LABORATORY 6

Sedimentary Processes, Rocks, and Environments

CONTRIBUTING AUTHORS

Harold Andrews • *Wellesley College*

James R. Besancon • *Wellesley College*

Pamela J.W. Gore • *Georgia Perimeter College*

Margaret D. Thompson • *Wellesley College*

The grains in this detrital sedimentary rock are clasts (broken pieces) of older rocks (x1). Some of the clasts are freshly broken and angular. Others clasts had their corners worn down and are now rounded.

BIG IDEAS

Sediments are loose particles of Earth materials, including rock fragments, mineral grains weathered from rocks, animal shells, twigs, crystals precipitated from evaporating water, and chemical residues like rust. Sedimentary rocks form wherever the loose particles of sediment are compacted, cemented, or otherwise hardened to a solid mass. Layers of sediments and sedimentary rocks are like pages of a book. Their fossils and geologic structures tell us about Earth's history and past environments and ecosystems.

FOCUS YOUR INQUIRY

THINK About It | What do sedimentary rocks look like? How can they be classified into groups?

THINK About It | What are sedimentary rocks made of, and how are they formed?

THINK About It | How do geologists describe, classify, and identify sedimentary rocks?

THINK About It | What can sedimentary rocks tell us about Earth's history and past environments and ecosystems?

ACTIVITY 6.1 Sedimentary Rock Inquiry

THINK About It What do sedimentary rocks look like? How can they be classified into groups?

OBJECTIVE Analyze and describe samples of sedimentary rocks, then infer how they can be classified into groups.

PROCEDURES

1. **Before you begin**, do not look up definitions and information. Use your current knowledge, and complete the worksheet with your current level of ability. Also, this is **what you will need** to do the activity:
   ____ Activity 6.1 Worksheet (p. 171) and pencil
   ____ optional: a set of sedimentary rock samples (obtained as directed by your instructor)
2. **Analyze the rocks, and complete the worksheet in a way that makes sense to you.**
3. **After you complete the worksheet**, read the Introduction below, and be prepared to discuss your observations, interpretations, and inferences with others.

Introduction

Sedimentary rocks form when sediments are compressed, cemented, or otherwise hardened together. Some sedimentary rocks form by a process similar to mud hardening in the Sun to form *adobe*. Others form when masses of intergrown mineral crystals precipitate from aqueous (water-based) solutions and lock together to form crystalline rock, like rock salt that remains when ocean water is evaporated.

Sediments are loose grains and chemical residues of Earth materials, including rock fragments, mineral grains, parts of plants or animals like seashells and twigs, and chemical residues like rust (hydrated iron oxide residue). Grains of sediment are affected by chemical and physical weathering processes until they are buried in a sedimentary deposit or else disintegrate to invisible atoms and molecules dissolved in water (aqueous solutions), like groundwater (water beneath Earth's surface), lakes, streams, and the ocean. The salty taste of ocean water or salty lake water (e.g., Great Salt Lake or the Dead Sea) is a clue that many Earth materials are dissolved into it, but even fresh water has some materials dissolved in it (just not as many). Only distilled water has no materials dissolved in it.

ACTIVITY 6.2 Mount Rainier Sediment Analysis

THINK About It What are sedimentary rocks made of, and how are they formed?

OBJECTIVE Investigate sediment forming on and near Mount Rainier, WA.

PROCEDURES

1. **Before you begin**, read about Sedimentary Processes, Composition, and Textures of Sediments and Sedimentary Rocks below. Also, this is **what you will need:**
   ___ Activity 6.2 Worksheet (p. 172) and pencil
   ___ optional: computer with access to Google Earth™
2. **Then follow your instructor's directions** for completing the worksheets.

ACTIVITY 6.3 Clastic and Detrital Sediment

THINK About It What are sedimentary rocks made of, and how are they formed?

OBJECTIVE Analyze clastic and detrital sediment and infer the environment in which sedimentary grains formed.

PROCEDURES

1. **Before you begin**, read about Sedimentary Processes and Composition and Textures of Sediments and Sedimentary Rocks below. Also, this is **what you will need:**
   ___ Activity 6.3 Worksheet (p. 174) and pencil
   ___ hand lens or stereo zoom microscope
   ___ grain size scale cut from GeoTools Sheet 1 or 2
   ___ small piece of shale
   ___ medium quartz sandpaper
   ___ 2 small pieces of granite or diorite
   ___ optional: computer with access to Google Earth™
2. **Then follow your instructor's directions** for completing the worksheets.

ACTIVITY

6.4 Biochemical and Chemical Sediment and Rock

THINK About It | **What are sedimentary rocks made of, and how are they formed?**

OBJECTIVE Analyze characteristics of biochemical and chemical sediment and rock and infer how they form.

PROCEDURES

1. **Before you begin**, read about Sedimentary Processes and Composition and Textures of Sediments and Sedimentary Rocks below. Also, this is **what you will need:**
   - ___ Activity 6.4 Worksheet (p. 176) and pencil
   - ___ dilute HCl (hydrochloric acid) in dropper bottle
   - ___ seashells, charcoal briquette
   - ___ coal, dolomite
   - ___ hand lens
   - ___ plastic sandwich bags
   - ___ piece of chalk from the chalkboard
2. **Then follow your instructor's directions** for completing the worksheets.

