks are recognized.

As the overview reminded us, sediment has two principal sources. **First**, it may be an accumulation of material that genesis = change originates and is transported as solid particles derived from both mechanical and chemical weathering. Deposits of this type are **termed detrital**, and the sedimentary rocks that they form are **called detrital sedimentary rocks**.

The second major source of sediment is soluble material produced largely by chemical weathering. When these ions in solution are precipitated by either **inorganic or biologic processes**, the material is known as chemical sediment, and the rocks formed from it are **called chemical sedimentary rocks**

*The third category is **organic sedimentary rocks**. The primary example **is coal**. This black combustible rock consists of organic carbon from the remains of plants that died and accumulated on the floor of a swamp. The bits and pieces of undecayed plant material that constitute the “sediments” in coal are quite unlike the weathering products that make up detrital and chemical sedimentary rocks.*

Outline the steps that would transform an exposure of granite in the mountains into various sedimentary rocks. List and briefly distinguish among the three basic sedimentary rock categories.

Sedimentary Rock:

A-Detrital sedimentary rocks.

B-Chemical sedimentary rocks

C-Organic sedimentary rocks

Detrital Sedimentary Rocks

Sedimentary Rocks Types of Sedimentary Rocks




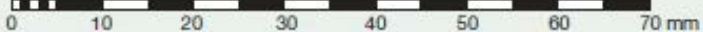
Though a wide variety of minerals and rock fragments may be found in detrital rocks, **clay minerals and quartz are the chief constituents of most sedimentary rocks in this category.** Recall from **Chapter 5** that clay minerals are the most abundant product of the chemical weathering of silicate minerals, especially the feldspars. *Clays are fine-grained minerals with sheet-like crystalline structures similar to the micas. The other common mineral, quartz, is abundant because it is extremely durable and very resistant to chemical weathering. Thus, when igneous rocks such as granite are attacked by weathering processes, individual quartz grains are freed. Other common minerals in detrital rocks are feldspars and micas.* **Because**

chemical weathering rapidly transforms these minerals into new substances, their presence in sedimentary rocks indicates that erosion and deposition were fast enough to preserve some of the primary minerals from the source rock before they could be decomposed.

Particle size is the primary basis for distinguishing among various detrital sedimentary rocks. FIGURE 6.3 presents the size categories for particles making up detrital rocks. Particle size is not only a convenient method of dividing detrital rocks, but the sizes of the component grains also provide useful information about environments of deposition. Currents of water or air sort the particles by size—the stronger the current, the larger the particle size carried. Gravels, for example, are moved by swiftly flowing rivers as well as by landslides and glaciers. Less energy is required to transport sand; thus, it is common to such features as windblown dunes and some river deposits and beaches. Very little energy is needed to transport clay, so it settles very slowly. Accumulations of these tiny particles are generally associated with the quiet waters of a lake, lagoon, swamp, or certain marine environments.

Common detrital sedimentary rocks, in order of increasing particle size, are shale, sandstone, and conglomerate or breccia. We will now look at each type and how it forms.

Figure 6.3 Particle size classification for detrital sedimentary rocks. Particle size is the primary basis for distinguishing among various detrital sedimentary rocks. (E.J. Tarbuck)

Size Range (millimeters)	Particle Name	Common Name	Detrital Rock
>256	Boulder	Gravel	Conglomerate or Breccia 
64-256	Cobble		
4-64	Pebble		
2-4	Granule		
1/16-2	Sand	Sand	Sandstone 
1/256-1/16 <1/256	Silt Clay	Mud	Shale, Mudstone or Siltstone 
			

Shale

Shale is a sedimentary rock consisting of silt- and clay-size particles. These fine-grained detrital rocks account for well over half of all sedimentary rocks. *The particles in these rocks are so small that they cannot be readily identified without great magnification and for this reason make shale more difficult to study and analyze than most other sedimentary rocks.*

Much of what can be learned is based on particle size. The tiny grains in shale indicate that deposition occurs as the result of gradual settling from relatively quiet, non-turbulent currents.

Such environments include lakes, river floodplains, lagoons, and portions of the deep-ocean basins. Even in these quiet environments, there is usually enough turbulence to keep clay-size particles suspended almost indefinitely. Consequently, much of the clay is deposited only after the individual particles join to form larger aggregates.

