CHAPTER 4

SEDIMENTARY ROCKS

MATERIALS NEEDED

- **Pencil**
- **Hand lens**
- **Metric ruler**
- Glass or knife to test hardness
- Dilute hydrochloric acid
- Binocular microscope (optional)
- Samples of sedimentary rocks to be identified
- Samples of sediment
- Rock samples illustrating cross-bedding, ripple marks, graded beds (or jars of sediment in water), and mud cracks (optional)
- Samples of weathered igneous rocks

INTRODUCTION

Sedimentary rocks form from sediment that accumulates on the Earth's surface. The components of the sediment, derived from weathering and erosion of preexisting rocks, are transported as solid particles or chemical ions to their site of deposition. Sedimentary rocks contain many kinds of clues about their history and the history of the Earth's surface. In this lab, you will learn how to recognize and interpret some of these clues and to identify common sedimentary rocks.

Sedimentary rocks cover most of the Earth's surface, so they are the kind of rock you are most likely to encounter. They have much to offer us. They contain oil, gas, and coal as well as many kinds of construction materials. They can tell us what surface conditions were like in the past and when seas were or were not present in an area, and their fossils tell us about the changing pagent of life through time. Sedimentary rocks can provide more details about the geologic past than other kinds of rock if we know how to read their pages, so let's learn how to do that.

Rocks and soils at the Earth's surface disintegrate and decompose as they interact with the surface environment. The solid particles and *ions* (atoms or molecules with an electrical charge) freed by this action are carried by water, wind, or glaciers from their source to the place where they are deposited, the **basin of deposition.** There, under the influence of gravity, they accumulate as layers, or **strata,** on the Earth's surface (though commonly underwater). This collection of loosely packed, unconsolidated minerals or rock fragments is **sediment.** In time, sediment is buried, hardened, and consolidated to form **sedimentary rock.**

The mineral composition and texture of many sedimentary rocks provide clues to the:

1. original source of the sediment;
2. type and extent of the weathering processes by which the source rock was broken down;
3. type of agent (water, wind, ice) that transported the sediment and, sometimes, the duration of transport;
4. physical, chemical, and biological environment in which the sediment was deposited; and
5. changes that may have occurred after deposition.

By carefully examining the clues in the rock and knowing how to interpret them, it is possible to learn a good deal about the history of the rock and the environment in which it formed.

WEATHERING

Weathering is the process by which rocks at the surface disintegrate or decompose; it produces most of the components of sedimentary rocks. **Mechanical weathering**—for example, by frost action or wind abrasion—causes rocks to disintegrate into pieces or loose mineral grains. During **chemical weathering,** chemical reactions cause the rock to decompose. As a result, the ions of such elements as calcium, sodium, potassium, and magnesium are freed from the rock and dissolve into water. The reactions also produce new minerals, principally clay minerals and iron oxides, and release nonreactive ones, especially quartz, from the rock. Table 4.1 lists the common mineral products of weathering.

EROSION AND TRANSPORTATION

As a rock is broken down by weathering, the freed rock fragments and minerals move downhill due to gravity and are eroded and transported away by water, glaciers, or wind. As transport distance

TABLE 4.1 COMMON WEATHERING PRODUCTS

Mechanical Weathering	*Chemical Weathering*
Quartz	Secondary Minerals:
K-feldspar	Clay minerals
Na-plagioclase	Iron oxides
Muscovite	Fine quartz
Rock fragments	Aluminum oxides
Other silicate minerals are less common because they undergo rapid chemical weathering.	Dissolved in water: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} HCO_3^{-}, CO_3^{2-}, SO_4^{2-}, Silicic acid

increases, each of these transport agents changes the **size, shape,** and **sorting** of the sedimentary particles. Geologists study these characteristics in modern sediments, in which the transporting process is known, in order to understand ancient sedimentary rocks, for which transport processes must be inferred.

PARTICLE OR GRAIN SIZE

To make scientific communication precise, geologists have assigned specific **grain sizes** to familiar words for sediments (Fig. 4.1A). For example, *sand* refers to particles between 0.25 and 2 mm in diameter, and *clay* refers to particles smaller than 0.004 mm. Note that "clay" can refer to either a grain size or a group of minerals (of which kaolinite, for example, is a member). Many clay mineral grains are in fact clay sized. Particles larger than those shown in Figure 4.1 include cobble (diameter of 6.4 to 25.6 cm [2.5 to 10.25 in]) and boulder (diameter greater than 25.6 cm [10.25 in]).

GRAIN SHAPE

Mechanical weathering, especially by freeze-thaw fracturing, produces highly angular particles. When moved by wind or water, the corners and sharp edges of angular grains are gradually smoothed and rounded away as the particles bump against each other and other rocks. Relative terms such as *angular, sub-rounded,* and *well-rounded* describe the overall degree of **roundness** of sedimentary grains (Fig. 4.1B). Particles larger than about 1 mm tend to become rounded fairly quickly as they bang into each other in turbulent streams. Smaller, lighter grains require more energetic collisions (greater turbulence) or longer transport distances in order to become rounded. Sand-sized particles are most effectively rounded in the crashing waves of a beach or in sand dunes formed by the wind, which often blows sand grains fast enough to sting your skin.

SORTING

Whereas grain size and shape refer to individual grains, **sorting** refers to the similarity in size of all grains in a rock or handful of sediment. If all grains are essentially the same size, they are *well-sorted* (Fig. 4.1C). If they show a wide range of sizes, they are *poorly sorted.* Poorly sorted sediments may display particles of a variety of different sizes, as in Fig. 4.1C, or they may show a set of larger **grains** (particles) imbedded in a **matrix** (Fig. 4.1D). The **matrix** is a mass of smaller particles filling the spaces between larger grains.

TRANSPORTING AGENTS

Sedimentary particles are produced by weathering and erosion. More and larger sedimentary particles are produced in mountainous areas. Rocks break loose from cliffs, roll or slide down steep slopes, and either land on ice (mountain glaciers) or roll into fast, turbulent streams. Both carry the sediment down the valley. Gravity is less effective at removing loose rock from low relief areas. Because loosened rock tends to stay in place in flatter areas, there is more time for chemical weathering to convert the rock into a thick layer of clay minerals and other fine-grained particles collectively known as soil. The erosion of soils in flat regions supplies fine-grained particles for water, ice, and wind transport.

WATER

Water moves more sediment than any other transporting agent. Fast, turbulent streams more effectively erode the landscape and transport larger particles than do slow-moving streams. It's like when you clean off pavement: you do a faster, better job with a hose with a nozzle than one without. Thus, steep, fast mountain streams carry and deposit much more coarse gravel than do the slower lowland streams. If you find an ancient deposit of nonglacial pebbles, cobbles, and boulders, you are likely to be near an ancient area of high elevation and the source of the sediment. The slower, less turbulent streams and rivers found in flatter areas do not move much gravel, but they transport their finer particles great distances by pushing sand along the bottom and carrying silt and clay in suspension in the water column. This suspended sediment is what gives some rivers their muddy look. River sediments are deposited along the river banks, in deltas, or ultimately in the oceans. Dissolved elements from chemical weathering (Table 4.1) are transported regardless of stream slope as long as there is water to carry them.

Because particles larger than about 1 mm are rapidly rounded during transport, coarse, angular particles suggest that you are very near the ridges and mountains that first produced them. Better rounding of coarse grains implies greater transport distances. Rivers are not good at rounding sand or finer particles. Instead, river sands are best rounded after they reach the oceans and become part of the beach. Here pounding waves and wind effectively round sand grains.

