SEDIMENTARY ROCKS

Smith and Pun, Chapter 5

WHAT ARE SEDIMENTARY ROCKS?

- **Sedimentary rocks are the weathering products of older rocks that have been deposited at the surface of the Earth by water, wind, and/or glaciers.**
- **Sedimentary rocks are the most common rocks on the surface of the Earth.**
- **Sedimentary rocks also preserve the remains of once-living organisms and record the emergence and evolution of life on Earth.**

PHYSICAL WEATHERING

Weathering refers to the processes that break down preexisting rocks at the surface of the Earth.

Physical weathering includes those processes that naturally break large rock fragments into smaller ones.

PHYSICAL WEATHERING (2)

- **Cracks provide pathways for water to enter a rock and cause physical weathering (see Figure 5.2a, page 106).**
- **Fractures may form when erosion removes overlying rock allowing the previously buried rock to expand upward and outward. Stresses in the crust resulting from plate tectonics also cause fractures (see Figure 5.2b, page 106).**

PHYSICAL WEATHERING (3)

- **<u>Exfoliation</u> is a process whereby rock sheets form parallel to the ground surface. Exfoliation may occur when cracks open up parallel to the ground surface when rock expands slightly outward when overlying materials are eroded away.**

PHYSICAL WEATHERING (4)

<u>Freezing and thawing of water is the most important physical weathering process</u> (see Figure 5.3, page 107).

Liquid water expands when it freezes and is converted to ice. The expansion in volume exerts sufficient force to break rock.

Water enters rock along fractures and cracks and then moves along boundaries between mineral grains or into open spaces, called <u>pores</u>.

PHYSICAL WEATHERING (5)

Expansion and contraction of minerals in rocks can also result in disintegration. Some rocks contain clay minerals that may shrink and swell upon wetting and drying.

Heating and cooling of air in contact with rocks also facilitates disintegration because of the resulting changes in volume of the minerals present within the rock. These changes are greatest in deserts where the daily fluctuations in temperature are the greatest.

CHEMICAL WEATHERING

Chemical weathering involves reactions of minerals with water and oxygen at the surface of the Earth.

<u>Dissolution</u> reactions break apart mineral molecules, and the constituents of the molecules disperse in water. Many minerals dissolve in water, particularly those with ionic bonds (see Figure 5.4a, page 109).

$$NaCl_{(s)} + H_2O \leftrightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)} + H_2O$$

CHEMICAL WEATHERING (2)

<u>Hydrolysis</u> reactions are more complicated than dissolution reactions and consume both the mineral and some of the water molecules while reorganizing the elements into new compounds and dissolved ions (see Figure 5.4c. Page 109).

$$2KAlSi_3O_8(s) + 11\ H_2O \leftrightarrow 2K^+(aq) + 2OH^-(aq) + 4H_4SiO_4(aq) + Al_2Si_2O_5(OH)_4(s)$$

CHEMICAL WEATHERING (3)

- **Chemical weathering does not just destroy preexisting minerals; it results in the formation of new minerals. The newly formed minerals are more stable in the surface environment than the original compounds were.**
- **Although chemical weathering reactions begin with “pure” water, these reactions result in an aqueous solution that contains other dissolved constituents.**

CHEMICAL WEATHERING (4)

No natural water is "pure". Water reacts with minerals when rainwater and snow melt percolate through soil and fractures in rock. Ground water also moves slowly between mineral grains (see Table 5.1, page 109).

Constituents that become dissolved in water ultimately bond to form new minerals that precipitate from the water. This is particularly true when reactions result in the water becoming more acidic.

CHEMICAL WEATHERING (5)

The most abundant acid in chemical weathering forms from mixing carbon dioxide (CO_2) with water.

$$H_2O + CO_2(g) \leftrightarrow H_2CO_3(aq)$$

Water and CO_2 mix readily because CO_2 is present in the atmosphere and organisms respire it in soil. The increased acidity of water reacting with CO_2 is very effective in dissolving carbonate minerals, such as calcite ($CaCO_3$; see Figure 5.4b, page109).