Sometimes the chemical composition of the rock provides additional information. One example is black shale, which is black because it contains abundant organic matter (carbon). *When such a rock is found, it strongly implies that deposition occurred in an oxygen-poor environment such as a swamp, where organic materials do not readily oxidize and decay.*

As silt and clay accumulate, they tend to form thin layers commonly referred to as **laminae**. Initially the particles in the laminae are oriented randomly. This disordered arrangement leaves a high percentage of open space (called pore space) that is filled with water. However, this situation usually changes with 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 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, shales are often described as being weak because they are poorly cemented and therefore not well lithified. The inability of water to penetrate its microscopic pore spaces explains why shale 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.

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. 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. As its name implies, siltstone is composed largely of silt-size particles and contains less clay-size material than shale and mudstone.

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 un-weathered 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 to the bold cliffs produced by more durable rocks. 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 clay, 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.

Sandstone:

Sandstone is the name given rocks in which sand-sized grains predominate (see Figure 6.3). After shale, sandstone is the 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 AND PARTICLE SHAPE.

Sorting is the degree of similarity in particle size in a sedimentary rock. For example, if all the grains in a sample of sandstone are 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 6.5A). *By studying the degree of sorting, we can learn much about the depositing current. Deposits of windblown sand are usually better sorted than deposits sorted by wave activity. 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.

The shapes of sand grains can also help read the history of a sandstone (Figure 6.5B). 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 materials were transported only a short distance before they were deposited and 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.

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 the feldspars and ferromagnesian minerals. Because quartz is very durable, it is usually the mineral that survives the long trip in a turbulent environment. The preceding discussion has shown that the origin and history of a 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 a significant amount 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 particles.

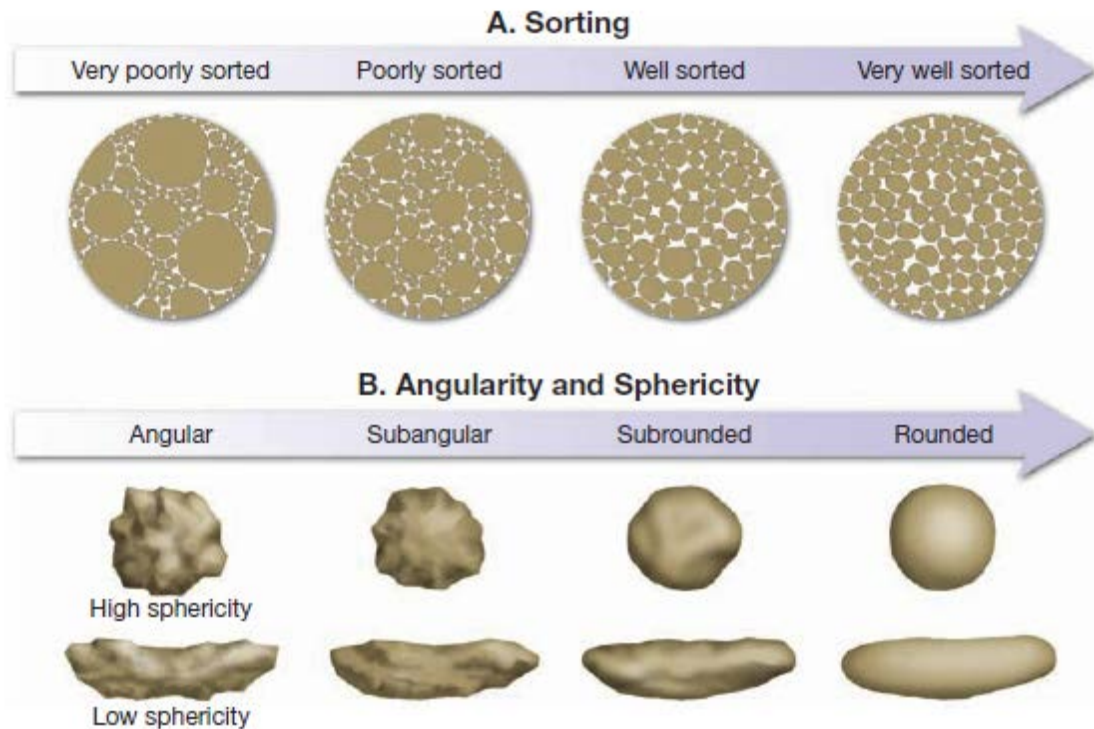


FIGURE 6.5 **A.** Detrital rocks commonly have a variety of different size clasts. *Sorting* refers to the range of sizes present. Rocks with clasts that are nearly all the same size are considered “well sorted.” When sediments are “very poorly sorted,” there is a wide range of different sizes. When a rock contains larger clasts surrounded by much smaller ones, the mass of smaller clasts is often referred to as the *matrix*. **B.** Geologists describe a particle’s shape in terms of its *angularity* (degree to which the clast’s edges and corners are rounded) and *sphericity* (how close the shape of the clast is to a sphere). Transportation reduces the size and angularity of clasts but does not change their general shape.