River sediments are better sorted in flatter areas mainly due to the loss of the large particle sizes of the mountainous areas. Nevertheless, all river sands are poorly sorted compared to beach and especially wind-blown sands. Beach waves sort sediment by transporting a certain maximum grain size, which depends on the average of the local waves, and by washing away finer particles.

GLACIERS

Moving glaciers act as huge conveyor belts that carry any size particle that gets trapped in the ice. The moving ice can polish rocks at the base of a glacier but otherwise does not further round its particles.

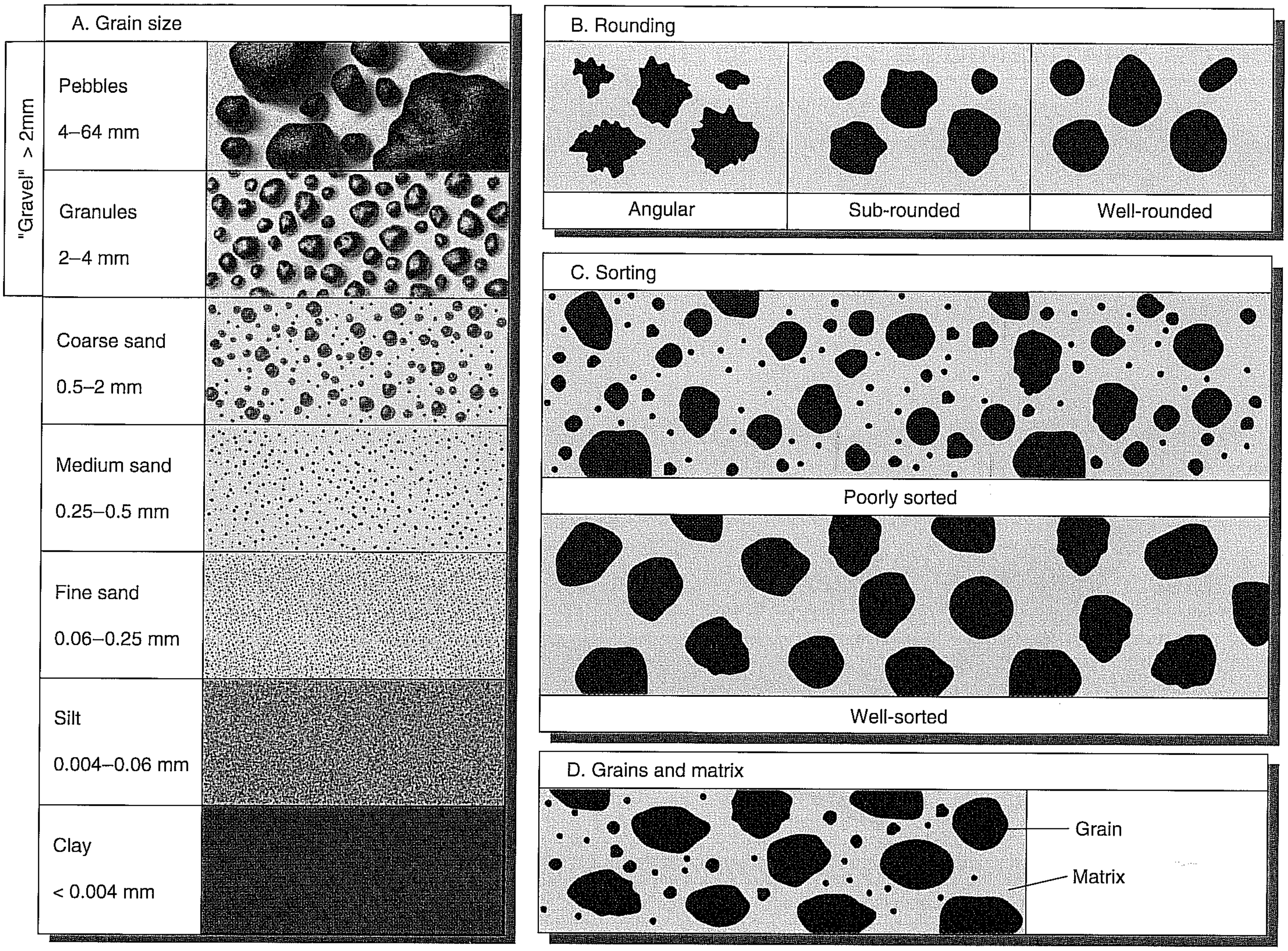


FIGURE 4.1
Characteristics of sedimentary grains. A. Scale of grain-size names for sediment and sedimentary rocks; not shown are cobbles (64–256 mm) and boulders (> 256 mm). B. Angular, sub-rounded, and well-rounded particles. Note that rounding is not synonymous with, nor does it imply, sphericity. C. Poorly sorted and well-sorted sediment. D. Larger particles, or *grains,* are surrounded by a *matrix* of much smaller particles.

When the ice melts, the sediment is deposited on the spot or transported further by melt-water streams. Thus, the particles in the glacial sediments that cover most of Canada and the northern United States are characteristically poorly sorted, ranging from clay to huge boulders. Glacial melt-water streams leave behind deposits of better sorted, sub-rounded sands and gravel.

Wind

Wind transports only sand, silt, and clay-sized particles. Sand grains generally bounce along the surface to form sand dunes and do not travel far during a single wind storm. Silt and clay particles get blown higher into the air and can travel great distances. In fact, dust from China blows across the Pacific and dust from the Sahara Desert in Africa ends up in south Florida and the Bahamas.

If you have ever felt sand stinging your legs during a windy day at the beach or sand dunes, you understand the high energy impacts that sand grains make with each other. These high-energy impacts rapidly create well-rounded sand grains.

Wind-blown sediments are remarkably well sorted. Wind bounces sand along to form sand dunes but carries away the silt and clay. The wind-blown silt can also form thick deposits known as loess (pronounced 'lus'). The loess of the upper Mississippi River valley of the United States was blown in from the barren expanses of fresh, loose sediment that were left behind roughly 11,000 years ago as the great ice sheets melted back at the end of the last Ice Age.

Deposition and Lithification

Types of Sediment

So far, we have spoken mainly of **detrital** (or **clastic**) **sediments,** which consist of rock fragments, mineral grains, or clay minerals that have been transported to a site of deposition as clay, silt, sand, and gravel. These almost synonymous names come from *detritus,* which refers to loose solid material resulting from rock disintegration and *clasts,* which are broken pieces of preexisting rocks and minerals. Detrital sediment deposition takes place when water or