CHEMICAL WEATHERING (6)

Reactions between minerals and oxygen (O_2) are also important in chemical weathering.

<u>Oxidation</u> is the process whereby substances react with oxygen to form new substances by exchanging electrons.

The formation of rust is one of the most common oxidation reactions. Iron (Fe^{2+}) reacts with oxygen and oxidizes to a new weaker compound, represented by rust (Fe^{3+}).

CHEMICAL WEATHERING (7)

Oxidation reactions involve the transfer of electrons from a substance to the O_2 molecule. In the process, the O_2 molecule is transformed into O^{2-}.

The most common ion in igneous and metamorphic minerals is Fe^{2+}. In the presence of O_2, iron readily donates an additional electron to oxygen and becomes the Fe^{3+} ion.

As a result, minerals containing abundant Fe^{2+}, such as olivine, pyroxene, amphibole, biotite, and pyrite, readily weather, because of reactions with water and because of oxidation reactions (see Figure 5.5, page 110).

LINK BETWEEN WEATHERING AND SEDIMENT

Clastic sediment is the residue of particles that remain after rocks weather. These particles consist of:

- **The physically weathered parts of the original rock, and**
- **Minerals, including clays that are formed by chemical weathering.**

LINK BETWEEN WEATHERING AND SEDIMENT (2)

Minerals are not equally affected by chemical weathering processes.

1. **Minerals dominated by ionic bonds most readily dissolve in water.**
2. **Silicate minerals are generally more resistant to chemical weathering**

   Minerals with a greater abundance of Si-O bonds weather more slowly than minerals with a greater abundance of ionic bonds, particularly if the ions present include those that are easily oxidized (Fe^{2+}).

LINK BETWEEN WEATHERING AND SEDIMENT (3)

Clastic particles may be picked up, and transported by, moving currents of wind or water, and in some cases, by slow moving glaciers.

The particles may be transported thousands of kilometers away from the location where they were originally deposited and mixed with sediments from numerous other weathered rock outcrops. Ultimately they may be redeposited and form thick layers of sedimentary rock.

LINK BETWEEN WEATHERING AND SEDIMENT (4)

Clastic particles do not constitute all of a weathered rock. The process of chemical weathering dissolves ions and transports them away in solution.

Most ions dissolved in water eventually precipitate as solid ionic compounds called <u>chemical</u> <u>sediment</u>.

Lakes and oceans are the ultimate destination for the continent's dissolved weathering products. As a result, most precipitation of chemical sediment at Earth's surface takes place in these bodies of water.

LINK BETWEEN WEATHERING AND SEDIMENT (5)

However, precipitation of minerals from water within pores between sediment grains also occurs; this process ultimately results in cementation of the grains into a coherent sedimentary rock (see Section 5.4, page 114).

OCCURRENCE OF FOSSILS IN SEDIMENTARY ROCKS

Fossils are the remains of organisms that have been preserved in rocks. There are three basic types of fossils including:

1. **Remains of shelly organisms and vertebrate teeth and bone are the original mineral matter secreted by the organism (see Figures 5.6a, b, page 113).**

2. **Ions dissolved in pure water replace the original cellular compounds of organic matter buried in sediment with minerals. The most common minerals formed in this process are calcite and quartz the petrify the organic remains, as illustrated by petrified wood (see Figure 5.6c, page 113).**

OCCURRENCE OF FOSSILS IN SEDIMENTARY ROCKS (2)

3. **In some cases, only an impression remains where the majority of, or all of, the organic material was completely destroyed by decay or mineral dissolution (see Figure 5.6d, page 113).**

   Only a very few organisms become fossils upon death. Shell, bone, teeth, and soft tissue are all subject to destruction by weathering. Some volcanic rocks, particularly those formed from ash layers that accumulated rapidly, also contain fossils. However, sedimentary rocks are the primary hosts for fossils since they are the most abundant rocks at the Earth's surface.