COMPOSITION. Owing to its durability, quartz is the predominant mineral in most sandstones. When this is the case, the rock may simply be called **quartz sandstone**. 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. Matrix refers to the silt- and clay-size particles found in spaces between larger sand grains. 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 then rapidly deposited. Before the sediment could be reworked and sorted further, it was most likely 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 gravels. As Figure 6.3 indicates, these particles may range in size from large boulders to particles as small as garden peas (FIGURE 6.7). The particles are commonly 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.*

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 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 6.3). Because large particles roughen 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.*

Chemical Sedimentary Rocks

Sedimentary Rocks Types of Sedimentary Rocks

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 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. 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 ocean as biochemical sediment.*

Limestone

Representing about 10 percent of the total volume of all sedimentary rocks, limestone is the most abundant chemical sedimentary rock.

It is composed chiefly of the mineral calcite (CaCO_3) and forms either by inorganic means or as the result of biochemical processes.

Regardless of its origin, the mineral composition of all limestone is similar, yet many different

types exist. This is true because lime-stones are produced under a variety of conditions. Those forms having a marine biochemical origin are by far the most common.

CARBONATE REEFS. Corals(الشعاب المرجانية) 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. 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 reefs.

Certainly the best-known modern reef is Australia's Great Barrier Reef, 2000 kilometers (1240 miles) long, but many lesser reefs also exist. They develop in the shallow, warm waters of the tropics and subtropics equator-ward of about 30° latitude. Striking examples exist in the Bahamas and Florida Keys.

Modern corals were not the first reef builders. Earth's first reef-building organisms were photosynthesizing bacteria living during carbonate. As water droplets become exposed to the air in a cavern, some of the carbon dioxide dissolved in the water escapes, causing calcium carbonate to precipitate.

Another variety of inorganic limestone is oolitic limestone. It is a rock composed of small spherical grains called **ooids**. Ooids form in shallow marine waters as tiny seed particles (commonly small shell fragments) and are moved back and forth by currents. As the grains are rolled about in the warm water, which is supersaturated with calcium carbonate, they become coated with layer upon layer of the chemical precipitate.

Dolostone:

Closely related to limestone is dolostone, a rock composed of the calcium-magnesium carbonate mineral dolomite [$\text{CaMg}(\text{CO}_3)_2$].

Although dolostone and limestone sometimes closely resemble one another, they can be easily distinguished by observing their reaction to dilute hydrochloric acid. When a drop of acid is placed on limestone, the reaction is obvious. However, unless dolostone is powdered, it will not visibly react to the acid.

The origin of dolostone is not altogether clear and remains a subject of discussion among geologists. No marine organisms produce hard parts of dolomite, and the chemical precipitation of dolomite from seawater occurs only under conditions of unusual water chemistry in certain near-shore sites. Yet, dolostone is abundant in many ancient sedimentary rock successions.

It appears that significant quantities of dolostone are produced when magnesium-rich waters circulate through limestone and convert calcite to dolomite by the replacement of some calcium ions with magnesium ions (a process called dolomitization). However, other dolostones lack evidence that they formed by such a process, and their origin remains uncertain.

Chert: (hard, dark, rock composed of silica (chalcedony) with an amorphous or microscopically fine-grained texture)

Chert is a name used for a number of very compact and hard rocks made of microcrystalline quartz (SiO_2). One well-known form is flint, whose dark color results from the 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 old as 500 million years, but corals similar to the modern colonial varieties have constructed reefs only during the last 60 million years. In the United States, reefs of Silurian age (416 to 444 million years ago) are prominent features in Wisconsin, Illinois, and Indiana. In west Texas and adjacent southeastern New Mexico, a massive reef complex formed during the Permian period (251 to 299 million years ago) is strikingly exposed in Guadalupe Mountains National Park (Figure 6.10B).

COQUINA AND CHALK. Although much limestone is the product of biological processes, this origin is not always evident, because shells and skeletons may undergo considerable change before becoming lithified into rock. However, one easily identified biochemical limestone is coquina, a coarse rock composed of poorly cemented shells and shell fragments (see Figure 6.9B). Another less obvious but nevertheless familiar example is chalk, a soft, porous rock made up almost entirely of the hard parts of microscopic marine organisms smaller than the head of a pin. Among the most famous chalk deposits are those exposed along the southeast coast of England (FIGURE 6.11).

