Welcome

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CE181404
Engineering Geology

Sedimentary Rocks

Origins of Sedimentary Rock

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.

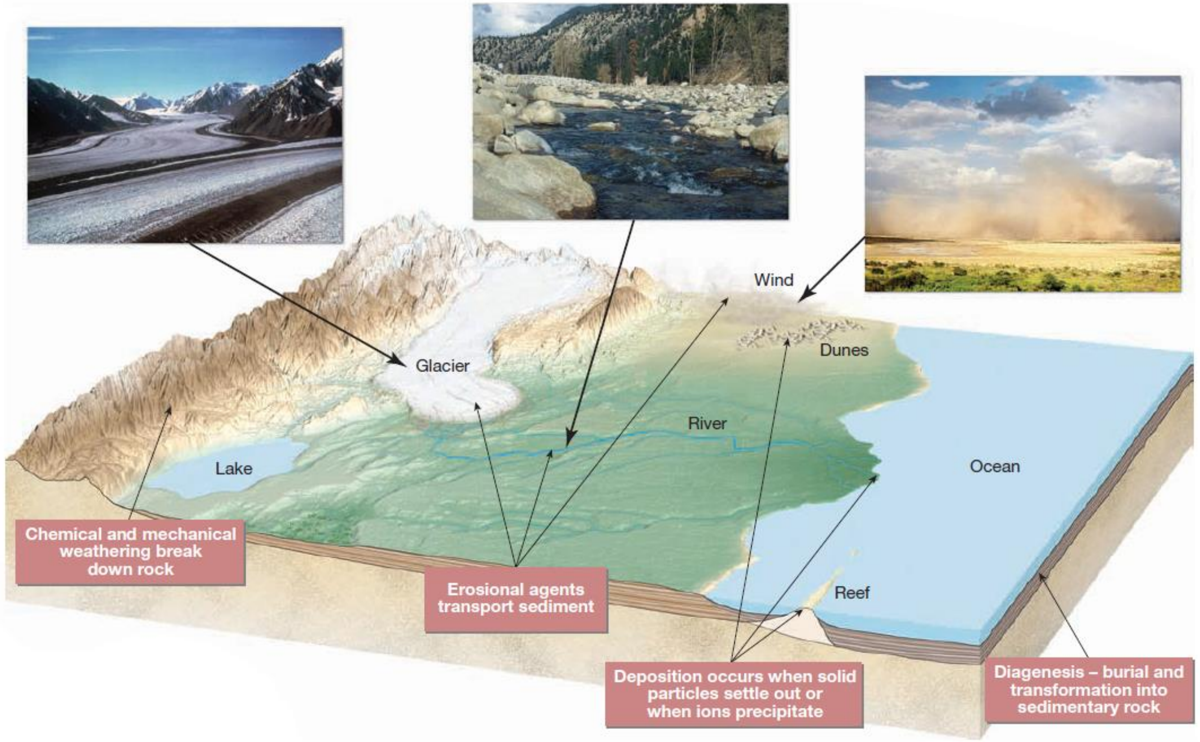

FIGURE 6.2 This diagram outlines the portion of the rock cycle that pertains to the formation of sedimentary rocks. Weathering, transportation, deposition, and diagenesis represent the basic processes involved. *(Left and center photos by E. J. Tarbuck; right photo by Jenny Elia Pfeiffer/Corbis)*

Origins of Sedimentary Rock

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(dia* = change; *genesis* = origin*)* 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.

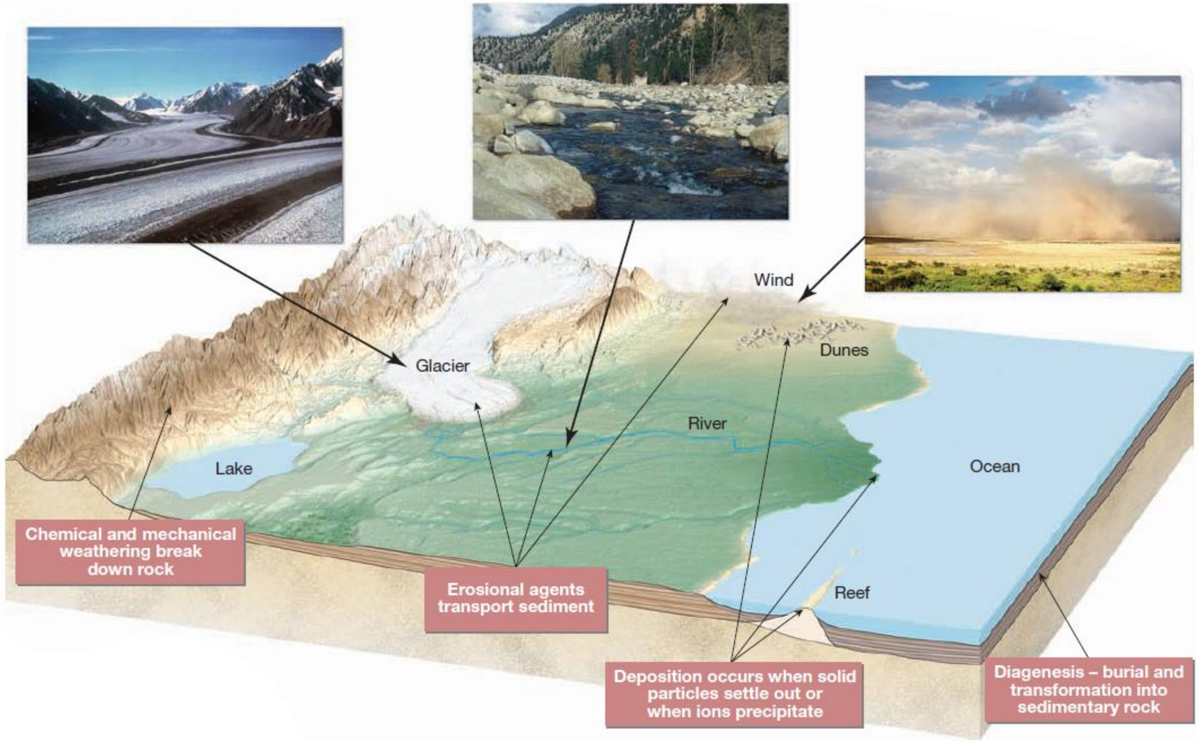

FIGURE 6.2 This diagram outlines the portion of the rock cycle that pertains to the formation of sedimentary rocks. Weathering, transportation, deposition, and diagenesis represent the basic processes involved. *(Left and center photos by E. J. Tarbuck; right photo by Jenny Elia Pfeiffer/Corbis)*