ACTIVITY

6.5 Sediment Analysis, Classification, and Interpretation

THINK About It | **What are sedimentary rocks made of, and how are they formed?**

OBJECTIVE Describe and classify samples of sediment in terms of texture and composition, and then infer environments in which they formed.

PROCEDURES

1. **Before you begin**, read about Sedimentary Processes, Composition, and Textures of Sediments and Sedimentary Rocks below. Also, this is **what you will need:**
   - ___ Activity 6.5 Worksheet (p. 178) and pencil
   - ___ Visual Estimation of Percent chart from GeoTools 1 or 2
2. **Then follow your instructor's directions** for completing the worksheets.

Sedimentary Processes

Sedimentary processes (**FIGURE 6.1**) include everything from the time and place that sediment forms to the time and place where it is *lithified* (hardened into sedimentary rock).

Formation of Chemical Sediment

Water is a *solvent* (a liquid capable of dissolving and dispersing solid materials), so all natural bodies of water are aqueous solutions. This means that they are filled with chemicals that are "in solution," dissolved and dispersed from the materials over and through which the water has flowed. When water full of dissolved chemicals (an aqueous solution) evaporates, the chemicals in the water combine and precipitate (form solids from the solution) as mineral crystals and chemical residues called **chemical sediment**. Chemical sediment is generally *in situ*, meaning that it formed where it is found. For example, think of the intergrown halite crystals in rock salt that formed in an evaporating sea. The crystals are intergrown and locked together as sedimentary rock as they form. Oxide residues, like rust, are often deposited *in situ* (in place, where the rust formed) as coatings on surfaces of rocks, but they can also form as powdery residues in the water and be carried by the water to new locations.

Chemical sediment is the end product of *chemical weathering*—the decomposition or dissolution of Earth materials. For example, feldspars are a group of the most common minerals in Earth's crust. When potassium feldspar decomposes in acidic groundwater, it chemically decays to clay minerals (kaolinite) plus chemicals (potassium and silica) in solution. This is the main way that clay forms to make soil. Olivine decomposes to iron and magnesium in solution, and then they combine with oxygen to make oxide residues, like rust. Chemical residues commonly coat the surfaces of visible grains of sediment and either discolor them or serve as a cement to "glue" them together and form sedimentary rock.

Formation of Clastic (Detrital) and Biochemical Sediment

Physical (mechanical) weathering is the cracking, crushing, and wearing away (scratching, abrasion, transportation) of Earth materials. Cracking and crushing processes cause big rocks to be fragmented into *clasts* (broken pieces: from the Greek *klastós*, meaning broken in pieces) or *clastic sediment*, including *rock fragments* and *mineral grains* (whole crystals or fragments of crystals). Continental bedrock, rich in silicate minerals, is fragmented into **siliciclastic sediment** made of quartz grains, feldspar grains, and rock fragments. Sediment worn and transported from the land, generally siliciclastic, is also called **detrital sediment** (from the Latin *detritus*, participle of *detero*, meaning to weaken, wear away, rub off). Rock fragments and mineral crystals