INORGANIC LIMESTONES.

Limestones having an inorganic origin form when chemical changes or high water temperatures increase the concentration of calcium carbonate to the point that it precipitates. Travertine, the type of limestone commonly seen in caves, is an example (Figure 6.8). When travertine is deposited in caves, groundwater is the source of the calcium organic matter it contains. Jasper, a red variety, gets its bright color from iron oxide. The banded form is usually referred to as agate. Like glass, most chert has a conchoidal fracture. Its hardness, ease of chipping, and ability to hold a sharp edge made chert a favorite of Native Americans for fashioning points for spears and arrows. Because of chert's durability and extensive use, "arrowheads" are found in many parts of North America.

Chert deposits are commonly found in one of two situations:
as layered deposits referred to as bedded cherts and as nodules, somewhat spherical masses varying in diameter from a few millimeters (pea size) to a few centimeters.

Most water-dwelling organisms that produce hard parts make them of calcium carbonate. But some, such as diatoms and radiolarians, produce glasslike silica skeletons. These tiny organisms are able to extract silica even though seawater contains only tiny quantities of the dissolved material. It is from their remains that most bedded cherts are believed to originate. Some bedded cherts occur in association with lava flows and layers of volcanic ash. For these occurrences it is probable that the silica was derived from the decomposition of the volcanic ash and not from biochemical sources. Chert nodules are sometimes referred to as secondary or replacement cherts and most often occur within beds of limestone.

They form when silica originally deposited in one place dissolves, migrates, and then chemically precipitates elsewhere, replacing older material.

Evaporites:

Very often, evaporation is the mechanism triggering deposition of chemical precipitates. Minerals commonly precipitated in this fashion include halite (sodium chloride, NaCl), the chief component of rock salt, and gypsum (hydrous calcium sulfate, CaSO₄ · 2H₂O), the main ingredient of rock gypsum. Both have significant commercial importance. Halite is familiar to everyone as the common salt used in cooking and for seasoning foods. Of course, it has many

other uses—from melting ice on roads to making hydrochloric acid—and has been considered important enough that people have sought, traded, and fought over it for much of human history. Gypsum is the basic ingredient of plaster of Paris. This material is used most extensively in the construction industry for wallboard and interior plaster.

In the geologic past, many areas that are now dry land were basins, submerged under shallow arms of a sea that had only narrow connections to the open ocean. Under these conditions, seawater continually moved into the bay to replace water lost by evaporation. Eventually the waters of the bay became saturated and salt deposition began. Such deposits are called evaporites.

Coal—An Organic Sedimentary Rock:

Coal is quite different from other sedimentary rocks. Unlike limestone and chert, which are calcite or silica rich, coal is made mostly of organic matter.

Close examination of a piece of coal under a microscope or magnifying glass often reveals plant structures such as leaves, bark, and wood that have been chemically altered but are still identifiable.

This supports the conclusion that coal is the end product of large amounts of plant material buried for millions of years. The initial stage in coal formation is the accumulation of large quantities of plant remains. However, special conditions are required for such accumulations because dead plants normally decompose when exposed to the atmosphere or other oxygen-rich environments. One important environment that allows for the buildup of plant material is a swamp.

Stagnant swamp water is oxygen deficient, so complete decay (oxidation) of the plant material is not possible. Instead, the plants are attacked by certain bacteria that partly decompose the organic material and liberate oxygen and hydrogen. As these elements escape, the percentage of carbon gradually increases. The bacteria are not able to finish the job of decomposition because they are destroyed by acids liberated from the plants.

The partial decomposition of plants in an oxygen-poor swamp creates a layer of peat, a soft brown material in which plant structures are still easily recognized. With shallow burial, peat slowly changes to lignite, a soft brown coal. Burial increases the temperature of sediments as well as the pressure on them.

The higher temperatures bring about chemical reactions within the plant materials and yield water and organic gases (volatiles). As the load increases from more sediment on top of the developing coal, the water and volatiles are pressed out and the proportion of fixed carbon (the remaining solid combustible material) increases. The greater the carbon content, the greater the coal's energy ranking as a fuel. During burial the coal also becomes increasingly compact.

For example, deeper burial transforms lignite into a harder, more compacted black rock called bituminous coal. Compared to the peat from which it formed, a bed of bituminous coal may be only 1/10 as thick.