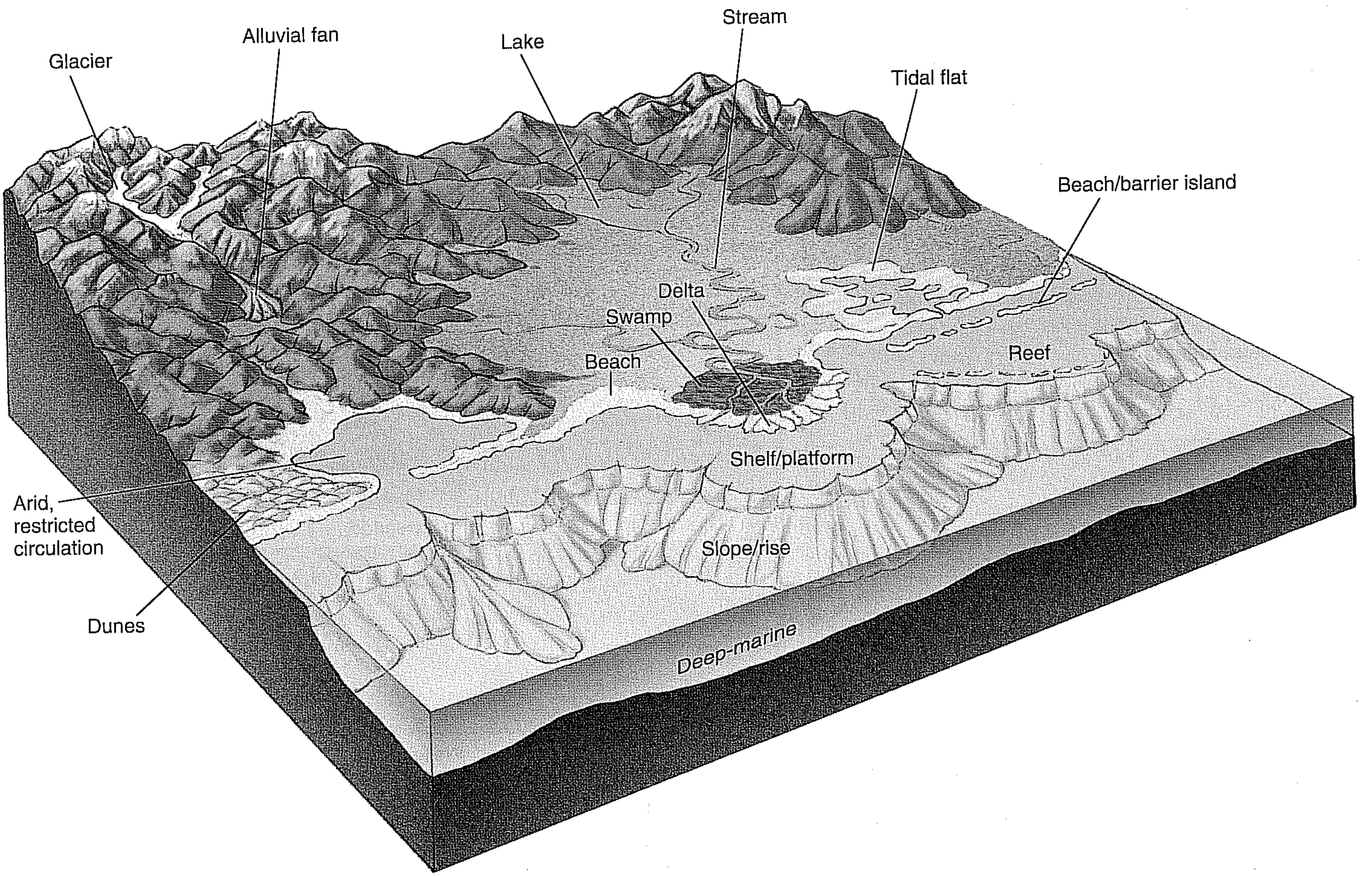


FIGURE 4.2
Typical sedimentary depositional environments.

wind currents slow enough to allow the particles to settle or when the glacier ice melts. The rate of settling in water or air depends mainly on particle size and density: large, heavy particles settle faster than small, light ones. Silt and larger particles settle rapidly as currents slow. Clay-sized particles can remain suspended in fresh water for long periods before settling, which is why slow-moving rivers are commonly muddy. When fresh water mixes with salty ocean water, the clay-sized particles clump together to form larger particles that settle rapidly near the river mouth.

Chemical sediments form when dissolved ions (such as Ca^{2+}, HCO_3^-, SO_4^{2-}, Na^+, and Cl^-) join together to form a solid. This solid, usually a mineral crystal, is called a *chemical precipitate. Inorganic chemical precipitation,* which occurs without the help of organisms, takes place when the chemistry of the water becomes appropriate. For example, the evaporation of seawater causes the concentration of ions in the remaining liquid to become so high that minerals precipitate. This is how rock salt (halite) and rock gypsum are formed. Such precipitation is most likely to take place in shallow basins that are almost closed off from the main oceans, especially if they occur in hot subtropical regions where rainfall is low and evaporation is high. This includes a number of famous areas around the Persian Gulf.

Biochemical sediments form through biological chemical precipitation: plants and animals extract calcium carbonate or silica from seawater to build such skeletal structures as shells, exoskeletons, or, in the case of calcareous algae, tiny calcium carbonate crystals that help support soft tissues. When these organisms die, most of the soft, carbon-rich tissue rots away and leaves the hard skeletal parts behind to become part of the bottom sediment. In some cases, organic carbon accumulates so rapidly that it does not rot completely away. The rapid accumulation of plant materials in swamps gives rise to peat deposits, which, following burial, ultimately become coals. Rapid accumulation of especially marine algae produces black muds on the seafloor that can, with sufficient burial and heating, form the sources of oil and natural gas.

Environments of Deposition

One of the most important goals of geology is to learn exactly how, and under what conditions, a particular rock formed. If we know these things, we can learn or predict many others. For example, we can reconstruct the history of the Earth, we can predict where we might find ore deposits or fossil fuels, we can see how climatic conditions have varied in the past, and we can even formulate hypotheses about the future.

We learn how and under what conditions ancient sedimentary rocks formed by studying the environments in which modern sediments accumulate. The most important depositional environments are illustrated in Figure 4.2; Table 4.2 is a

TABLE 4.2
DEPOSITIONAL ENVIRONMENTS OF COMMON SEDIMENTARY ROCKS

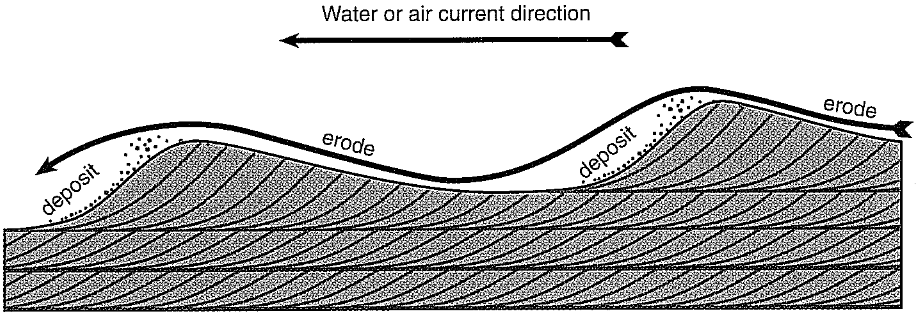
Depositional Environment			*Characteristic Sedimentary Rocks*
Continental	River/Stream	Channel	Pebble conglomerate and sandstone with current ripple marks, crossbeds, and discontinuous beds
		Flood plain	Shale, possible mud cracks, root traces, soil horizons
		Base of cliff/steep slope	Pebble to boulder breccia
		Alluvial fan	Pebble to boulder conglomerates, arkosic sandstone, poor sorting, cross-bedded
		Dune	Sandstone, well-sorted, large crossbeds
	Glacier	Till	Tillite—poorly sorted, unlayered conglomerate; particles angular to rounded; some may have scratches
		Stratified drift	Sandstone and conglomerate, similar to stream channel deposits
		Swamp	Coal
		Lake	Shale, freshwater limestone away from shore; sandstone, conglomerate near shore
Transitional		Delta	Complex association of marine and nonmarine sandstone, siltstone, and mudstone, possibly with crossbeds and ripple marks; coal and plant debris common
		Beach/barrier island	Fine- to medium-grained, well-sorted sandstone; crossbeds common
		Tidal flat	Mudstone, siltstone, and fine-grained sandstone; ripple marks, bidirectional crossbeds, mud cracks; evaporites possible
Marine	Shelf	Inner shelf (near shore, shallow water)	Fine-grained sandstones; crossbeds and ripple marks common
		Middle shelf (deeper water)	Siltstones, claystones; marine fossils common
		Outer shelf/platform (may build up to sea level)	Limestones, possibly fossiliferous, or reefs (see below)
		Reef	Fossiliferous limestone, massive; coral and algae fossils common
		Slope/rise	Mudstone, graywacke (graded bedding common)
		Deep marine	Chert, chalk, micritic limestone, mudstone
		Evaporite basin (hot, arid, restricted access to sea)	Evaporites (gypsum, anhydrite, halite)

summary of the sedimentary rocks and their characteristics for each of these environments.