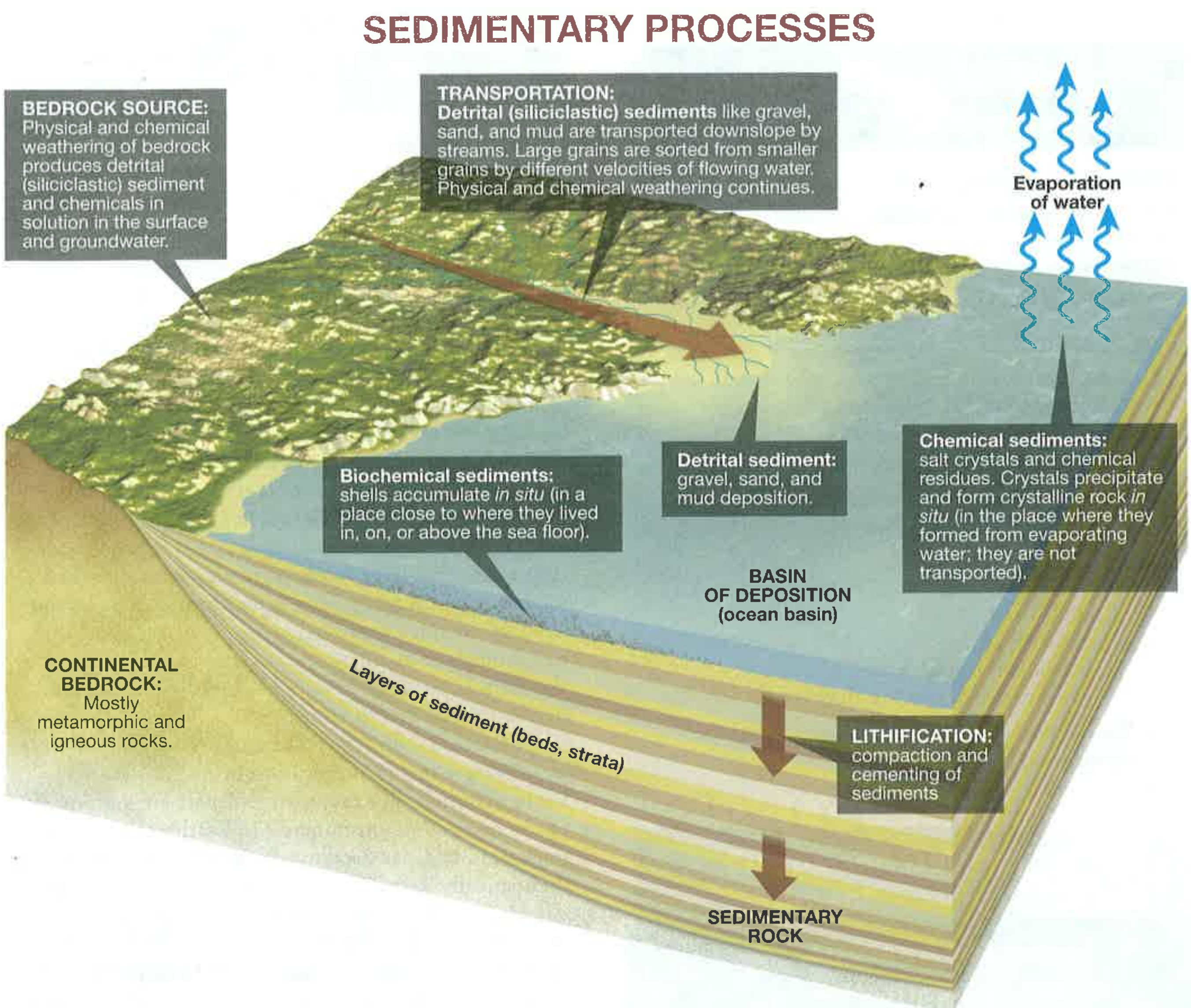


FIGURE 6.1 Sedimentary processes. Sedimentary processes include everything from the formation of detrital (siliciclastic), biochemical (bioclstic), and chemical sediments to the lithification (hardening) of sediments that results in sedimentary rock.

broken and transported away from bedrock surfaces (cliffs, valley walls, other outcrops) are detrital grains comprising detrital sediment. Detrital sediment is not *in situ*; it is transported away from its source. Plants and animals are fragmented into bioclastic **biochemical sediment** made of things like shells, fragmented shells, twigs, and leaves. This kind of sediment is easily broken, worn, and chemically decayed, so it is generally *in situ*. If you find a **fossil** (any evidence of ancient life), then the organism probably lived where it was fossilized.

Erosion, Transportation, and Deposition of Sediment

The place where sediment originates or forms is called its *source*. Although most biochemical and chemical sediment remains close to where it formed (is *in situ*), detrital sediment is **eroded** (loosened, removed) from its *source* and **transported** (moved, carried) over great distances. Agents of erosion and transportation include wind, water, ice, organisms, and gravity. For example, gravity forces water to flow downhill, and water is a physical agent that picks up and carries sediment. Eventually, the water flows into a *basin* (depression where water and sediment accumulate), becomes part of a lake or ocean, and sediment deposition occurs. **Deposition** is what happens when transportation stops and sediment accumulates by settling out of the water (or air or melting ice) that carried it. (In contrast, chemical and biochemical sediment is usually not transported, so it is deposited *in situ*—where it forms.)

Layering of Sediment

The result of deposition is a **deposit** of sediment. So erosion, transportation, and deposition are a sequence of related events. The events are also episodic (happen infrequently, not continuously). Erosion happens when it rains, transportation happens when it floods, and deposition happens when flood waters accumulate in a lake or ocean and stop moving (and sediment settles out or precipitates out of the water). The net result is, therefore, a layered deposit. Each time a new episode of flood water washes into the lake or ocean, a new layer of sediment is deposited on top of the last (older) one. In between the depositional events, there is *nondeposition* (a time during which no deposition occurs). The times of nondeposition become surfaces, called **bedding planes**, between the layers of sediment (called **beds**, **bedding**, or **strata**).

Lithification of Sediment

Lithification is the process of changing loose particles of sediment (unconsolidated sediment) to solid rock (consolidated sediment). This happens most often when sediment is *compacted* (squeezed together) or *cemented* (glued together by tiny crystals or chemical residues).

Composition and Textures of Sediments and Sedimentary Rocks

Sediment and sedimentary rocks are described, classified, named, and interpreted on the basis of their composition and textures.

Composition of Sediment and Sedimentary Rocks

The **composition** of a sediment or sedimentary rock is a description of the kinds and abundances of grains that compose it (**FIGURE 6.2**). Sediments and sedimentary rocks are classified as biochemical (bioclastic), chemical, or detrital (siliciclastic) based on their composition. **Biochemical** sediments and rocks consist of whole and broken **(bioclastic)** parts of organisms, such as shells and plant fragments. **Chemical** sediments and rocks consist of chemical residues and intergrown mineral crystals precipitated from aqueous solutions. The precipitated minerals commonly include gypsum, halite, hematite, limonite, calcite, dolomite, and chert (microcrystalline variety of quartz). **Detrital** sediments and rocks consist of **siliciclastic** grains (rock fragments, quartz, feldspar, clay minerals) that are also *detrital* grains—rock fragments and mineral grains that were worn and transported away from the landscape.

Textures of Sediment and Sedimentary Rocks

Processes of weathering, transportation, precipitation, and deposition that contribute to the formation of a sediment or sedimentary rock also contribute to forming its texture. The **texture** of a sediment or sedimentary rock is a description of its parts and their sizes, shapes, and arrangement (**FIGURE 6.3**).