Lignite and bituminous coals are sedimentary rocks. However, when sedimentary layers are subjected to the folding and deformation associated with mountain building, the heat and pressure cause a further loss of volatiles and water, thus increasing the concentration of fixed carbon. This metamorphoses bituminous coal into anthracite, a very hard, shiny, black metamorphic rock. Although anthracite is a clean burning fuel, only a relatively small amount is mined. Anthracite is not widespread and is more difficult and expensive to extract than the relatively flat-lying layers of bituminous coal. Coal is a major energy resource. Its role as a fuel and some of the problems associated with burning coal are discussed later in this chapter.

Turning Sediment into Sedimentary Rock: Diagenesis and Lithification:

A great deal of change can occur to sediment from the time it is deposited until it becomes a sedimentary rock and is subsequently subjected to the temperatures and pressures that convert it to metamorphic rock. The term diagenesis is a collective term for all of the chemical, physical, and biological changes that take place after sediments are deposited and during and after lithification.

Burial promotes diagenesis because as sediments are buried, they are subjected to increasingly higher temperatures and pressures. Diagenesis occurs within the upper few kilometers of Earth's crust at temperatures that are generally less than 150° to 200° C. Beyond this somewhat arbitrary threshold, metamorphism is said to occur.

One example of diagenetic change is recrystallization, the development of more stable minerals from less stable ones. It is illustrated by the mineral aragonite, the less stable form of calcium carbonate (CaCO₃). Aragonite is secreted by many marine organisms to form shells and other hard parts, such as the skeletal structures produced by corals. In some environments, large quantities of these solid materials accumulate as sediment. As burial takes place, aragonite recrystallizes to the more stable form of calcium carbonate, calcite, the main constituent in the sedimentary rock limestone.

Another example of diagenesis was provided in the preceding discussion of coal. It involved the chemical alteration of organic matter in an oxygen-poor environment.

Instead of completely decaying, as would occur in the presence of oxygen, the organic matter is slowly transformed to solid carbon.

Diagenesis includes lithification (,), the processes by which unconsolidated sediments are transformed into solid sedimentary rocks. Basic lithification processes include compaction and cementation. The most common physical diagenetic change is compaction. As sediment accumulates, the weight of overlying material compresses the deeper sediments. The deeper a sediment is buried, the more it is compacted and the firmer it becomes. As the grains are pressed closer and closer, there is considerable reduction in pore space (the open space between particles). For example, when clays are buried beneath several thousand meters of material, the volume of clay may be reduced by as much as 40 percent. As pore space decreases, much of the water that was trapped in the sediments is driven out.

Because sands and other coarse sediments are less compressible, compaction is most significant as a lithification process in fine-grained sedimentary rocks.

Cementation is the most important process by which sediments are converted to sedimentary rock. It is a diagenetic change that involves the crystallization of minerals among the individual sediment grains.

Groundwater carries ions in solution. Gradually, the crystallization of new minerals from these ions takes place in the pore spaces, cementing the clasts together. Just as the amount of pore space is reduced during compaction, the addition of cement into a sedimentary deposit reduces its porosity as well.

Calcite, silica, and iron oxide are the most common cements. It is often a relatively simple matter to identify the cementing material. Calcite cement will bubble with dilute hydrochloric acid. Silica is the hardest cement and thus produces the lithos = stone fic = making As is the case with many (perhaps most) classifications of natural phenomena, the categories presented in Figure 6.16 are more rigid than the actual state of nature.

In reality, many of the sedimentary rocks classified into the chemical group also contain at least small quantities of detrital sediment. Many lime-stones, for example, contain varying amounts of mud or sand, giving them a “sandy” or “shaly” quality.

Conversely, because practically all detrital rocks are cemented with material that was originally dissolved in water, they too are far from being “pure.”

As was the case with the igneous rocks examined in Chapter 3, texture is a part of sedimentary rock classification. Two major textures are used in the classification of sedimentary rocks: clastic and nonclastic.

The term clastic is taken from a Greek word meaning “broken.” Rocks that display a clastic texture consist of discrete fragments and particles that are cemented and compacted together. Although cement is present in the spaces between particles,

Detrital Sedimentary Rocks Chemical and Organic Sedimentary Rocks

Travertine

FIGURE 6.16 Identification of sedimentary rocks. Sedimentary rocks are divided into three groups—detrital, chemical, and organic. The main criterion for naming detrital sedimentary rocks is particle size, whereas the primary basis for distinguishing among chemical sedimentary rocks is their mineral composition.

hardest sedimentary rocks. An orange or dark red color in a sedimentary rock means that iron oxide is present.