Weathering, Erosion, Transportation, Deposition

- Earth is a web of interconnected dynamic systems that are responsible for geologic, hydrologic, atmospheric, and biologic change over time.
- 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.
- 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.”

Sedimentary rocks

- Sedimentary rocks are either made up of broken and eroded fragments of pre-existing rocks that have been transported to their site of deposition by the action of water, ice, wind or gravity (e.g. sandstone and mudstone) or formed by the accumulation of the remains or secretions of animals and plants (e.g. fossiliferous limestone and coal) by the precipitation of minerals from solution (salt and other evaporite deposits).
- These three processes have resulted in the formation of ***detrital, biological*** and ***chemical sedimentary rocks***, respectively.

TYPES OF SEDIMENTARY ROCKS

Sedimentary rocks are formed from

(1) eroded mineral grains,

(2) minerals precipitated from low-temperature solution, or

(3) consolidation of the organic remains of plants.

These different types of sedimentary rocks are called, respectively, *detrital, chemical,* and *organic* rocks.

Types Of Sedimentary Rocks

- ***Detrital sedimentary rocks***

  (also called Clastic or Terrigenous sedimentary rocks), formed from fragments of pre existing rocks.

- ***Chemical Sedimentary rocks***,

  formed from chemical precipitates or from the shells of organisms.

- ***Organic sedimentary rocks***,

  composed of organic matter or carbon.

Types Of Sedimentary Rocks

- First, it may be an accumulation of material that 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.

Detrital sedimentary rocks

- Detrital sedimentary rocks are formed from the weathered and eroded remains (detritus) of bedrock. Detrital rocks are also often referred to as *terrigenous clastic rocks* because they are composed of *clasts* (broken pieces) of mineral derived from the erosion of the land.
- Detrital sedimentary rocks are derived from pre-existing rocks. They are composed of rock fragments and mineral grains that have been weathered, eroded, transported, deposited, and cemented together to form a sedimentary rock.
- The individual grains (or clasts) in these rocks are mechanically durable (able to withstand abrasion during transport) and chemically stable.
- *Typical clasts are made of:*
  - quartz,
  - feldspar,
  - muscovite,
  - clay minerals, or
  - rock fragments.

Detrital sedimentary rocks

Particle size is the primary basis for distinguishing among various detrital sedimentary rocks.

Common detrital sedimentary rocks, in order of increasing particle size, are:

- shale,
- sandstone, and
- conglomerate or breccia.

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

0 10 20 30 40 50 60 70 mm

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

Detrital sedimentary rocks: Shale

Rocks consisting of fine-grained silt and clay are called *shale, siltstone, claystone,* and *mudstone.*

Shale is a sedimentary rock consisting of silt- and clay-size particles.

Shale is a fine-grained sedimentary rock notable for its ability to split into layers (called *fissility*). Splitting takes place along the surfaces of very thin layers (called *laminations*) within the shale (figure 14.11).

A rock consisting mostly of silt grains is called *siltstone.* Somewhat coarser-grained than most shales, siltstones lack the fissility and laminations of shale.

Claystone is a rock composed predominately of clay-sized particles but lacking the fissility of shale.

Mudstone contains both silt and clay, having the same grain size and smooth feel of shale but lacking shale's laminations and fissility. Mudstone is massive and blocky, while shale is visibly layered and fissile.

Size Range (millimeters)	Particle Name	Common Name	Detrital Rock
>256	Boulder	Gravel	Conglomerate 
64–256	Cobble		or
4–64	Pebble		
2–4	Granule		Breccia 
1/16–2	Sand	Sand	Sandstone 
1/256–1/16	Silt	Mud	Shale, Mudstone or Siltstone 
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FIGURE 6.3 Particle size classification for detrital sedimentary rocks. Particle size is the primary basis for distinguishing among various detrital sedimentary rocks. *(Photos by E. J. Tarbuck)*

Detrital sedimentary rocks: Shale

A

B

FIGURE 14.11

(A) An outcrop of shale from Hudson Valley in New York. Note how this fine-grained rock tends to split into very thin layers. (B) Shale pieces; note the very fine grain (scale in centimeters), very thin layers (laminations) on the edge of the large piece, and tendency to break into small, flat pieces (fissility). *Photo A © John Buitenkant/Photo Researchers Inc.; Photo B by David McGeary*