OCCURRENCE OF FOSSILS IN SEDIMENTARY ROCKS (3)

Fossil Fuels

Burial of organic matter with sediment results in the formation of combustible energy sources called fossil fuels.

Coal, oil, and natural gas originate from organic matter deposited with the sediment. The energy in fossil fuels is a type of stored energy that is primarily derived from the Sun and utilized during photosynthesis. Organic molecules in plants and some microscopic organisms are created during the photosynthetic process. Organisms, like humans, that consume photosynthesizers can utilize this converted solar energy.

OCCURRENCE OF FOSSILS IN SEDIMENTARY ROCKS (3)

Fossil Fuels

Where fossil organic molecules occur in sedimentary rock, the stored energy can be liberated as heat when the fuel burns.

It is important to remember that fossil fuels account for only a small amount of Earth's energy budget. All of the know reserves of fossil fuels on Earth add up to about 10 days worth of energy to the planet from the Sun.

OCCURRENCE OF FOSSILS IN SEDIMENTARY ROCKS (4)

Fossil Fuels

Special circumstances are required for the burial of organic matter in sediments. Carbon-rich organic tissue is generally consumed by decomposing organisms or oxidized to form CO_2 and other gases.

However, in some deep lakes and ocean basins, swamps, and nearshore lagoons, the oxygen in the water is completely consumed by oxidation of organic matter and Fe^{2+}-bearing minerals.

OCCURRENCE OF FOSSILS IN SEDIMENTARY ROCKS (5)

Fossil Fuels

When oxygen is no longer available, additional organic matter cannot be oxidized and is buried along with inorganic sediment. As more sediment accumulates above (overburden), the pressure and temperature rise in the organic-rich deposit, which promotes chemical reactions that form new compounds.

Coal is a sedimentary rock composed almost entirely of the compacted remains of fossil plants (see Figure 5.7a, page 114).

OCCURRENCE OF FOSSILS IN SEDIMENTARY ROCKS (6)

Fossil Fuels

Oil and natural gas are organic compounds produced by the high temperature alteration of organic molecules that are primarily the remains of aquatic protozoa and plants.

These energy resources accumulate in the pore spaces within sediment and sedimentary rock (see Figure 5.7b, page 114).

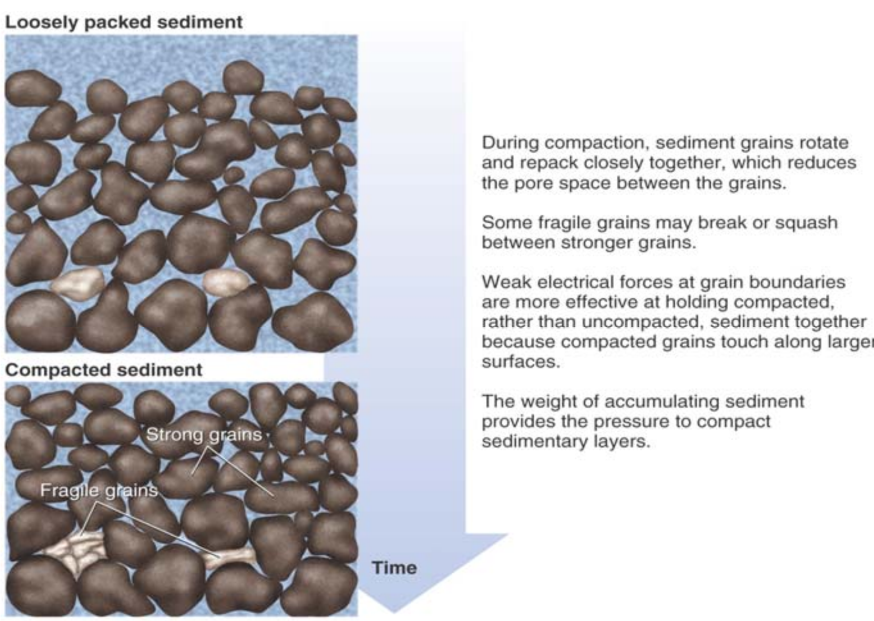
CONVERTING LOOSE SEDIMENT TO SEDIMENTARY ROCK

The term <u>lithification</u> refers to the processes that convert sediment to rock.