Most sedimentary rocks are lithified by means of compaction and cementation. However, some initially form as solid masses of inter-grown crystals rather than beginning as accumulations of separate particles that later become solid. Other crystalline sedimentary rocks do not begin that way but rather are transformed into masses of interlocking crystals sometime after the sediment is deposited.

For example, with time and burial, loose sediment consisting of delicate calcareous skeletal debris may be recrystallized into a relatively dense crystalline limestone. Because crystals grow until they fill all the available space, pore spaces are frequently lacking in crystalline sedimentary rocks. Unless the rocks later develop joints and fractures, they will be relatively impermeable to fluids like water and oil.

Classification of Sedimentary Rocks:

The classification scheme in FIGURE 6.16 divides sedimentary rocks into two major groups: detrital and chemical/organic. Further, we can see that the main criterion for subdividing the detrital rocks is particle size, whereas the primary basis for distinguishing among different rocks in the chemical group is their mineral composition. As is the case with many (perhaps

most) classifications of natural phenomena, the categories presented in Figure 6.16 are more rigid than the actual state of nature.

In reality, many of the sedimentary rocks classified into the chemical group also contain at least small quantities of detrital sediment. Many limestones, for example, contain varying amounts of mud or sand, giving them a “sandy” or “shaly” quality.

Conversely, because practically all detrital rocks are cemented with material that was originally dissolved in water, they too are far from being “pure.”

As was the case with the igneous rocks examined in Chapter 3, texture is a part of sedimentary rock classification. Two major textures are used in the classification of sedimentary rocks: clastic and nonclastic. The term clastic is taken from a Greek word meaning “broken.” Rocks that display a clastic texture consist of discrete fragments and particles that are cemented and compacted together. Although cement is present in the spaces between particles these openings are rarely filled completely. All detrital rocks have a clastic texture. In addition, some chemical sedimentary rocks exhibit this texture. For example, limestone composed of shells and shell fragments, is obviously as clastic as conglomerate or sandstone. The same applies for some varieties of oolitic limestone. Some chemical sedimentary rocks have a nonclastic or crystalline texture in which the minerals form a pattern of interlocking crystals. The crystals may be microscopically small or large enough to be visible without magnification. Common examples of rocks with nonclastic textures are evaporates (FIGURE 6.17). The materials that make up many other nonclastic rocks may actually have originated as detrital deposits.

In these instances, the particles probably consisted of shell fragments and other hard parts rich in calcium carbonate or silica.

The clastic nature of the grains was subsequently obliterated or obscured because the particles recrystallized when they were consolidated into limestone or chert. Nonclastic rocks consist of intergrown crystals, and some may resemble igneous rocks, which are also crystalline. The two rock types are usually easy to distinguish because the minerals that make up nonclastic sedimentary rocks are different from those found in most igneous rocks. For example, rock salt, rock gypsum, and some forms of limestone consist of intergrown crystals, but the minerals contained within these rocks (halite, gypsum, and calcite) are seldom associated with igneous rocks.




Detrital Sedimentary Rocks				Chemical and Organic Sedimentary Rocks				
Clastic Texture (particle size)		Sediment Name	Rock Name	Composition	Texture	Rock Name		
Coarse (over 2 mm)		Gravel (Rounded particles)	Conglomerate	Calcite, CaCO ₃	Nonclastic: Fine to coarse crystalline	Crystalline Limestone		
		Gravel (Angular particles)	Breccia			Travertine		
Medium (1/16 to 2 mm)		Sand	Sandstone		Clastic: Visible shells and shell fragments loosely cemented	Bioclastic Limestone	Coquina	
		(If abundant feldspar is present the rock is called Arkose)			Clastic: Various size shells and shell fragments cemented with calcite cement		Fossiliferous Limestone	
Fine (1/16 to 1/256 mm)	Mud	Siltstone	Clastic: Microscopic shells and clay		Chalk			
Very fine (less than 1/256 mm)	Mud	Shale or Mudstone						
					Quartz, SiO ₂	Nonclastic: Very fine crystalline	Chert (light colored) Flint (dark colored)	
					Gypsum CaSO ₄ •2H ₂ O	Nonclastic: Fine to coarse crystalline	Rock Gypsum	
				Halite, NaCl	Nonclastic: Fine to coarse crystalline	Rock Salt		
				Altered plant fragments	Nonclastic: Fine-grained organic matter	Bituminous Coal		

FIGURE 6.16 Identification of sedimentary rocks. Sedimentary rocks are divided into three groups—detrital, chemical, and organic. The main criterion for naming detrital sedimentary rocks is particle size, whereas the primary basis for distinguishing among chemical sedimentary rocks is their mineral composition.