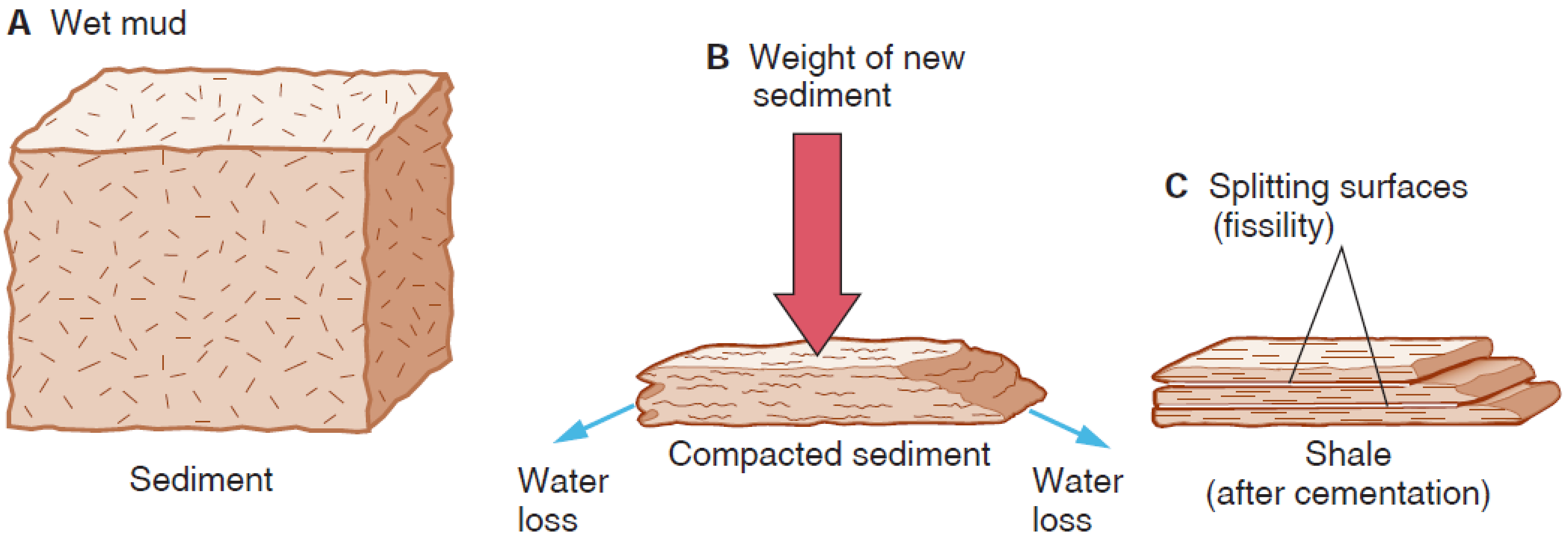

FIGURE 14.12

Lithification of shale from the compaction and cementation of wet mud. (*A*) Randomly oriented silt and clay particles in wet mud. (*B*) Particles reorient, water is lost, and pore space decreases during compaction caused by the weight of new sediment deposited on top of the wet mud. (*C*) Splitting surfaces in cemented shale form parallel to the oriented mineral grains.

Detrital Sedimentary Rocks: Sandstone

Sandstone is the name given rocks in which sand-sized grains predominate.

Sandstones form in a variety of environments and often contain significant clues about their origin, including sorting, particle shape, and composition.

Size Range (millimeters)	Particle Name	Common Name	Detrital Rock
>256	Boulder	Gravel	Conglomerate 
64–256	Cobble		or
4–64	Pebble		Breccia 
2–4	Granule		
1/16–2	Sand	Sand	Sandstone 
1/256–1/16	Silt	Mud	Shale, Mudstone or Siltstone 
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0 10 20 30 40 50 60 70 mm

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

Detrital Sedimentary Rocks: Sandstone

Sandstone is formed by the cementation of sand grains (figure 14.7). Any deposit of sand can lithify to sandstone.

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*.

A third variety of sandstone is known as *graywacke* (pronounced “gray-wacky”). 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.