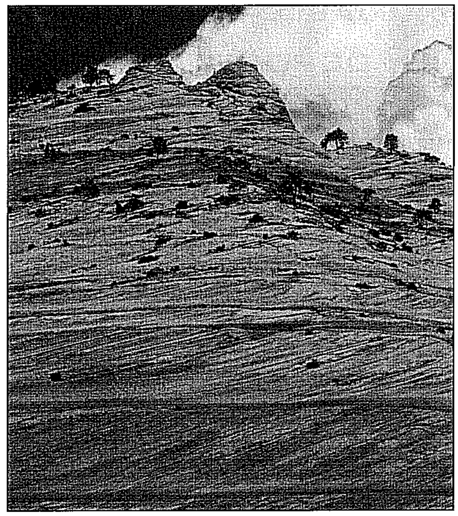
SEDIMENTARY STRUCTURES AND THEIR SIGNIFICANCE

Sedimentary structures are features in sedimentary rocks that formed during or after deposition of the sediment, but before lithification (see below), and are large enough to be visible in the field. They are important because they provide evidence of the transporting agent and the environment of deposition. Figures 4.3 through 4.7 illustrate some common sedimentary structures.

FIGURE 4.3
Stratification (bedding or **layering)** is the most distinctive feature of sedimentary rocks. Strata accumulate by deposition on horizontal or gently inclined surfaces. The strata shown here, exposed near Arkadelphia, Arkansas, are tilted from their original horizontal position. If the characteristics of the sediment being deposited remain constant for a long enough period, a thick stratum, or **bed** (1 cm or thicker), is formed; if characteristics fluctuate, thin strata, or **laminations** (less than 1 cm thick), accumulate. The top or bottom surface of a bed or lamination is a **bedding plane.**

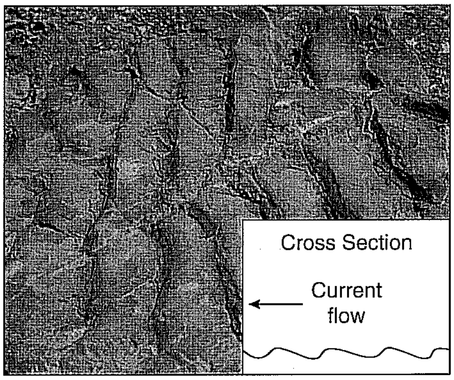


A.

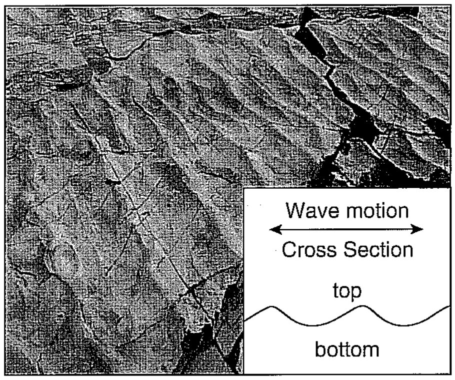


B.

FIGURE 4.4
A. Wind and water currents create ripples and dunes in sand. Both move down-current because sand is eroded off one side and, where the current 'jumps' off the ripple crest, is dumped down the steep face of the ripple or dune. The successive burial of the steep faces is recorded as a succession of **cross-beds** that always tilt down-current. Cross-beds are preserved in layers only when erosion removes just the top parts of the ripple or dune. Geologists use cross-beds in sedimentary rocks to infer the flow direction of ancient rivers, wind systems, deltas, and beaches. In addition, many cross-beds form concave-up curves; geologists use these to tell if sedimentary layers in complexly deformed regions have been turned upside down. B. The **cross-bedding** (or *cross-stratification*) in the Navajo Sandstone (Arizona) indicates that it was deposited by a current moving from right to left. In this case, the current was wind and the sandstones most likely represent sand dunes deposited in a vast desert roughly 200 million years ago.



A.



B.

FIGURE 4.5
Ripple marks are wave-like features found on bedding planes. A. **Current ripple marks,** like these in Utah, form when wind or water currents moving in one direction shape the loose sediment into asymmetrical wave forms whose gentle slope is on the side from which the current came. In this example, the current moved from right to left as shown in the schematic cross section. B. **Oscillation ripple marks** commonly are formed where the back-and-forth motion of water waves shapes the bottom sediment into symmetrical wave forms (see cross section). This can occur only in relatively shallow water—less than 10 m for normal waves and up to 200 m for large storm waves. (Loraine Formation, near Desbarets, Ontario, Canada.)

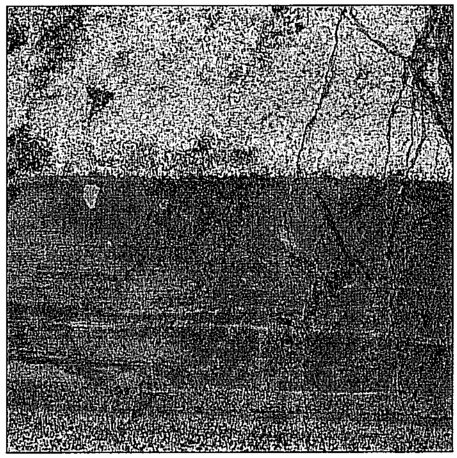


FIGURE 4.6
In **graded beds,** larger grains on the bottom usually grade to finer ones on the top, as shown here. Graded beds may form when a sediment-laden (turbidity) current slows after moving down an underwater slope; larger grains settle first, smaller ones last. (Lake Vermillion Formation, near Tower, Minnesota.)

Lithification

Lithification is the conversion of sediment to sedimentary rock. It is accomplished by *compaction* caused by the weight of the overlying sediment, *cementation* by new minerals that fill the open spaces between grains (Fig. 4.8), and various kinds of *recrystallization* processes that cause grains to interlock.

Sedimentary Rocks

Classification

The two types of sediment provide the basis for two categories of sedimentary rocks (Fig. 4.9): (1) **detrital**—those made of solid particles derived from outside the basin of deposition, and (2) **chemical and biochemical**—those formed by precipitation of ions or accumulation of organic materials within the basin of deposition. Classification within these groups is based on texture and mineral composition.

Texture

Most **sedimentary rocks** have a **clastic texture** (Fig. 4.10), which is characterized by discrete clasts or grains of

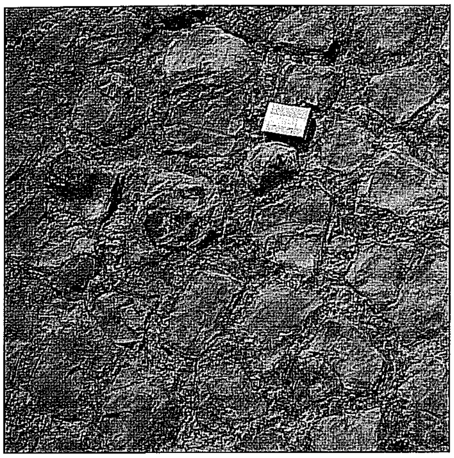


FIGURE 4.7
Mud cracks form when mud (fine-grained sediment) dries and shrinks. In side view, the cracks are widest at the top and taper to a point. From above, most ancient mud cracks appear as rough polygons formed when new sediment washed into the cracks and defined a color or textural contrast with the original mud. The example above is from the Moenkopi Formation, near Moab, Utah. Mud cracks indicate such depositional environments as desert lakes, tidal flats, or other places where periodic wetting and drying occurs.