Grain Size. The particles that make up sedimentary rocks are called **grains**. Size of the grains is commonly expressed in these *Wentworth classes,* named after C. K. Wentworth, an American geologist who devised the scale in 1922:

- **Gravel** includes grains larger than 2 mm in diameter (granules, pebbles, cobbles, and boulders).
- **Sand** includes grains from 1/16 mm to 2 mm in diameter (in decimal form, 0.0625 mm to 2.000 mm). This is the size range of grains in a sandbox. The grains are visible and feel very gritty when rubbed between your fingers.
- **Silt** includes grains from 1/256 mm to 1/16 mm in diameter (in decimal form, 0.0039 mm to 0.0625 mm). Grains of silt are usually too small to see, but you can still feel them as very tiny gritty grains when you rub them between your fingers or teeth.
- **Clay** includes grains less than 1/256 mm diameter (in decimal form, 0.0039 mm). Clay-sized grains are too small to see, and they feel smooth (like chalk dust) when rubbed between your fingers or teeth. Note that the word *clay* is used not only to denote a grain size, but also a clay mineral. However, clay mineral crystals are usually clay-sized.

Rounding of Sediment. All sediment has a *source* (place of origin; **FIGURE 6.1**). Sediments deposited quickly at or near their source tend to lack abrasion. Sediments that have been moved about locally (as in waves on a beach) or transported away from their source are abraded (worn). **Roundness** is a description of the degree to which the sharp corners and points of a fragmented grain have been worn away and its profile has become round (**FIGURE 6.3**). A newly formed clast is *very angular*. As it is transported and worn it will become *subangular*, then *subround*, and then *well rounded*. A freshly broken rock fragment, mineral grain, or seashell has sharp edges and is described as *angular*. The more rounded a grain becomes, the smaller it generally becomes. Gravel gets broken and abraded down into sand, and sand gets broken and abraded into silt and clay-sized grains. When combined, the silt plus clay mixture is called *mud*.

Sorting of Sediment. Different velocities of wind and water currents are capable of transporting and naturally separating different densities and sizes of sediments from one another. **Sorting** is a description of the degree to which one size class of sediment has been separated from the others (**FIGURE 6.3**). *Poorly sorted* sediments consist of a mixture of many different sizes of grains. *Well-sorted* sediments consist of grains that are of similar size and/or density.

COMPOSITIONAL CLASSIFICATION OF SEDIMENT AND SEDIMENTARY ROCKS

A. DETRITAL (SILICICLASTIC) SEDIMENT AND SEDIMENTARY ROCK IS MOSTLY ONE OR MORE OF THESE:

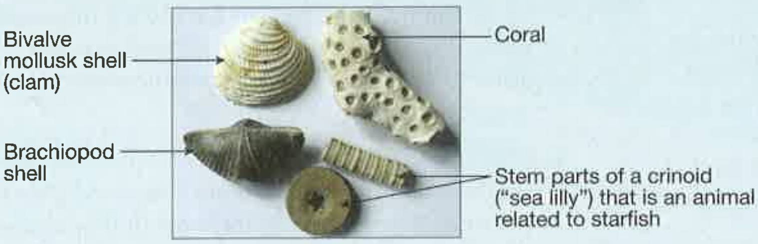
Rock fragments: may be angular or rounded; can include detrital chert grains (see "chert" below)

Quartz grains: angular grains freshly broken from their source and pebbles rounded during transportation

Feldspar grains: large angular grains freshly broken from their source and small subangular grains

Clay: commonly forms from chemical decay of feldspars and micas

B. BIOCHEMICAL SEDIMENT AND SEDIMENTARY ROCK IS MOSTLY EITHER OR BOTH OF THESE:



Shell bioclasts: broken and whole animal shells

Plant fragments: are brown in peat and black in coal

C. CHEMICAL SEDIMENT AND SEDIMENTARY ROCK IS MOSTLY MADE OF ONE OR MORE OF THESE:

Gypsum: white or gray, easily scratched with your fingernail

Calcite spar (crystals): reacts with dilute HCl, breaks into rhombohedral shapes

Dolomite: usually cryptocrystalline; reacts with dilute HCl only if it is powdered

Halite: gray to red cubic crystals (often intergrown as rock salt); salty taste

Ooids: tiny (< 2 mm) spheres of calcite or aragonite that resemble miniature pearls; reacts to dilute HCl

Limonite: opaque brown to yellow rusty-looking crusts, layers; cements sediment, making it look yellow to brown

Hematite: opaque brick red to silver gray layers; cements sediment, making it look red

Chert: a gray, red, brown or black cryptocrtstalline variety of quartz (may contain fossils, including silica microfossils

FIGURE 6.2 Composition of sedimentary rocks. Scale for all images is × 1 unless noted otherwise.