The first step in lithification is generally compaction (see Figure 5.8, page 115).

Natural compaction occurs when layers of sediment accumulate and particles on the bottom are impacted by the weight of the overlying sediment.

The total volume of solid material remains the same during compaction, but the air- or water-filled pore space between grains is decreased.



CONVERTING LOOSE SEDIMENT TO SEDIMENTARY ROCK (2)

The second step in the process of converting sediment to rock is <u>cementation</u> (see Figure 5.9, page 116).

Mineral grains not only precipitate from water and accumulate as chemical sediment; minerals also precipitate from water in the pore spaces between sediment particles. Over time, the particles become cemented into rock.

The most common cementing agents are:

- **Calcite**
- **Quartz**
- **Clay minerals**
- **Hematite**

CONVERTING LOOSE SEDIMENT TO SEDIMENTARY ROCK (3)

Precipitation is caused by the increasing concentration of ions in water, because there is an upper limit to how much of each ion can be dissolved in water.

Precipitation is also affected by temperature. Calcite, for example, dissolves more readily in cold water and precipitates in warmer water. Therefore, calcite could precipitate from pore water containing abundant calcium and carbonate ions when experiencing higher temperature at depth as it is buried.

Compaction and cementation result in lithification of unconsolidated sediment into sedimentary rock; pore space is lost in the process.

CLASSIFYING SEDIMENTARY ROCKS

The two primary categories of sedimentary rock are:

Clastic sedimentary rocks – Composed primarily of mineral grains produced by the weathering of preexisting rocks and cemented by minerals precipitated from pore water or which formed from the interaction of the grains with pore water.

Chemical and biogenic sedimentary rocks – Composed of minerals precipitated from water by biologic or inorganic processes or the remains of organisms.

CLASSIFYING SEDIMENTARY ROCKS (2)

Clastic Sedimentary Rocks

The most important property in classifying clastic sedimentary rocks is grain size.

Sorting describes the range in grain size. Well-sorted sediments consist primarily of one grain size; poorly sorted sediments contain a variety of grain sizes (see Figure 5.10, page 117).

Rounding of the grains is also considered in classification of clastic sedimentary rocks. Clastic grains typically have sharp edges and corners when initially produced by weathering (more angular). The sharp edges and corners are abraded during transport by wind and water, and the grains become progressively more rounded.

CLASSIFYING SEDIMENTARY ROCKS (3)

Clastic Sedimentary Rocks

The classification of clastic sediment is based first on grain size (see Figure 5.11, page 118).

Conglomerate – Rock composed primarily of gravel-sized (> 2 mm) particles

Sandstone – Rock composed primarily of sand-sized (1/16 to 2 mm) particles

Mudstone – Rock composed primarily of silt to clay-sized particles (> 1/16 mm)

CLASSIFYING SEDIMENTARY ROCKS (4)

Clastic Sedimentary Rocks

Another aspect of clastic sedimentary rock classification is the rounding of grains (see Figure 5.11, page 118).

Conglomerate and breccia are distinguished by rounded or angular fragments, respectively.

Composition plays a secondary role in classification and is most commonly applied to sandstones. Quartz sandstone consists almost entirely of quartz; arkose is a sandstone containing at least 25 percent feldspar.

CLASSIFYING SEDIMENTARY ROCKS (5)

Chemical and Biogenic Sedimentary Rocks

Composition is the most useful characteristic for classifying the chemical and biogenic sedimentary rocks.

Most chemical sedimentary rocks consist primarily of one mineral, since it is very unusual for conditions to favor the precipitation of two or more minerals from solution at the same time (see Figure 5.12, page 119).