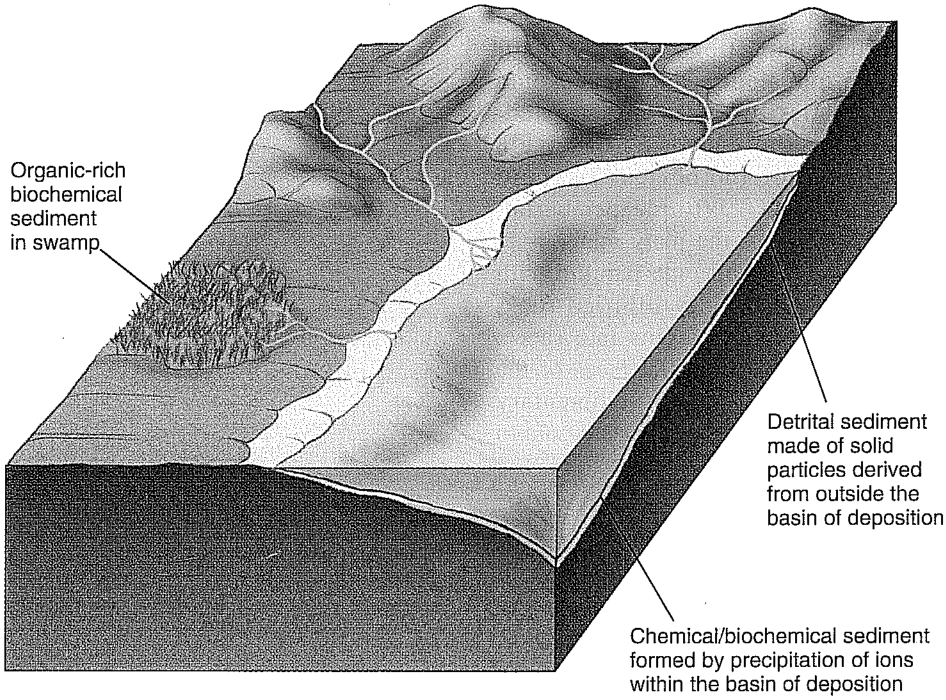


FIGURE 4.9
The two means by which sediment accumulates serve as a basis for classifying sedimentary rocks into detrital and chemical/biochemical.

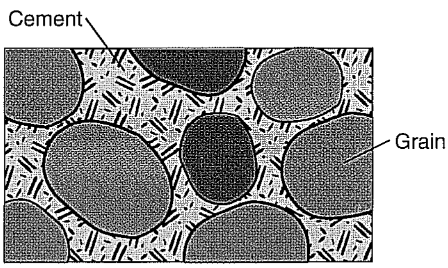


FIGURE 4.8
Lithification by cementation occurs when larger grains are "glued" together with crystalline **cement,** as shown in this "microscopic" view.

rocks, minerals, or fossils. The originally loose grains are not intergrown with each other, but are generally bound together or cemented by a chemical precipitate of silica, calcite, dolomite, or iron oxide. This **cement** generally has a crystalline texture (see Fig. 4.8). If the clastic texture is due to abundant fossils or fossil fragments, the rock is called **bioclastic.**

Although many chemical and biochemical sedimentary rocks have clastic textures, some have **crystalline** textures: careful examination reveals a rock made of interlocking crystals. A primary crystalline texture forms during or just after deposition, as in the cases of rock gypsum and rock salt. Secondary crystalline textures result from the recrystallization or replacement of primary grains or minerals by new minerals. This occurs during or after lithification, as in the case of many crystalline limestones and dolostone.

The textures seen in extremely fine-grained rocks depend on what they are made of. Chert (Fig. 2.4E), flint (Fig. 2.4F), and some limestones represent recrystallized biochemical rocks with crystals so tiny that they can be seen only under a microscope. These rocks are termed **microcrystalline.**

The texture seen in fine-grained detrital rocks (clay- and silt-sized particles) depends on the amount of compaction during lithification. When first deposited, clay-sized particles of platy or flat minerals, such as clays and micas, mimic a pile of loose leaves: most are roughly horizon-

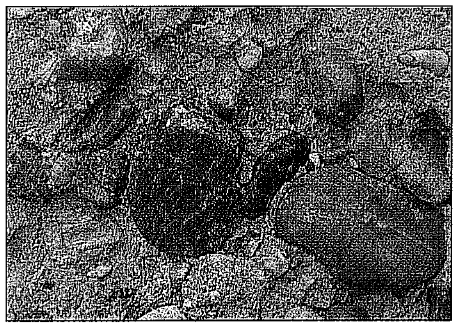


FIGURE 4.10
Clastic texture in **conglomerate.** Conglomerates contain rounded granules, pebbles, cobbles, even boulders, in a matrix of finer-grained particles. The largest fragments can be any kind of rock that is durable enough to be transported by water or ice. Some conglomerates contain a variety of large fragments that are made up principally of one rock type. Granule- and pebble-size pieces in some conglomerates are made entirely of quartz because it is so resistant to abrasion. Common matrix minerals are sand-size quartz and feldspar. Conglomerates form from gravels, and common depositional environments are alluvial fans, stream channels, and beaches along rocky coasts.

tal, but many are not. Shallow burial and moderate compaction of clay and silt creates a **mudstone,** which breaks into characteristically blocky pieces. Mudstones may show layering or have a **massive** texture (no obvious layers or color variations). With deeper burial, compaction forces the platy minerals to flatten until they become parallel with the bottom. This fully lithified rock, called a **shale,** easily splits into sheets that are parallel to the flat faces of the tiny compacted clays. A sedimentary rock that splits into such sheets is said to be **fissile.**

Mineral Composition

The major mineral components of sedimentary rocks, and their salient properties, are listed in Table 4.3.

Identification of Sedimentary Rocks

Common sedimentary rocks are listed in Table 4.4 (Detrital Sedimentary Rocks) and Table 4.5 (Chemical and Biochemical Sedimentary Rocks). Choose which table to use as follows:

A. If grains or crystals are visible without a hand lens, and:
   1. The rock is harder than 5.5 (scratches glass), use Table 4.4 (the common detrital minerals in rocks with silt-size and larger grains will scratch glass).
   2. The rock is softer than 5.5, use Table 4.5.

B. If grains or crystals are not visible, or barely visible with a hand lens:
   1. The rock is a shale or mudstone (Table 4.4), or
   2. It is a chemical or biochemical rock (Table 4.5).

If Table 4.4 is chosen, determine the grain size (Fig. 4.1 may be helpful) and mineral composition (see Table 4.3) to identify the rock. The terms *claystone, siltstone, shale, mudstone, sandstone,* and *conglomerate* refer to grain size; *graywacke, quartz sandstone,* and *arkose* are sandstones with specific mineral compositions. When naming a detrital sedimentary rock, it is most informative if both mineral composition and grain size are given (e.g., *quartz sandstone, granite-pebble conglomerate,* and *coarse-grained graywacke*). In addition, the textural names for sedimentary rocks made of grains larger than about 2 mm are based on grain roundness: if the rock or mineral fragments are angular, the rock is a *breccia;* if they are rounded, it is a *conglomerate.*

Table 4.5 lists chemical and biochemical sedimentary rocks. They are named primarily on the basis of mineral composition, although the names of *limestones* (sedimentary rocks composed mostly of calcite) also depend on texture or fossil content. If the rock is listed in Table 4.5, first determine the mineral composition (Table 4.3 will help), then, in the case of limestones, the texture.