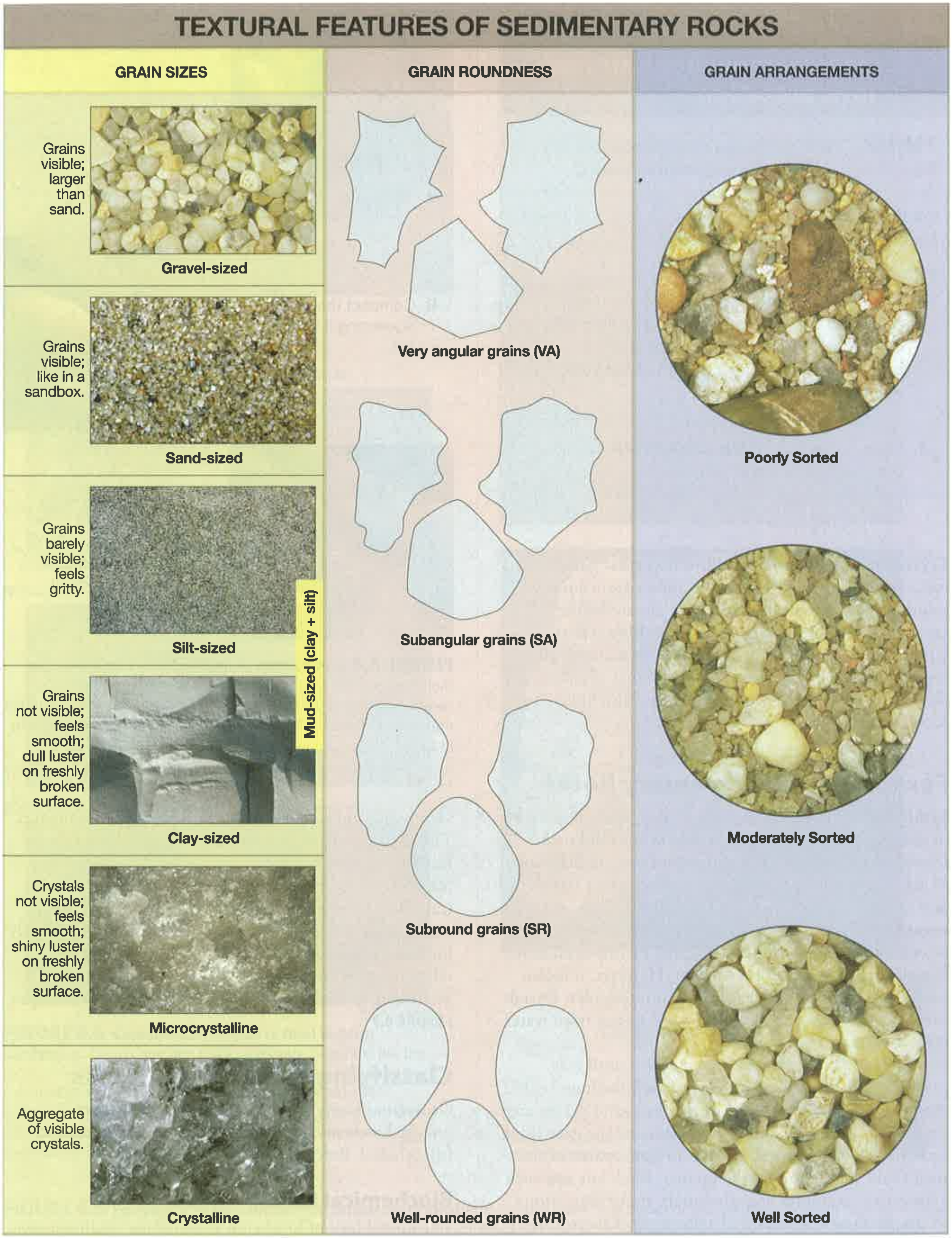


FIGURE 6.3 Textures of sedimentary rocks. Scale for all images is × 1.

ACTIVITY

6.6 Hand Sample Analysis and Interpretation

THINK About It | **How do geologists describe, classify, and identify sedimentary rocks?**

OBJECTIVE Be able to describe, classify, and identify hand samples of sedimentary rocks.

PROCEDURES

1. **Before you begin**, read about the Formation of Sedimentary Rocks, Classifying Sedimentary Rocks, and Hand Sample Analysis and Interpretation below. Also, this is **what you will need:**

   ___ Activity 6.6 Worksheet (p. 179) and pencil

2. **Then follow your instructor's directions** for completing the worksheets.

Crystalline and Microcrystalline Textures. Sedimentary rocks that form when crystals precipitate from aqueous solutions have a **crystalline texture** (clearly visible crystals; see **FIGURE 6.2**) or **microcrystalline texture** (crystals too small to identify; see **FIGURE 6.2**). As the crystals grow, they interfere with each other and form an intergrown and interlocking texture that also holds the rock together.