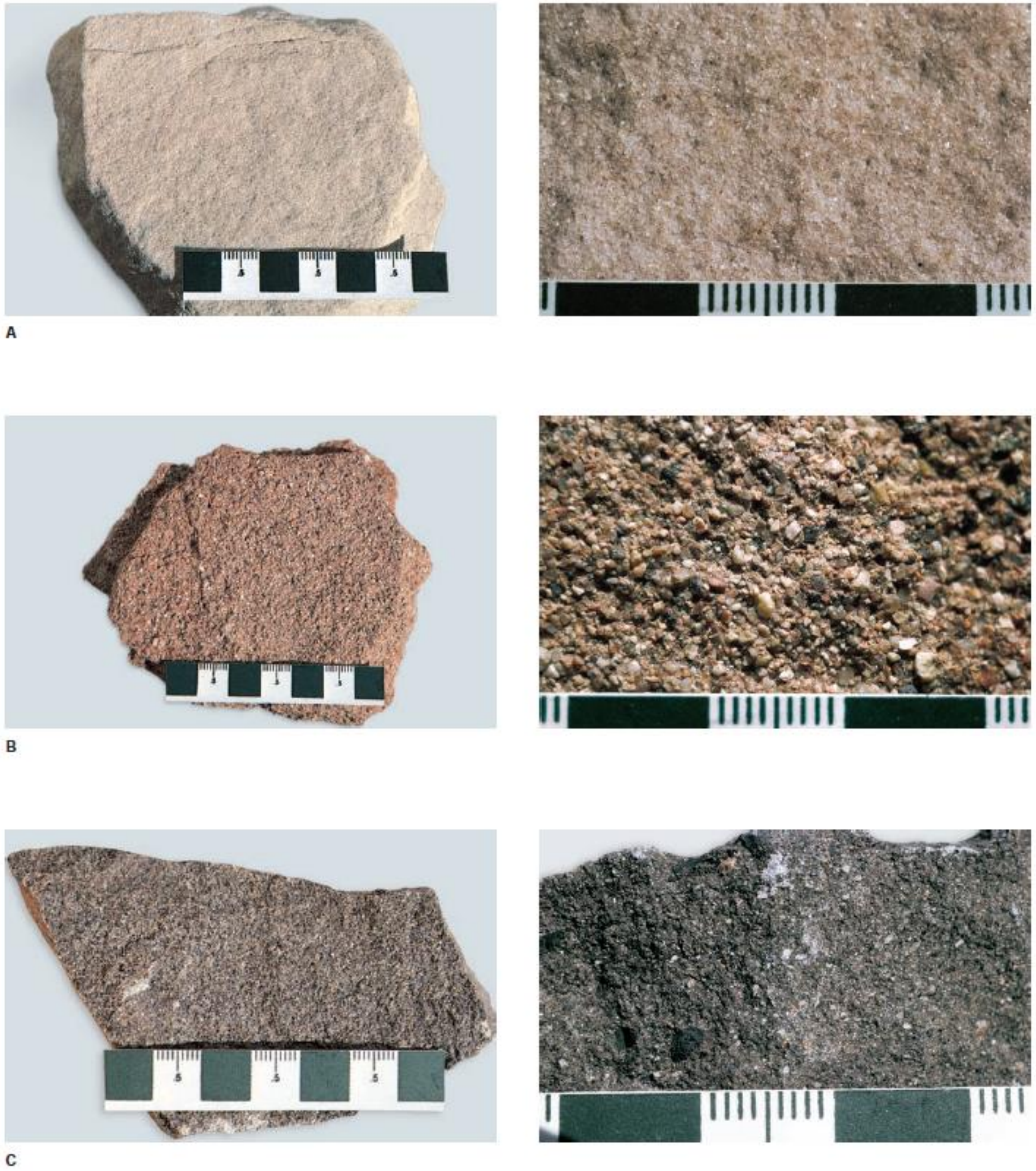
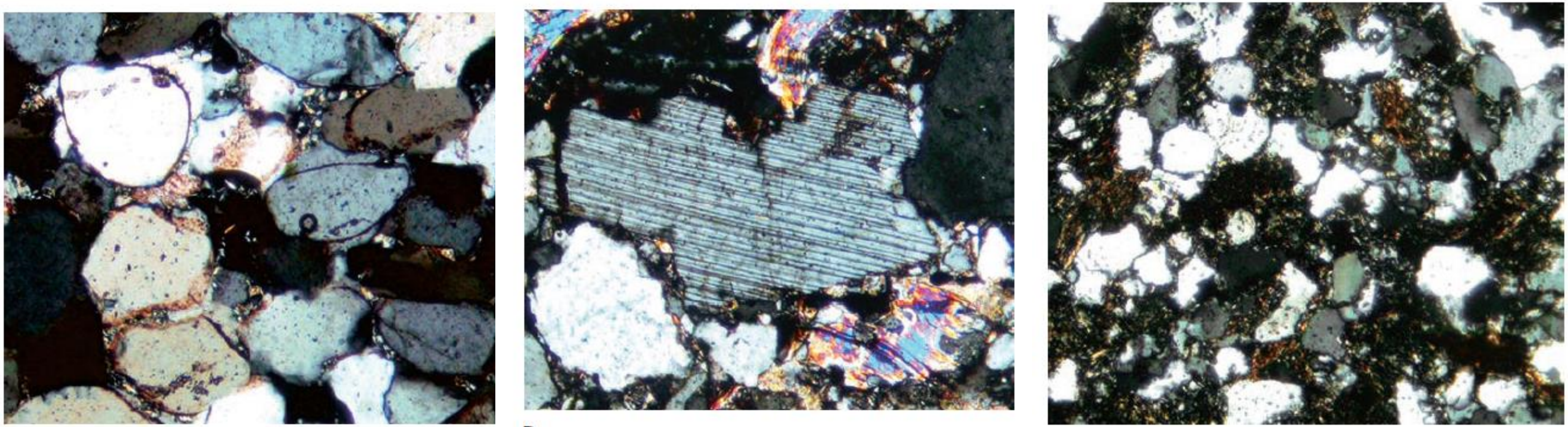


FIGURE 14.7

Types of sandstone. (*A*) Quartz sandstone; more than 90% of the grains are quartz. (*B*) Arkose; the grains are mostly feldspar and quartz. (*C*) Graywacke; the grains are surrounded by dark, fine-grained matrix. (Small scale divisions are 1 millimeter; most of the sand grains are about 1 millimeter in diameter.) *Photos by David McGeary*



A B C

FIGURE 14.8

Detrital sedimentary rocks viewed through a polarizing microscope. (*A*) Quartz sandstone; note the well-rounded and well-sorted grains. (*B*) Arkose; large feldspar grain in center surrounded by angular quartz grains. (*C*) Graywacke; quartz grains surrounded by brownish matrix of mud. *Photos by Bret Bennington*