Some common sedimentary rocks are shown in Figures 4.10 through 4.21. The photographs are representative examples only, and your samples may differ *considerably* in color and general appearance from those illustrated here.

TABLE 4.3 RECOGNIZING MINERALS IN SEDIMENTARY ROCKS

Mineral	*Properties*
Quartz	White to light gray Exterior may be frosted; broken grains glassy Hardness = 7
Chert (white, gray, pink) Flint (black) Jasper (red)	Color varieties of microcrystalline (extremely fine grained) SiO_2 Smooth, conchoidal fracture Hardness = 7
Feldspar	K-feldspar most common White or pink Two cleavages Commonly angular
Biotite	Shiny and black (gold if altered) One perfect cleavage
Muscovite	Shiny and silvery One perfect cleavage
Clay (e.g., kaolinite)	White, gray, green, red, black Clay-sized particles (microscopic) Soft (H = 1–2.5)
Iron oxide	Yellow, orange, red, brown—strong coloring agent Usually very small particles Mainly a cement or surface stain
Calcite	White, gray, black Hardness = 3 Bubbles readily in acid
Dolomite	Gray, buff Hardness = 3.5 Bubbles slowly in acid if powdered
Gypsum	White to gray Soft (H = 1)
Halite	White, light gray, pinkish white Hardness = 2.5 Tastes like salt

TABLE 4.4
CLASSIFICATION OF DETRITAL SEDIMENTARY ROCKS

Grain Size	*Comments*		*Rock Name*	
"Gravel" (>2 mm)	Rounded grains. Rock name may be modified by type and size of dominant grains (e.g., quartz-pebble conglomerate) or composition of grains and matrix (e.g., arkosic conglomerate). Clastic texture.		Conglomerate	
"Gravel" (>2 mm)	Angular grains. Rock name may be modified by type of dominant grains (e.g., chert breccia). Clastic texture.		Breccia	
Sand (0.06–2 mm)	Mostly quartz grains. Grains commonly well rounded and well sorted. Clastic texture.		Quartz sandstone	Sandstone
Sand (0.06–2 mm)	Mostly quartz and feldspar. Grains commonly angular and poorly sorted. Commonly reddish. Clastic texture.		Arkose	Sandstone
Sand (0.06–2 mm)	Composed of quartz, feldspar, rock fragments, and clay. Grains angular and poorly sorted. Dark color common. "Graywacke" is an imprecise general term for such sandstones. May require hand lens to see clastic texture.		Graywacke	Sandstone
Silt (0.06–0.004 mm)	Commonly massive. Feels gritty on teeth. Fine grained.	Grains too small to identify composition. Mudstone and shale are made of silt and clay. Mudstone breaks with conchoidal fracture; shale is fissile.	Siltstone	Shale (fissile) or mudstone
Clay (<0.004 mm)	Commonly laminated. Feels smooth on teeth. Fine grained.		Claystone	Shale (fissile) or mudstone

TABLE 4.5
CLASSIFICATION OF CHEMICAL AND BIOCHEMICAL SEDIMENTARY ROCKS

Composition		*Comments*	*Rock Name*
Calcite ($CaCO_3$)	All effervesce in dilute HCl	Crystalline texture.	Crystalline limestone*
Calcite ($CaCO_3$)	All effervesce in dilute HCl	Microcrystalline. Breaks with conchoidal fracture.	Micritic limestone
Calcite ($CaCO_3$)	All effervesce in dilute HCl	Sand-size spheres with concentric layers (ooids). Clastic texture.	Oolitic limestone
Calcite ($CaCO_3$)	All effervesce in dilute HCl	Abundant fossils or fossil debris cemented together with a fine-grained or crystalline matrix. Bioclastic texture.	Fossiliferous limestone*
Calcite ($CaCO_3$)	All effervesce in dilute HCl	Angular to rounded grains that are neither ooids nor clearly bioclastic. Fine-grained or crystalline matrix. Clastic texture.	Clastic limestone
Calcite ($CaCO_3$)	All effervesce in dilute HCl	Poorly cemented shell fragments; little or no matrix. Bioclastic texture.	Coquina
Calcite ($CaCO_3$)	All effervesce in dilute HCl	Fine-grained, massive, earthy, poorly cemented, generally white.	Chalk
Calcite ($CaCO_3$)	All effervesce in dilute HCl	Banded, finely crystalline to microcrystalline.	Travertine
Dolomite ($CaMg(CO_3)_2$)		Effervesces weakly with dilute HCl; powder effervesces more strongly. Commonly crystalline. May contain small, crystal-lined cavities.	Dolostone†
Quartz (SiO_2)		Dense, microcrystalline texture, hardness = 7. See Table 4.3.	Chert/Flint/Jasper
Gypsum ($CaSO_4 \cdot 2H_2O$)		Massive, crystalline, soft, generally white to gray.	Rock gypsum
Halite (NaCl)		Massive, crystalline, tastes like salt, generally white, clear, gray, reddish.	Rock salt
Plant debris (mostly C)		Black, shiny to earthy luster, low density. Plant fossils may be visible. Combustible.	Coal

*Limestones can display more than one texture, sometimes mixed together and sometimes in separate layers. For example, we find fossiliferous micritic limestones and clastic micritic limestones. The important thing is to recognize the components and name the limestone so that communication is clear.

†Since dolostones are recrystallized and chemically altered limestones, there are crystalline, microcrystalline, oolitic, and fossiliferous dolostones. If you recognize a component, name it!

FIGURE 4.11
Breccia is similar to conglomerate (Fig. 4.10), but has angular, rather than rounded, particles. Because the angular pieces have not moved far from their source, they commonly are all of the same rock type, rather than a mixture of rock types. The matrix of a breccia may be finer particles or cement with a crystalline texture. The angular particles imply a nearby source, so common depositional environments include the bases of cliffs or steep slopes, landslide areas, or places where caves have collapsed.

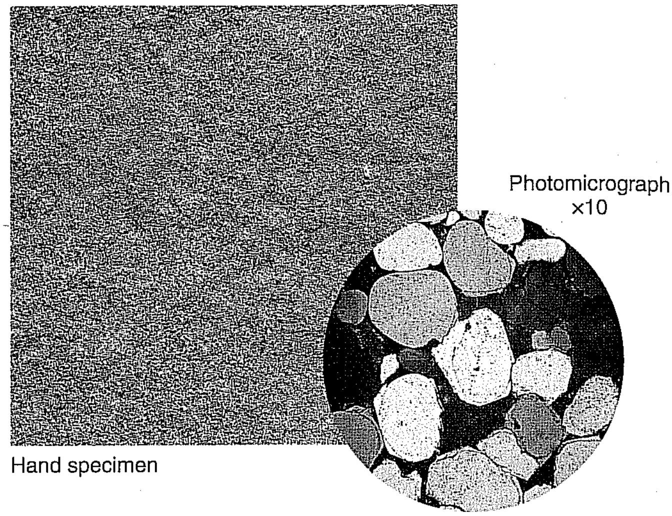


FIGURE 4.12
Quartz sandstone is made almost entirely of sand grains of quartz. The quartz grains are commonly rounded (see photomicrograph) and cemented together by calcite, iron oxide, or secondary quartz. Some quartz sandstone is white, but more commonly it is buff or rusty brown because of a small amount of iron oxide cement. Relatively pure quartz sand accumulates only when other minerals have weathered away, or where quartz is the only material available in the source area. Depositional environments are beach and near-shore areas, extensive sand-dune fields, and some stream channels.