CLASSIFYING SEDIMENTARY ROCKS (6)

Chemical and Biogenic Sedimentary Rocks

Limestone, which is composed primarily of calcite, and chert, composed mainly of quartz, are the most abundant rocks formed by chemical precipitation.

Both may be formed by inorganic and biologic processes.

Calcite and quartz dissolve to a limited extent in water and readily precipitate from water when the chemistry or temperature change slightly.

CLASSIFYING SEDIMENTARY ROCKS (7)

Chemical and Biogenic Sedimentary Rocks

Many invertebrate animals, protozoans, and algae secrete shells and other hard tissues composed of calcium carbonate as calcite or as aragonite that slowly transforms to calcite over time.

Other protozoans and algae, such as diatoms, and some inveterbrates, including sponges, secrete hard tissues composed of silica.

Most limestone and chert form primarily by these biologic precipitation processes, with additional inorganic precipitation of calcite or quartz as cement after sediment burial.

CLASSIFYING SEDIMENTARY ROCKS (8)

Chemical and Biogenic Sedimentary Rocks

Dolostone is a chemical sedimentary rock composed primarily of dolomite [$CaMg(CO_3)_2$].

No organisms secrete dolomite, and dolomite precipitates from seawater only under rare chemical conditions in some nearshore lagoons.

Most dolomite forms by reaction of groundwater with calcite in limestone long after the original sediment has been deposited.

CLASSIFYING SEDIMENTARY ROCKS (9)

Chemical and Biogenic Sedimentary Rocks

Other minerals, including halite and gypsum, are very soluble in water. Considerable evaporation must occur so that these minerals may precipitate from solution. Rock salt and rock gypsum, therefore, are commonly referred to as evaporites, emphasizing their formation in arid lagoons or desert lakes upon drying.

CLASSIFYING SEDIMENTARY ROCKS (10)

Chemical and Biogenic Sedimentary Rocks

The remaining rock in this category is coal, which is composed entirely of plant organic matter. The greater the extent of transformation of the original plant tissue under elevated heat and pressure upon burial, the greater the combustibility or heat production from coal when burned.

Peat refers to plant material before it is transformed into the low-density, black rock called bituminous coal.

If metamorphosed, the coal is transformed to anthracite, which is more accurately classified as a metamorphic rock.

CLASSIFYING SEDIMENTARY ROCKS (11)

How does the combustion of coal produce acid rain?

The abundance of organic matter in swamps where coal may formed exhausts all of the oxidizing capacity of the water. Microbes in the oxygen deficient environment reduce the S^{+6} in sulfate (SO_4^{2-}) to S^-, which then bonds with Fe^{2+} ions to produce pyrite (FeS_2).

When the coal is combusted, the pyrite is oxidized and produces sulfur dioxide gas (SO_2), which mixes with water in the atmosphere to produce acid rain containing sulfuric acid.

$$SO_2(g) + 1/2O_2(g) \rightarrow SO_3(g)$$
$$SO_3(g) + H_2O \leftrightarrow H_2SO_4$$

SEDIMENTARY ROCKS AND ANCIENT ENVIRONMENTS

Fossils occurring in sedimentary rocks provide the most easily interpreted record of past environments, because organisms adapt to specific living conditions.

Identification of the environmental requirements (land vs. water, shallow lagoons vs. deep oceans, dry deserts vs. tropical rainforests, etc.) for organisms preserved in the fossil record provides geologists with important information regarding ancient depositional environments.

SEDIMENTARY ROCKS AND ANCIENT ENVIRONMENTS (2)

Geologists determine details about past depositional environments from ancient rocks by examining the type of sediment that accumulates in those environments today (see Figure 5.13, page 121).

Coarse-grained clastic rocks, like conglomerate, require environments with strong currents for transport, whereas fine-grained mudstone requires quiet water where fine silt and clay settle slowly from suspension.

The occurrence of limestone reveals submerged lake bottoms or seafloor.

Evaporites indicate arid lakes and shoreline lagoons where evaporation of water concentrated ions that subsequently precipitated as minerals.