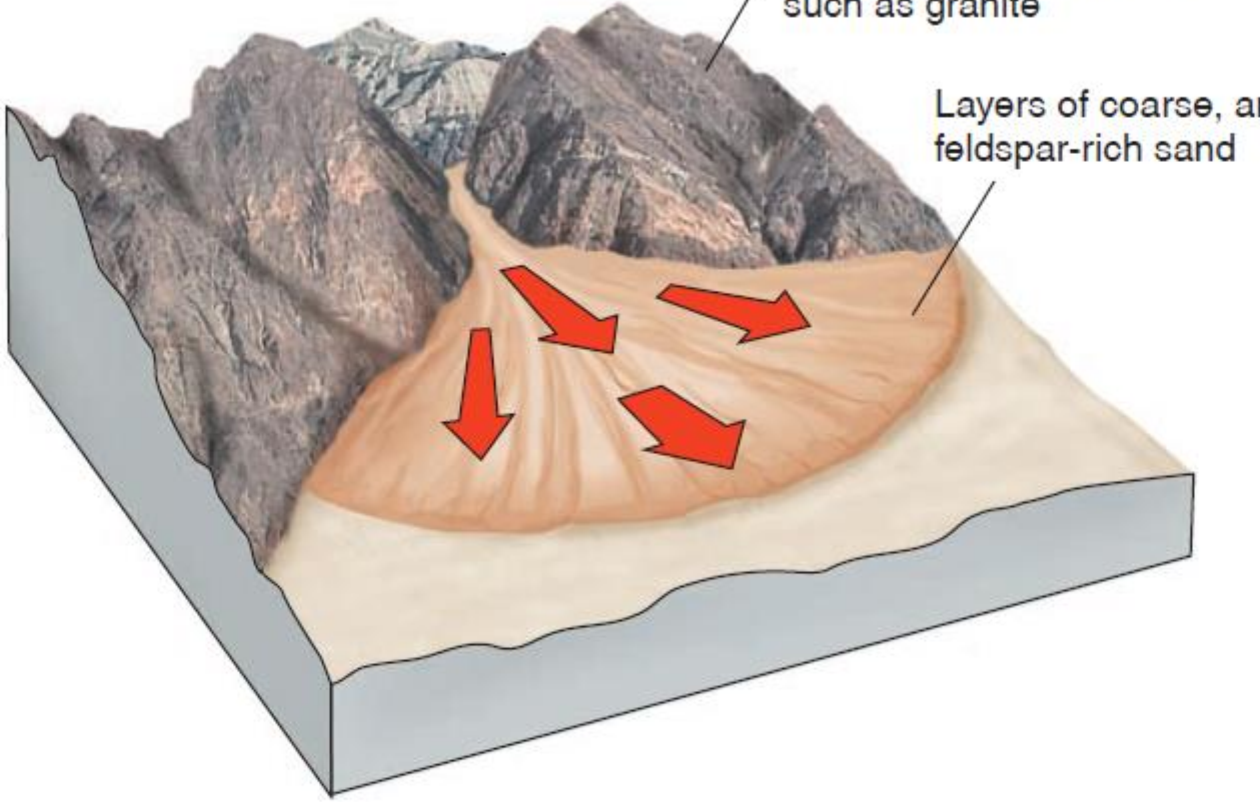


FIGURE 14.9

Feldspar-rich sand (arkose) may accumulate from the rapid erosion of feldspar-containing rock such as granite. Steep terrain accelerates erosion rates so that feldspar may be eroded before it is completely chemically weathered into clay minerals.

Detrital Sedimentary Rocks: Sandstone

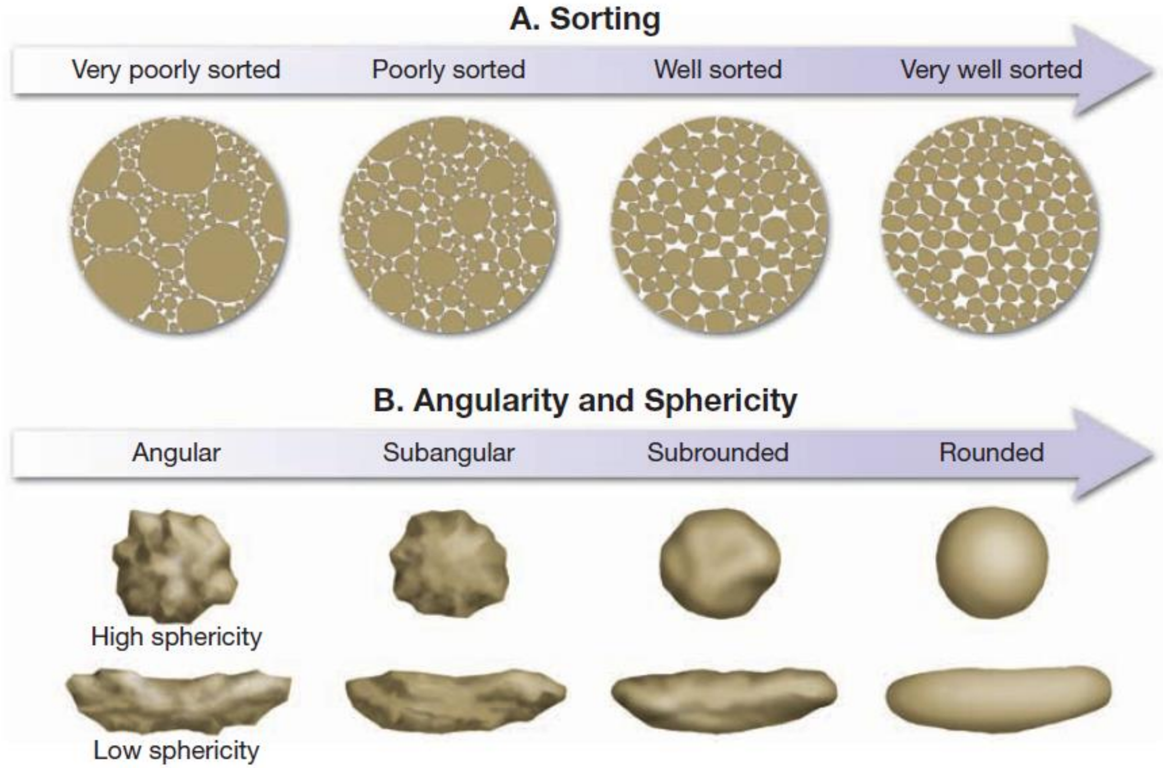


FIGURE 6.5 **A.** Detrital rocks commonly have a variety of different size clasts. *Sorting* refers to the range of sizes present. Rocks with clasts that are nearly all the same size are considered "well sorted." When sediments are "very poorly sorted," there is a wide range of different sizes. When 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.

Detrital Sedimentary Rocks: Conglomerate or Breccia

Size Range (millimeters)	Particle Name	Common Name	Detrital Rock
>256	Boulder	Gravel	Conglomerate 
64–256	Cobble		or
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2–4	Granule		Breccia 
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FIGURE 6.3 Particle size classification for detrital sedimentary rocks. Particle size is the primary basis for distinguishing among various detrital sedimentary rocks. *(Photos by E. J. Tarbuck)*

Detrital Sedimentary Rocks: Conglomerate or Breccia

Breccia is a coarse-grained sedimentary rock formed by the cementation of coarse, angular fragments of rubble (figure 14.5).

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.

Sedimentary breccia might form from fragments that have accumulated at the base of a steep slope of rock that is being mechanically weathered.

Landslide deposits also might lithify into sedimentary breccia.