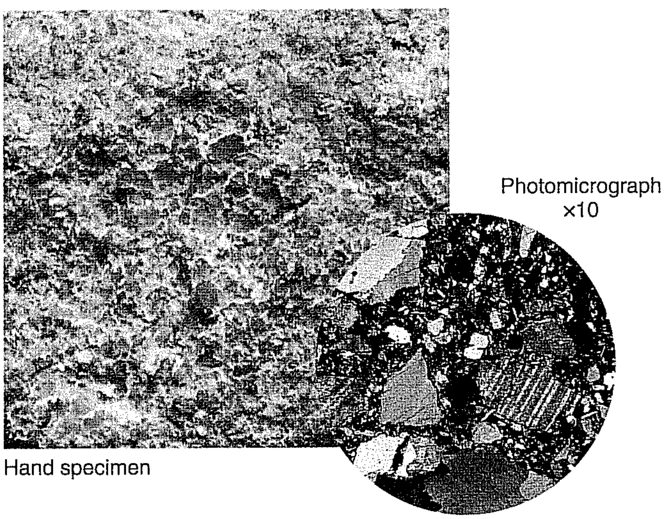


FIGURE 4.13
Arkose. While most sandstones contain a small amount of feldspar, arkose is unusual because feldspar is a prominent component along with quartz. The grains are commonly less rounded and more poorly sorted than in quartz sandstone (see inset). The combination of pink potassium feldspar and rusty iron oxide gives arkoses their typical reddish color. Many arkoses were derived from erosion of granite in steep terrains and were deposited in nearby alluvial fans or beach-near-shore settings.

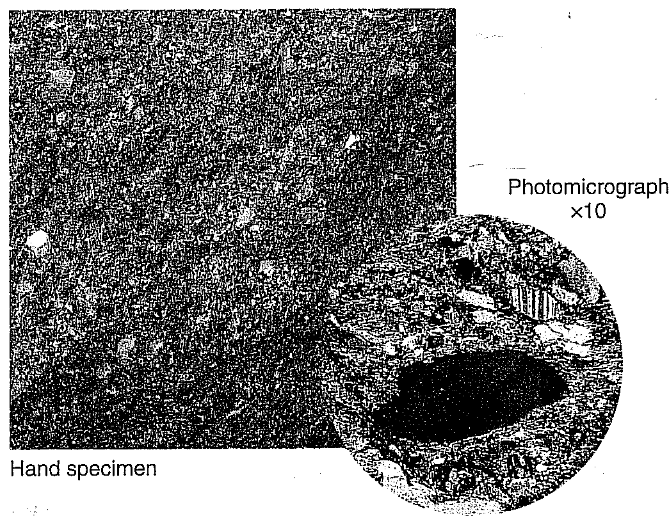
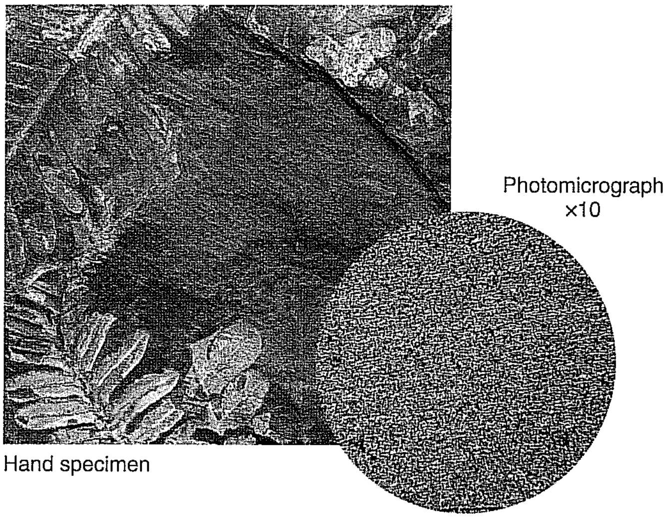
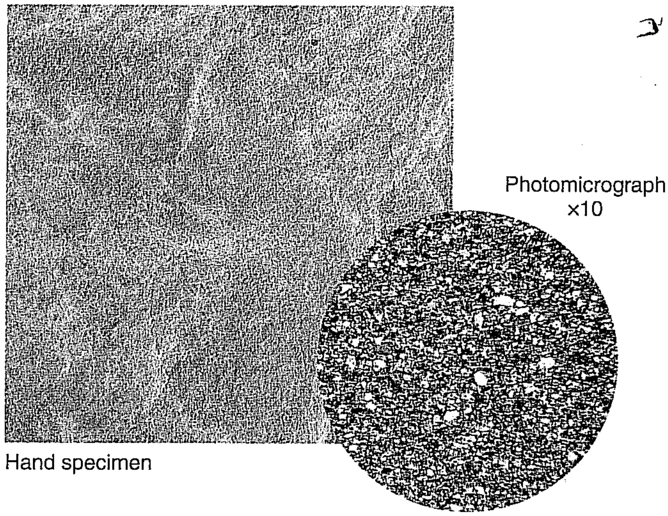


FIGURE 4.14
Graywacke is a general field term for gray to dark gray sandstones with fine-grained matrices. Common components include quartz, feldspar (especially plagioclase), rock fragments (especially volcanic rocks), and micas. The angular grains tend to be fine sand, rather than coarse, and the combination of small grain size and even finer-grained matrix give graywacke a rather nondescript appearance. A hand lens may be needed to recognize the clastic texture. Graywackes are common sedimentary rocks in the vicinity of volcanic island arcs or off the margins of continental shelves, where they were deposited from dense, sediment-laden (turbidity) currents that periodically flow off the shelf edge into the deep ocean.

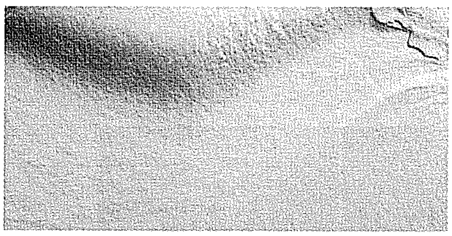


A.

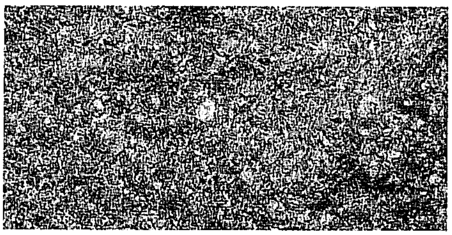


B.

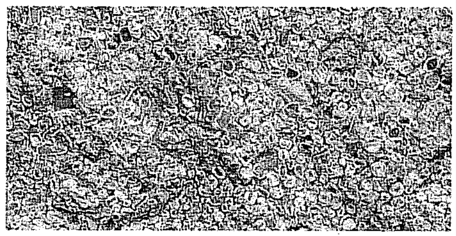
FIGURE 4.15
(A) **Shale** and (B) **mudstone.** The finest particles end up as components of these mud rocks. Shale is fissile; mudstone is not. Both tend to break up easily in outcrops, but mudstone is more likely to break into larger pieces with a conchoidal fracture. If rich in organic matter, shales and mudstones are black; if not, they are gray, red, or green. Some geologists distinguish two types of mudstone—claystone and siltstone—based on particle size. Siltstone feels gritty when chewed; claystone does not. (So, if you like, take a chew.) Mudstone and shale are by far the most abundant kinds of sedimentary rocks. They accumulate in the quiet water of floodplains, lagoons, and lakes, and offshore in shallow and deep marine environments. The shale shown here contains fossil ferns.