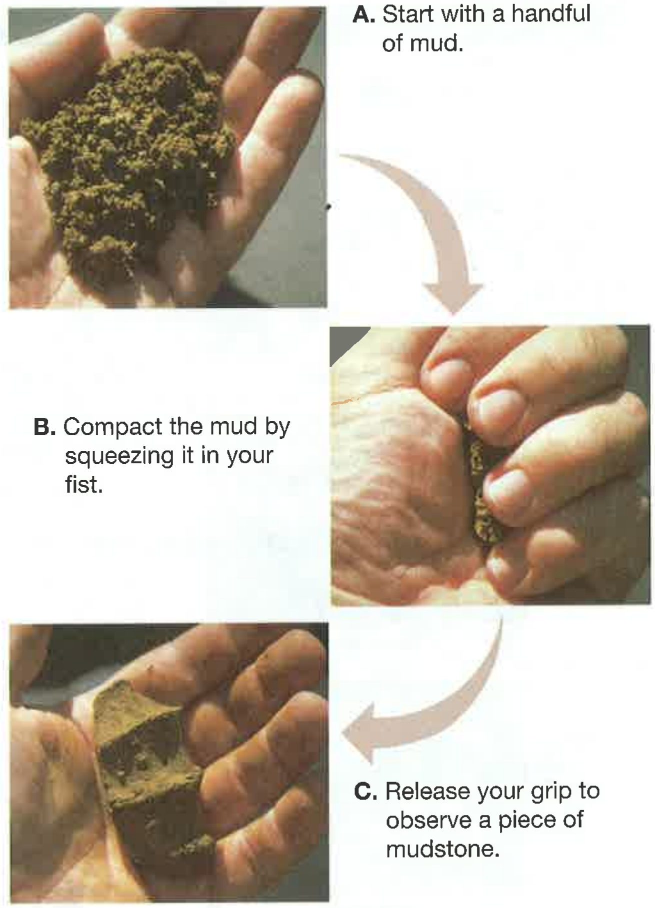


FIGURE 6.4 Compaction of mud to form mudstone. The more the mud (silt and clay sized grains of detrital sediment) is compacted, the harder (more lithified) it will become. Deeply buried mud is also lithified by heat as it is compacted, like baking clay pots in a kiln.

Formation of Sedimentary Rocks

Lithification is the process of changing loose particles of sediment (unconsolidated sediment) to solid rock (consolidated sediment). Sediment is loose particles such as pebbles, gravel, sand, silt, mud, shells, plant fragments, and mineral crystals. Sediment is lithified when it is **compacted** (pressure-hardened, squeezed: **FIGURE 6.4**) or **cemented** together (glued together by tiny crystals or chemical residues, **FIGURES 6.5, 6.6**). However, it is also possible to form a dense hard mass of intergrown crystals that lock together directly, as they precipitate from water (**FIGURES 6.7** and **6.8**).

Sand (a sediment) can be *compacted* until it is pressure-hardened into sandstone (a sedimentary rock). Alternatively, sandstone can form when sand grains are *cemented* together by chemical residues or the growth of interlocking microscopic crystals in pore spaces of the rock (void spaces among the grains). Rock salt and rock gypsum are examples of sedimentary rocks that form *in situ* by the *precipitation* of aggregates of intergrown and interlocking crystals during the evaporation of salt water or brine.

Ocean water is the most common aqueous solution and variety of salt water on Earth. As it evaporates, a variety of minerals precipitate in a particular sequence. The first mineral to form in this sequence is aragonite (calcium carbonate). Gypsum forms when about 50–75% of the ocean water has evaporated, and halite (table salt) forms when 90% has evaporated. Ancient rock salt units buried under modern Lake Erie probably formed from evaporation of an ancient ocean. The salt units were then buried under layers of mud and sand, long before Lake Erie formed on top of them (see **FIGURE 6.7**).

Classifying Sedimentary Rocks

Geologists classify sedimentary rocks into three main groups: biochemical, chemical (inorganic), and detrital (siliciclastic). Refer to **FIGURES 6.2, 6.9.** and **6.10**.

Biochemical Rocks

The main kinds of biochemical (bioclastic) sedimentary rocks are limestone, peat, lignite, and coal. Biochemical limestone is made of broken and whole animal skeletons (usually seashells, coral, or microscopic shells), as in **FIGURE 6.6**. Differences in the density and size of the

×2

CEMENTATION

A. Sandstone cemented with white quartz or calcite.

×1

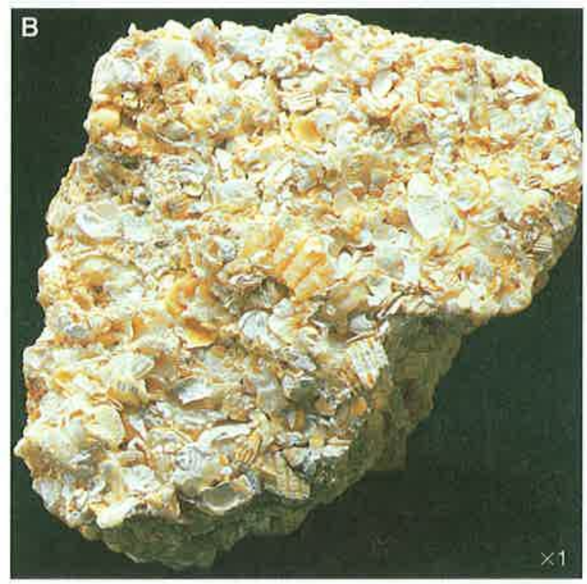
B. Sandstone cemented with reddish hematite.

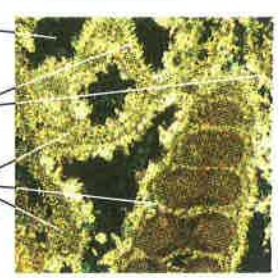
×1

C. Sandstone cemented with yellow to brown limonite.

×1

FIGURE 6.5 Cementation of quartz sand to form sandstone. Quartz and iron oxides (limonite, hematite) are the most common cements that help hold together quartz sandstone. Calcite (FIGURE 6.6) can also cement together sandstones. Compaction (FIGURE 6.4) and fusion of quartz sand grains (like pushing together two balls of clay) may accompany cementation in deeply buried layers of sandstone.