FIGURE 14.5

Breccia is characterized by coarse, angular fragments. The cement in this rock is colored by hematite. The wide black and white bars on the scale are 1 centimeter long, the small divisions are 1 millimeter. Note that most grains exceed 2 millimeters (table 14.1). *Photo by David McGeary*

Detrital Sedimentary Rocks: Conglomerate or Breccia

Conglomerate is a coarse-grained sedimentary rock formed by the cementation of rounded gravel. It can be distinguished from breccia by the definite roundness of its particles (figure 14.6).

Thus, as with many other sedimentary rocks, conglomerates and breccias contain clues to their history.

FIGURE 14.6

An outcrop of a poorly sorted conglomerate. Note the rounding of cobbles, which vary in composition and size. The cement in this rock is also colored by hematite. Long scale bar is 10 centimeters; short bars are 1 centimeter. *Photo by David McGeary*

Chemical Sedimentary Rocks

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

Chemical Sedimentary Rocks

- Precipitation of chemical sediments occurs in two ways:

(1) *inorganic processes*, such as evaporation and chemical activity; or

(2) *organic processes* of water-dwelling organisms that produce sediments of *biochemical origin.*

Chemical Sedimentary Rocks

- *Limestone*, the most abundant chemical sedimentary rock, consists of the mineral calcite ($CaCO_3$) and forms either by inorganic means or as the result of biochemical processes.
- Inorganic limestones include:
  - *travertine*, which is commonly seen in caves, and
  - *oolitic limestone*, consisting of small spherical grains of calcium carbonate.
- Other common chemical sedimentary rocks include:
  - *dolostone* (composed of the calcium-magnesium carbonate mineral dolomite),
  - *chert* (made of microcrystalline quartz), and
  - *evaporites* (such as rock salt and rock gypsum).

Chemical Sedimentary Rocks

- 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.

Chemical Sedimentary Rocks

Chemical sedimentary rocks are precipitated from a low temperature aqueous environment. Chemical sedimentary rocks are precipitated either directly by inorganic processes or by the actions of organisms.

Chemical rocks include:

- *Carbonates,*
- *Chert, a*nd
- *Evaporites.*

Chemical Sedimentary Rocks:Carbonate Rocks

Carbonate rocks contain the CO_3^{2-} ion as part of their chemical composition. The two main types of carbonates are:

- Limestone
- Dolomite

Chemical Sedimentary Rocks: *Carbonate rocks*

Limestone is a sedimentary rock composed mostly of calcite (CaCO3). Limestones are precipitated either by the actions of organisms or directly as the result of inorganic processes. Thus, the two major types of limestone can be classified as either *biochemical* or *inorganic limestone.*

Biochemical limestones are precipitated through the actions of organisms. Most biochemical limestones are formed on continental shelves in warm, shallow water. Biochemical limestone may be precipitated directly in the core of a reef by corals, encrusting algae, or other shell-forming organisms (figure 14.13). Such a rock would contain the fossil remains of organisms preserved in growth position.

FIGURE 14.13

Corals precipitate calcium carbonate to form limestone in a reef. Water depth about 8 meters (25 feet), San Salvador Island, Bahamas. *Photo by David McGeary*

Chemical Sedimentary Rocks: *Carbonate rocks*

The great majority of limestones are biochemical limestones formed of wave-broken fragments of algae, corals, and shells. The fragments may be of any size (gravel, sand, silt, and clay) and are often sorted and rounded as they are transported by waves and currents across the sea floor (figure 14.14).

The action of these waves and currents and subsequent cementation of these fragments into rock give these limestones a clastic texture. These *bioclastic* (or *skeletal*) *limestones* take a great variety of appearances.

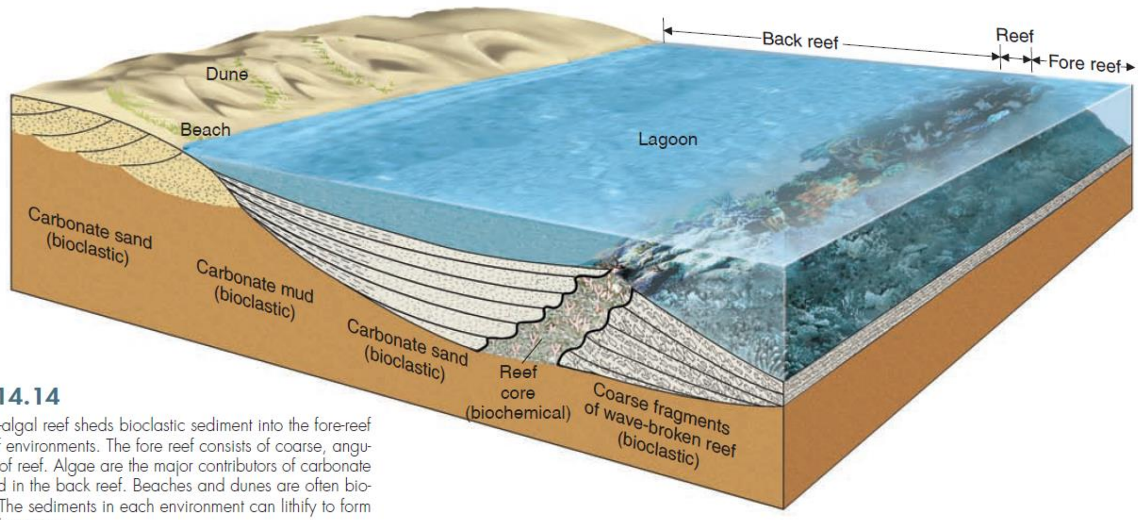


FIGURE 14.14
A living coral-algal reef sheds bioclastic sediment into the fore-reef and back-reef environments. The fore reef consists of coarse, angular fragments of reef. Algae are the major contributors of carbonate sand and mud in the back reef. Beaches and dunes are often bioclastic sand. The sediments in each environment can lithify to form highly varied limestones.