Sedimentary Rocks Represent Past Environments

Sedimentary Rocks Sedimentary Environments

Sedimentary rocks are important in the interpretation of Earth history. By understanding the conditions under which sedimentary rocks form, geologists can often deduce the history of a rock, including information about the origin of its component particles, the method of sediment transport, and the nature of the place where the grains eventually came to rest; that is, the environment of deposition. An environment of deposition or sedimentary environment is simply a geographic setting where sediment is accumulating. Each site is characterized by a particular combination of geologic processes and environmental conditions. Thus, when a series of sedimentary layers is studied, we can see the successive changes in environmental conditions that occurred at a particular place with the passage of time.

At any given time, the geographic setting and environmental conditions of a sedimentary environment determine the nature of the sediments that accumulate.

Therefore, geologists carefully study the sediments in present-day depositional environments because the features they find can also be observed in ancient sedimentary rocks. By applying a thorough knowledge of present-day conditions, geologists attempt to reconstruct the ancient

environments and geographical relationships of an area at the time a particular set of sedimentary layers were deposited. Such analyses often lead to the creation of maps depicting the geographic distribution of land and sea, mountains and river valleys, deserts and glaciers, and other environments of deposition. The foregoing description is an excellent example of the application of a fundamental principle of modern geology, namely that “the present is the key to the past.”* Sedimentary environments are commonly placed into one of three categories: continental, marine, or transitional (shoreline). Each category includes many specific subenvironments. FIGURE 6.18 is an idealized diagram illustrating a number of important sedimentary environments associated with each category. Later, Chapters 9 through 13 will describe these environments in detail. Each is an area where sediment accumulates and where organisms live and die. Each produces a characteristic sedimentary rock or assemblage that reflects prevailing conditions.

Sedimentary Structures

In addition to variations in grain size, mineral composition, and texture, sediments exhibit a variety of structures. Some, such as graded beds, are created when sediments are cumulating and are a reflection of the transporting medium. Others, such as mud cracks, form after the materials have been deposited and result from processes occurring in the environment. When present, sedimentary structures provide additional information that can be useful in the interpretation of Earth history.

Sedimentary rocks form as layer upon layer of sediment accumulates in various depositional environments. These layers, called strata or beds, are probably the single most common and characteristic feature of sedimentary rocks. Each stratum is unique. It may be a coarse sandstone, a fossil-rich limestone, a black shale, and so on. When you look at FIGURE 6.19, or look back through this chapter at Figures 6.1 and 6.4, you will see many such layers, each different from the others. The variations in texture, composition, and thickness reflect the different conditions under which each layer was deposited.

The thickness of beds ranges from microscopically thin to tens of meters thick. Separating the strata are bedding planes, flat surfaces along which rocks tend to separate or break.

Changes in the grain size or in the composition of the sediment being deposited can create bedding planes. Pauses in deposition can also lead to layering because chances are slight that newly deposited material will be exactly the same as previously deposited sediment.

Generally, each bedding plane marks the end of one episode of sedimentation and the beginning of another. Because sediments usually accumulate as particles that settle from a fluid, most strata are originally deposited as horizontal layers. There are circumstances, however, when sediments do not accumulate in horizontal beds. Sometimes when a bed of sedimentary rock is examined, we see layers within it that are inclined to the horizontal. When this occurs, it is called cross-bedding and is most characteristic of sand dunes, river deltas, and certain stream channel deposits (see Figure 6.6A and FIGURE 6.20).

Graded beds represent another special type of bedding. In this case the particles within a single sedimentary layer gradually change from coarse at the bottom to fine at the top. Graded beds are most characteristic of rapid deposition from water containing sediment of varying sizes. When a current experiences a rapid energy loss, the largest particles settle first, followed by successively smaller grains. The deposition of a graded bed is most often associated with a

turbidity current, a mass of sediment choked water that is denser than clear water and that moves downslope along the bottom of a lake or ocean (FIGURE 6.21).

As geologists examine sedimentary rocks, much can be deduced. A conglomerate, for example, may indicate a high energy environment, such as a surf zone or rushing stream, where only coarse materials settle out and finer particles are kept suspended.