C
Photomicrograph (× 26.6)
Original sample width is 1.23 mm

FIGURE 6.6 Formation of the biochemical (bioclastic) limestone. A. Shell gravel and blades of the sea grass *Thalassia* have accumulated on a modern beach of Crane Key, Florida. Note pen (12 cm long) for scale. B. Sample of gravel like that shown in part A, but it is somewhat older and has been cemented together with calcite to form limestone (coquina). C. Photomicrograph of a thin section of the sample shown in B. Note that the rock is very porous and that it is cemented with microscopic calcite crystals that have essentially glued the shells together.

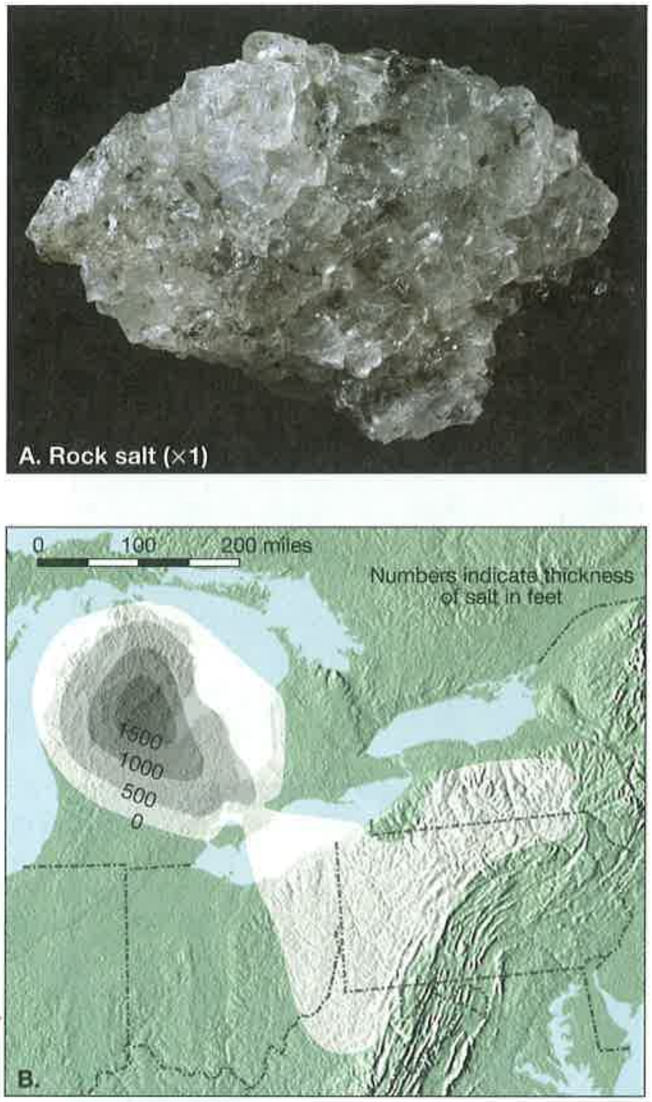


FIGURE 6.7 Rock salt, a chemical sedimentary rock with crystalline texture. A. Hand sample from mines deep below Lake Erie shows how crystals grew together to make the rock salt *in situ* (in place, where the crystals precipitated). B. Map showing the thickness and distribution of rock salt deposits formed about 400 million years ago, when a portion of the ocean was trapped and evaporated in what is now the Great Lakes region, millions of years before any lakes existed.