Chemical Sedimentary Rocks: *Carbonate rocks*

Limestone

These *bioclastic* (or *skeletal*) *limestones* take a great variety of appearances. They may be relatively coarse-grained with recognizable fossils (figure 14.15) or uniformly fine-grained and dense from the accumulation of microscopic fragments of calcareous algae (figures 14.15).

FIGURE 14.15

Bioclastic limestones. The two on the left are coarse-grained and contain visible fossils of corals and shells. The limestone on the right consists of fine-grained carbonate mud formed by calcareous algae. *Photo by David McGeary*

Chemical Sedimentary Rocks: *Carbonate rocks*

Limestone

A variety of limestone called *coquina* forms from the cementation of shells and shell fragments that accumulated on the shallow sea floor near shore.

It has a clastic texture and is usually coarse grained, with easily recognizable shells and shell fragments in it.

FIGURE 14.17

Coquina, a variety of bioclastic limestone, is formed by the cementation of coarse shells. *Photo by David McGeary*

Chemical Sedimentary Rocks: *Carbonate rocks*

Limestone

Chalk is a light-coloured, porous, very fine-grained variety of bioclastic limestone that forms from the seafloor accumulation of microscopic marine organisms that drift near the sea surface.

FIGURE 14.18

Chalk is a fine-grained variety of bioclastic limestone formed of the remains of microscopic marine organisms that live near the sea surface. *Photo by David McGeary*

FIGURE 6.11 The White Chalk Cliffs, Sussex, England.
(Photo by Charles Bowman/Photolibrary)

Chemical Sedimentary Rocks: *Carbonate rocks*

Inorganic Limestone

Inorganic limestones are precipitated directly as the result of inorganic processes.

Oolitic limestone is a distinctive variety of inorganic limestone formed by the cementation of sand-sized *oöids,* small spheres of calcite inorganically precipitated in warm, shallow seawater (figure 14.19).

Strong tidal currents roll the oolites back and forth, allowing them to maintain a nearly spherical shape as they grow. Wave action may also contribute to their shape. Oolitic limestone has a clastic texture.

FIGURE 14.19

(A) Aerial photo of underwater dunes of oöids chemically precipitated from seawater on the shallow Bahama Banks, south of Bimini. Tidal currents move the dunes. (B) An oölitic limestone formed by the cementation of oöids (small spheres). Small divisions on scale are 1 millimeter wide. *Photos by David McGeary*

Chemical Sedimentary Rocks: *Carbonate rocks*

DOLOMITE

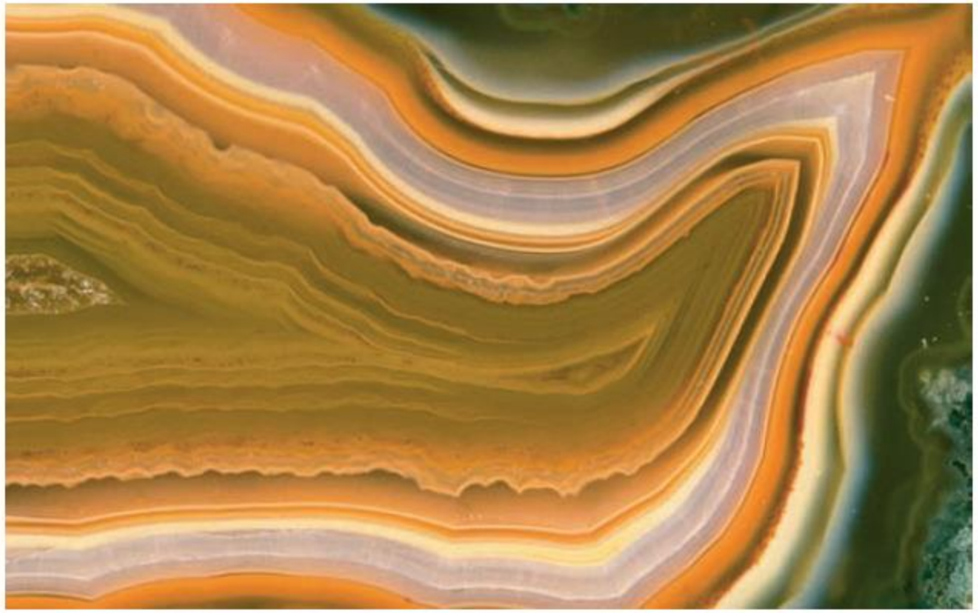
The term **dolomite** is used to refer to both a sedimentary rock and the mineral that composes it, CaMg(CO3)2. (Some geologists use *dolostone* for the rock.) Dolomite often forms from limestone as the calcium in calcite is partially replaced by magnesium, usually as water solutions move through the limestone.

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*).

$$\underset{\text{magnesium in solution}}{Mg^{++}} + \underset{\text{calcite}}{2CaCO_3} \rightarrow \underset{\text{dolomite}}{CaMg(CO_3)_2} + \underset{\text{calcium in solution}}{Ca^{++}}$$

Chemical Sedimentary Rocks: Chert

- *Chert* is a name used for a number of very compact and hard rocks made of microcrystalline quartz (SiO2).
- One well-known form is *flint*, whose dark color results from the organic matter it contains.
- *Jasper*, a red variety, gets its bright color from iron oxide.
- The banded form is usually referred to as *agate*



A. Agate

B. Flint

C. Jasper

FIGURE 6.13 *Chert* is a name used for a number of dense, hard rocks made of microcrystalline quartz. Three examples are shown here. **A.** *Agate* is the banded variety. *(Photo by Jeffrey A. Scovil)* **B.** The dark color of *flint* results from organic matter. **C.** The red variety, called *jasper*, gets its color from iron oxide.

Chemical Sedimentary Rocks: Evaporites

Rocks formed from crystals that precipitate during evaporation of water are called **evaporites.**

They form from the evaporation of seawater or a saline lake.

Rock gypsum, formed from the mineral gypsum ($CaSO_4 \cdot 2H_2O$), is a common evaporite.