If the rock is arkose, it may signify a dry climate where little chemical alteration of feldspar is possible. Carbonaceous shale is a sign of a low-energy, organic-rich environment, such as a swamp or lagoon.

Other features found in some sedimentary rocks give clues to past environments.

Ripple marks are such a feature. Ripple marks are small waves of sand that develop on the surface of a sediment layer by the action of moving water or air (FIGURE 6.22A). The ridges form at right angles to the direction of motion. If the ripple marks were formed by air or water moving in essentially one direction, their form will be asymmetrical. These current ripple marks will have steeper sides in the down-current direction and more gradual slopes on the up-current side. Ripple marks produced by a stream flowing across a sandy channel or by wind blowing over a sand dune are two common examples of current ripples.

When present in solid rock, they may be used to determine the direction of movement of ancient wind or water currents.

Other ripple marks have a symmetrical form. These features, called oscillation ripple marks, result from the back-and-forth movement of surface waves in a shallow near-shore environment. Mud cracks (Figure 6.22B) indicate that the sediment in which they were formed was alternately wet and dry. When exposed to air, wet mud dries out and shrinks, producing cracks. Mud cracks are associated with such environments as tidal flats, shallow lakes, and desert basins.

Fossils, the remains or traces of prehistoric life, are important inclusions in sediment and sedimentary rock. They are important tools for interpreting the geologic past. Knowing the nature of the life forms that existed at a particular time helps researchers decipher past environmental conditions. Further, fossils are important time indicators and play a key role in correlating rocks that are of similar ages but are from different places. Fossils will be examined in more detail in Chapter 18.

Nonmetallic Mineral Resources from Sedimentary Rocks

Earth materials that are not used as fuels or processed for the metals they contain are referred to as **nonmetallic mineral resources**. Realize that use of the word “mineral” is very broad in this economic context and is quite different from the geologist’s strict definition of mineral found in Chapter 2. Nonmetallic mineral resources are extracted and processed either for the nonmetallic elements they contain or for the physical and chemical properties they possess. Although these resources have diverse origins, many are sediments or sedimentary rocks.

People often do not realize the importance of nonmetallic minerals, because they see only the products that resulted from their use and not the minerals themselves.

That is, many nonmetallics are used up in the process of creating other products.

Examples include the fluorite and limestone that are part of the steelmaking process, the abrasives required to make a piece of machinery, and the fertilizers needed to grow a food crop. The quantities of nonmetallic minerals used each year are enormous. Per capita consumption of nonfuel resources in the United States is nearly 11 metric tons, of which over 95 percent are nonmetallic (FIGURE 6.23). Nonmetallic mineral resources are commonly divided into two broad groups: building materials and industrial minerals. Because some substances have many

different uses, they are found in both categories. Limestone, perhaps the most versatile and widely used rock of all, is the best example. As a building material, it is used not only as crushed rock and building stone but also in making cement.

Moreover, as an industrial mineral, limestone is an ingredient in the manufacture of steel and is used in agriculture to neutralize acidic soils.

Other important building materials include cut stone, aggregate (sand, gravel, and crushed rock), gypsum for plaster and wallboard, clay for tile and bricks, and cement, which is made from limestone and shale. Cement and aggregate go into the making of concrete, a material that is essential to practically all construction.

A wide variety of resources are classified as industrial minerals. In some instances these materials are important because they are sources of specific chemical elements or compounds. Such minerals are used in the manufacture of chemicals and the production of fertilizers. In other cases their importance is related to the physical properties they exhibit.

Examples include minerals such as corundum and garnet, which are used as abrasives. Although supplies are generally plentiful, most industrial minerals are not nearly as abundant as building materials. Moreover, deposits are far more restricted in distribution and extent.

As a result, many of these nonmetallic resources must be transported considerable distances, which of course adds to their cost. Unlike most building materials, which need a minimum of processing before they are ready to use, many industrial minerals require considerable processing to extract the desired substance at the proper degree of purity for its ultimate use.

Energy Resources from Sedimentary Rocks:

Coal, petroleum, and natural gas are the primary fuels of our modern industrial economy. About 84 percent of the energy consumed in the United States today comes from these basic fossil fuels (FIGURE 6.24). Although major shortages of oil and gas will not occur for many years, proven reserves are declining. Despite new exploration, even in very remote regions and severe environments, new sources of oil are not keeping pace with consumption. Unless large, new petroleum reserves are discovered (which is possible but not likely), a greater share of our future needs