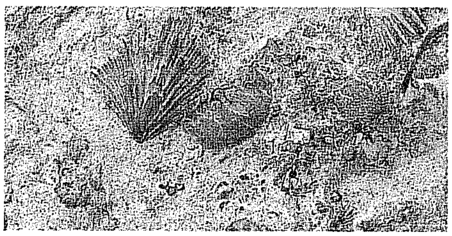
A. Micritic limestone



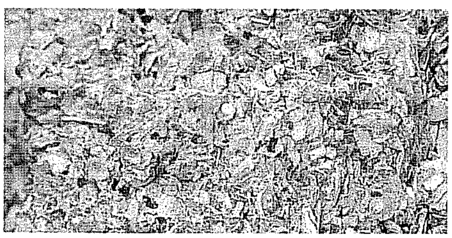
B. Crystalline limestone



C. Oolitic limestone



D. Fossiliferous limestone



E. Coquina

FIGURE 4.16
Limestone is made of calcite, so its hardness of 3 and ability to bubble readily in acid are distinctive. Only a few of the many types of limestone are mentioned here. *Micritic* or *microcrystalline limestone* (A) has such tiny crystals that it often forms smooth fracture surfaces. Most samples represent the recrystallized remains of billions of microscopic particles released by the decay of calcareous algae. *Crystalline limestone* (B) is made of small but recognizable interlocking calcite crystals. Many samples formed when coarse bioclastic fossil debris was extensively recrystallized during or after lithification. Few obvious fossils remain. *Oolitic limestone* (C) (the *oo* is pronounced like the two o's in moo) consists of sand-sized spheres of calcite (called *ooids*) cemented together. The interior of an ooid shows concentric layers of calcite formed around a central tiny bioclastic particle. Ooids form like tiny snowballs in warm shallow waters in response to wave or tidal currents that wash them back and forth. *Fossiliferous limestones* (D) contain abundant calcareous (made of calcium carbonate) fossils or fossil fragments that are cemented together with microcrystalline or crystalline calcite. Such limestones frequently formed in shallow continental shelves; many contain impurities in the form of clay and silt-sized clastic particles. *Coquina* (E) consists almost entirely of poorly cemented, coarse, bioclastic debris. There is little or no fine-grained matrix so the rock is very open and porous. Coquinas generally form near beaches where waves wash away the finer grains. *Chalk* is a white, soft limestone composed of microscopic calcareous fossils that accumulate in deeper ocean waters. In general, most limestones form in warm, shallow seas far from shore, where the water is clear and free from land-derived detritus. Although today confined to small parts of the outer continental shelves, the geologic record of limestones tells us that in the past such seas covered vast areas of the continents.

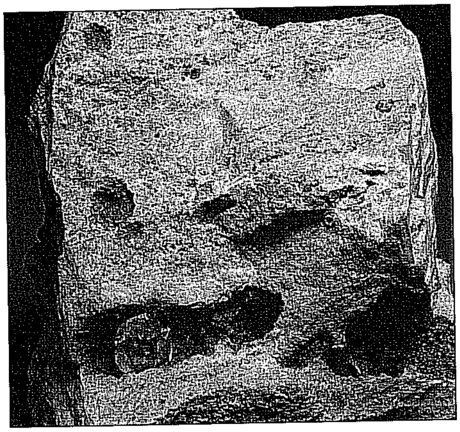


FIGURE 4.17
Dolostone is made of the mineral dolomite. It is distinguishable from limestone by its lesser reaction with acid. It is sometimes necessary to use a hand lens to see that it actually bubbles, or to scratch the rock (to make a powder) before testing with acid. Dolostone has a crystalline texture and commonly is light gray or buff. A common, but not invariable, feature is the presence of crystal-lined cavities, or *vugs*. The sample shown here contains a crystal of clear quartz (a "Herkimer diamond"). Most dolostone is formed by replacement of limestone.

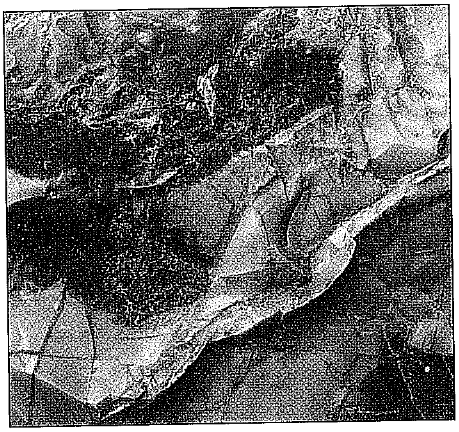


FIGURE 4.18
Chert (shown here), **flint,** and **jasper** are made of microcrystalline quartz. They break with a conchoidal fracture and have smooth surfaces. They most resemble micritic limestone, but their hardness of 7 gives them away. See Table 4.3 and Figure 2.4D, E, and F for characteristic colors. Some chert forms by replacement of limestone and may retain some of the textural elements, such as fossils or ooids. Most chert forms by biochemical extraction of silica from ocean water. Such chert consists of microscopic plant (diatom) or animal (radiolaria and sponge spicules) fossils.

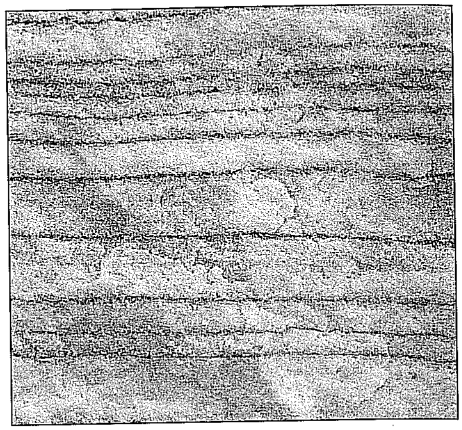


FIGURE 4.19
Rock gypsum is usually white, light gray, or pale shades of red or orange. It has a crystalline texture and can be scratched with your fingernail. Dark impurities may be present as layers or outlines around irregular areas. Gypsum is an evaporite mineral; when seawater evaporates, gypsum is one of the minerals that precipitates. Thick deposits accumulate in bays in arid regions that have restricted access to the open ocean; deposition also occurs in salty inland seas or lakes.

FIGURE 4.20
Rock salt is made of halite. It has a crystalline texture and is white, light gray, or tinged with red or orange. It forms in the same manner and depositional environment as does gypsum. The reddish mineral here is sylvite (KCl).

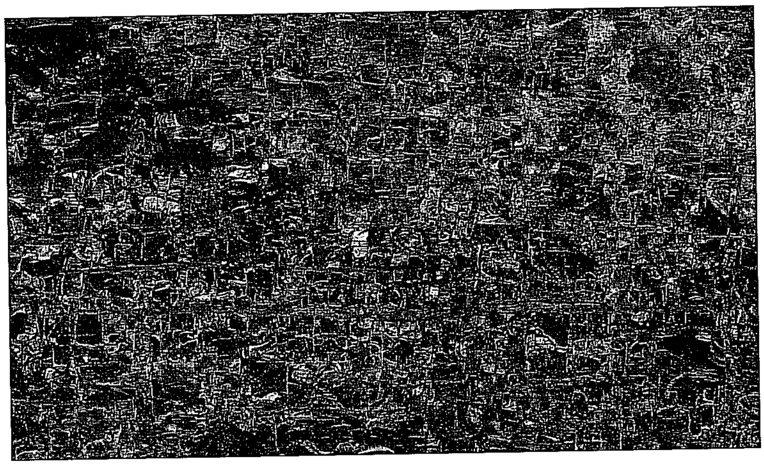


FIGURE 4.21
Coal is brown to black, depending on the amount of carbon it contains. Brown to brownish black *lignite* contains less carbon than black *bituminous coal,* which, in turn, contains less carbon than metamorphic coal, *anthracite.* Coal is noncrystalline and has a luster that ranges from dull to vitreous as carbon content increases. Coal forms by burial and compaction of vegetation that accumulated in swamps.