SEDIMENTARY ROCKS AND ANCIENT ENVIRONMENTS (3)

Sedimentary structures are physical features that form during sediment deposition or shortly after deposition, but prior to the sediment becoming sedimentary rock.

Bedding or stratification is a fundamental sedimentary structure that refers to the layering that exists in sedimentary rocks (see Figure 5.14, page 122).

Bedding reflects changes in depositional processes. For example, fluctuations in sediment transport ability will result in variations in the grain size and sorting of deposited sediment.

SEDIMENTARY ROCKS AND ANCIENT ENVIRONMENTS (4)

<u>Mud</u> <u>cracks</u> represent another type of sedimentary structure (see Figure 5.15, page 122). Mud cracks are formed whenever wet mud dries out. This occurs because muddy sediment typically contains abundant clay minerals that swell upon wetting, and shrink and crack upon drying.

The presence of mud cracks in sedimentary rocks implies a depositional environment exposed to the air where sediment dries, like a river floodplain.

SEDIMENTARY ROCKS AND ANCIENT ENVIRONMENTS (5)

<u>Cross-beds</u> are inclined layers in sediment or sedimentary rock that reveal current or wave transport of sediment (see Figure 5.16, page 123).

Cross-beds, as implied by their name, are crosswise to the bedding that forms parallel to nearly horizontal land and sea floor features.

Cross-beds form by the movement of sediment <u>dunes</u> and <u>ripples</u>. Dunes and ripples are curving ridges of loose sediment that move along with water or wind currents or move back and forth beneath oscillating water waves.

SEDIMENTARY ROCKS AND ANCIENT ENVIRONMENTS (6)

Graded beds form where sediment grain size changes uniformly from coarser at the base of the bed to finer-grained at the top (see Figure 5.17, page 124).

Graded beds reveal intermittent currents that transport a wide range of sediment sizes and then slow so that the larger particles are deposited first and the smaller particles accumulate progressively on top of them.

Graded beds typically result from rapid sediment deposition during river floods, settling of sediment stirred up by storm waves on the sea floor, and by episodic currents of sediment laden water, called turbidity currents, that sweep across lake bottoms and the seafloor.

SEDIMENTARY ROCKS AND ANCIENT ENVIRONMENTS (7)

A vertical transition from one sedimentary rock type to another represents a change in depositional environment (see Figure 5.18, page 124).

Figure 5.18 shows an upward progression from sandstone, to shale, to limestone. All of the layers contain the fossils of marine organisms.

SEDIMENTARY ROCKS AND ANCIENT ENVIRONMENTS (8)

Figure 5.19 on page 125 demonstrates how geologists would interpret this succession based on where the different rock types were likely to form relative to a shoreline.

Clastic sediment is produced by weathering on continents and delivered to the coastline by rivers. Coarser-grained sediment is deposited closest to the shore as the river currents slow upon entering the ocean. Waves wash the sand alongshore to form beaches.

SEDIMENTARY ROCKS AND ANCIENT ENVIRONMENTS (9)

Next, wave agitation suspends the remaining silt and clay, and these fine-grained sediments settle out further offshore. Calcite-secreting organisms live throughout the area of sand and mud deposition, and their hard mineral parts are buried in the sediment.

Farther offshore, there is less continent-derived clastic debris settling to the seafloor, so abundant calcite remains. In this setting, precipitated crystals accumulate on the seafloor in the near absence of clastic sediment.

THE CONNECTION BETWEEN PLATE TECTONICS AND SEDIMENTARY ROCKS

Sedimentary rocks on continents are thickest where depressions, called basins, form on Earth's surface. Tectonic processes raise mountains and cause basins to subside (see Figure 5.23, page 129).

The presence of thick sedimentary rock accumulations, therefore, tells geologists where tectonic processes actively formed basins at various times during geologic history.

Where basins formed, the depositional environments revealed by the sedimentary structures and rocks present provide clues regarding the basin size and the direction to, and proximity to, mountains.