Rock salt, composed of the mineral halite (NaCl), may also form if evaporation continues.

FIGURE 14.21

Salt deposited on the floor of a dried-up desert lake, Death Valley, California. *Photo © Michael Collier*

Chemical Sedimentary Rocks: Evaporites

Other less common evaporites include the borates, potassium salts, and magnesium salts.

All evaporites have a crystalline texture.

Extensive deposits of rock salt and rock gypsum have formed in the past where shallow, continental seas existed in hot, arid climates.

Similarly, modern evaporite deposits are forming in the Persian Gulf and in the Red Sea.

FIGURE 14.21

Salt deposited on the floor of a dried-up desert lake, Death Valley, California. *Photo © Michael Collier*

TABLE 14.2 Chemical Sedimentary Rocks

Inorganic Sedimentary Rocks			
Rock	**Composition**	**Texture**	**Origin**
Limestone	$CaCO_3$	Crystalline Oolitic	May be precipitated directly from seawater. Cementation of oolites (ooids) precipitated chemically from warm shallow seawater (*oolitic* limestone). Also forms in caves as *travertine* and in springs, lakes, or percolating ground water as *tufa*
Dolomite	$CaMg(CO_3)_2$	Crystalline	Alteration of limestone by Mg-rich solutions (usually)
Evaporites			Evaporation of seawater or a saline lake
Rock salt	NaCl	Crystalline	
Rock gypsum	$CaSO_4 \cdot 2H_2O$	Crystalline	

Biochemical Sedimentary Rocks			
Rock	**Composition**	**Texture**	**Origin**
Limestone	$CaCO_3$ (calcite)	Clastic or crystalline	Cementation of fragments of shells, corals, and coralline algae (*bioclastic limestone* such as coquina and chalk). Also precipitated directly by organisms in reefs.
Chert	SiO_2 (silica)	Crystalline (usually)	Cementation of microscopic marine organisms; rock usually recrystallized

Organic Sedimentary Rocks

Biological sedimentary rocks were formed by the accumulation of animal and plant material in the same locality over a considerable period of time.

For example

- coral limestone,
- algal limestone and
- coal beds.

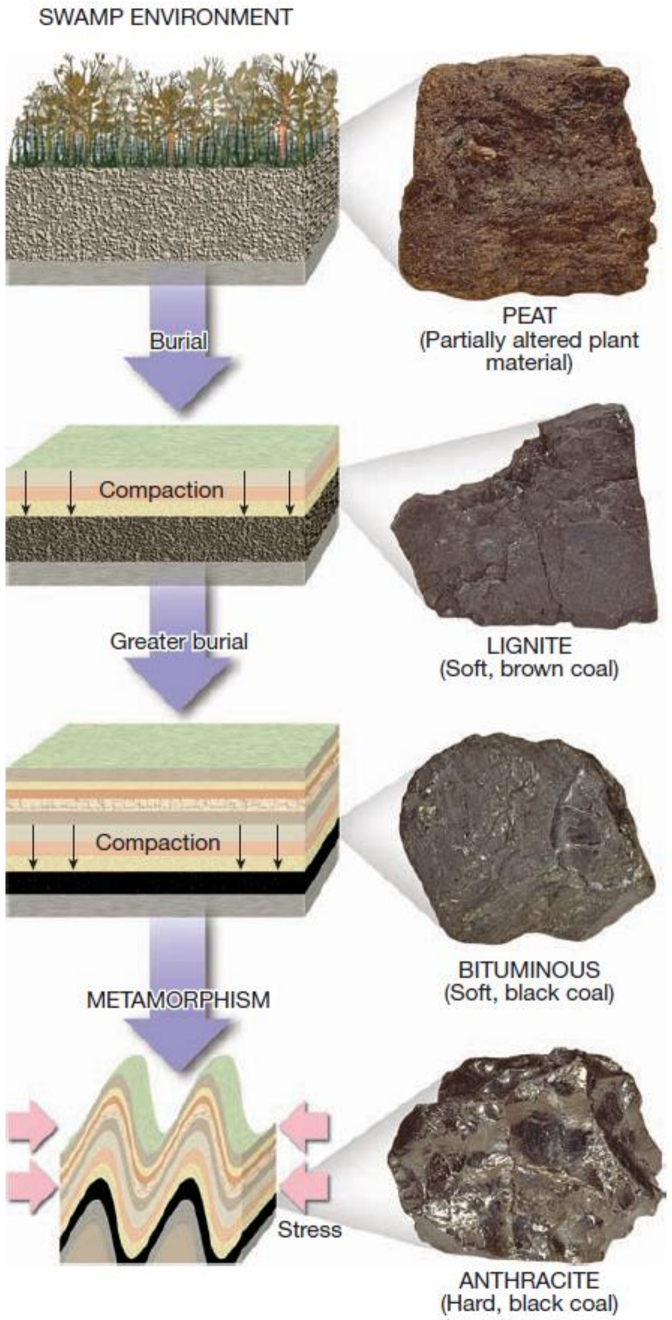


FIGURE 6.15 Successive stages in the formation of coal.

DIAGENESIS

- The chemical, physical and biological changes that occur after the deposition or accumulation of the sediment are termed *diagenesis*,

This includes:

- The reworking of the sediment by organisms,
- The loss of water by compaction, and
- The binding of the constituent grains by interstitial cements, together with the complex process of solution and redeposition of material from within the sediment itself.
- The overall transformation of a sediment into a rock is referred to as ***lithification***.

Lithification

- *Lithification* refers to the processes by which unconsolidated sediments are transformed into solid sedimentary rock.
- Most sedimentary rocks are lithified by means of *compaction* and/or *cementation*.
- Compaction occurs when the weight of overlying materials compresses the deeper sediments.
- Cementation, the most important process by which sediments are converted to sedimentary rock, occurs when soluble cementing materials, such as *calcite, silica*, and *iron oxide*, are precipitated onto sediment grains, fill open spaces, and join the particles.