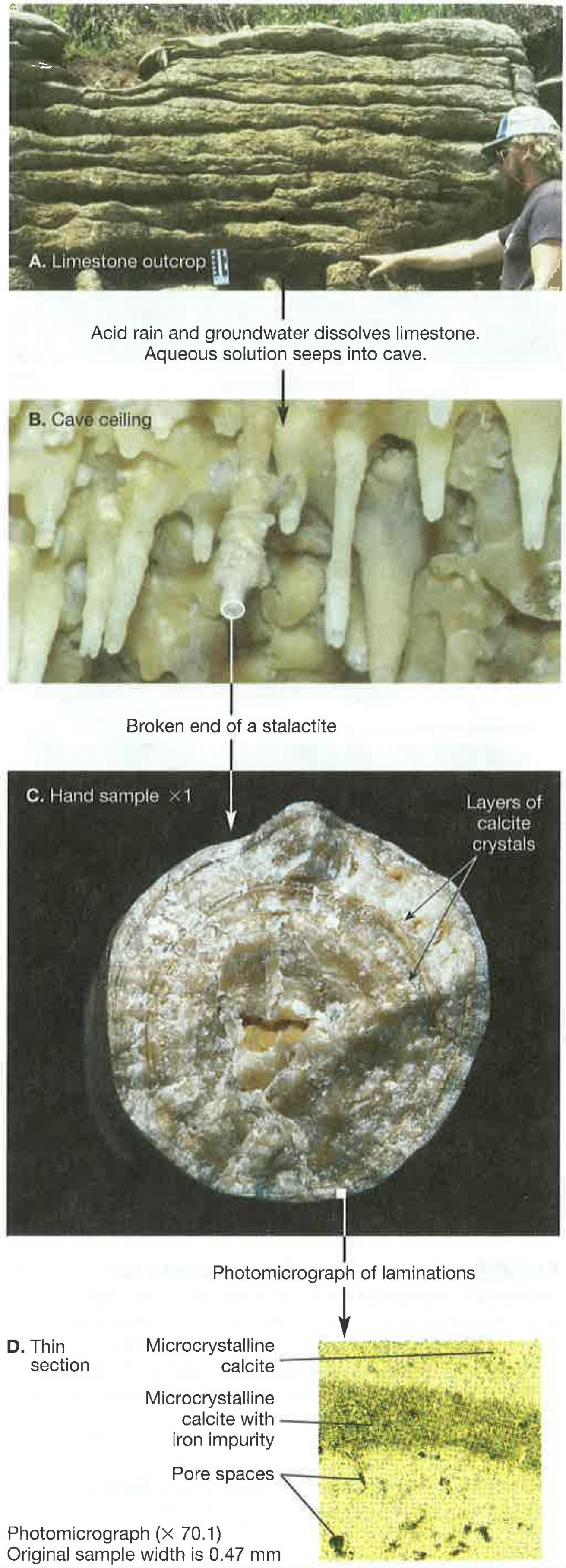


FIGURE 6.8 Formation of the chemical sedimentary rock, travertine. A. Limestone bedrock is dissolved by acidic rain near the Earth's surface. B. The resulting aqueous solution of water, calcium ions, and bicarbonate ions seeps into caves. As the solution drips from the roof of a cave, it forms icicle-shaped stalactites. C. Broken end of a stalactite reveals that it is actually an aggregate of *in situ* (in the place where they formed), chemically precipitated calcite crystals. D. Thin section photomicrograph reveals that the concentric laminations of the stalactite are caused by variations in iron impurity and porosity of the calcite layers.

constituent grains of a biochemical (bioclastic) limestone can also be used to call it a **coquina, calcarenite (fossiliferous limestone), micrite,** or **chalk** (FIGURE 6.9). **Peat** is a very porous brown rock with visible plant fragments that can easily be pulled apart from the rock. **Lignite** is brown but denser than peat. Its plant fragments cannot be pulled apart from the rock. **Bituminous coal** is a black rock made of sooty charcoal-like or else shiny brittle layers of carbon and plant fragments.

Chemical Rocks

There are seven main kinds of chemical (inorganic) sedimentary rocks in the classification in FIGURE 6.9. **Chemical limestone** refers to any mass of crystalline limestone that has no color banding or visible internal structures. **Travertine** is a mass of intergrown calcite crystals that may have light and dark color banding, cavities, or pores (FIGURE 6.8C). **Oolitic limestone** is composed mostly of tiny spherical grains (ooids, FIGURE 6.2) that resemble beads or miniature pearls and are made of concentric layers of microcrystalline aragonite or calcite. They form in intertidal zones of some marine regions (FIGURE 6.10) where the water is warm and detrital sediment is lacking. **Dolostone** (FIGURE 6.9) is an aggregate of dolomite mineral crystals that are usually microcrystalline. It forms in very salty lagoons and desert playa lakes (FIGURE 6.10). Because calcite and dolomite closely resemble one another, the best way to tell them apart is with the "acid test." Calcite will effervesce (fizz) in dilute HCl, but dolomite will effervesce *only* if it is powdered first. **Rock gypsum** is an aggregate of gypsum crystals, and **rock salt** is an aggregate of halite crystals (FIGURE 6.7). Two other chemical sedimentary rocks are **chert** (microcrystalline or even cryptocrystalline quartz) and **ironstone** (rock made mostly of hematite, limonite, or other iron-bearing minerals or chemical residues).

Detrital Rocks

The main kinds of detrital (siliciclastic) sedimentary rocks are mudstone, sandstone, breccia, and conglomerate (FIGURE 6.9). It is very difficult to tell the percentage of clay or silt in a sedimentary rock with the naked eye, so sedimentary rocks made of clay and/or silt are commonly called **mudstone.** Mudstone that is *fissile* (splits apart easily into layers) can be called **shale.** Mudstone can also be called siltstone or claystone, depending upon whether silt or clay is the most abundant grain size. Any detrital rock composed mostly of sand-sized grains is simply called **sandstone** (FIGURES 6.5 and 6.9); although you can distinguish among *quartz sandstone* (made mostly of quartz grains), *arkose* (made mostly of feldspar grains), *lithic sandstone* (made mostly of rock fragments), or *wacke* (made of a mixture of sand-sized and mud-sized grains). **Breccia** and **conglomerate** are both made of gravel-sized grains and are often poorly sorted or moderately sorted. The grains in breccia are very angular and/or subangular, and the grains in conglomerate are subrounded and/or well rounded.

ACTIVITY 6.7 Grand Canyon Outcrop Analysis and Interpretation

THINK About It What can sedimentary rocks tell us about Earth's history and past environments and ecosystems?

OBJECTIVE Analyze and interpret sedimentary rocks from the edge of the Grand Canyon.

PROCEDURES

1. **Before you begin**, read about Ancient Environments and Ecosystems and Indicators of Ancient Environments next. Also, this is **what you will need:**

   ___ Activity 6.7 Worksheet (p. 183) and pencil

2. **Then follow your instructor's directions** for completing the worksheets.

ACTIVITY 6.8 Using the Present to Imagine the Past—Dogs to Dinosaurs

THINK About It What can sedimentary rocks tell us about Earth's history and past environments and ecosystems?

OBJECTIVE Infer characteristics of an ancient environment by comparing modern dog tracks in mud with fossil dinosaur tracks in sedimentary rock.

PROCEDURES

1. **Before you begin**, read about Ancient Environments and Ecosystems and Indicators of Ancient Environments next. Also, this is **what you will need:**

   ___ Activity 6.8 Worksheet (p. 184) and pencil

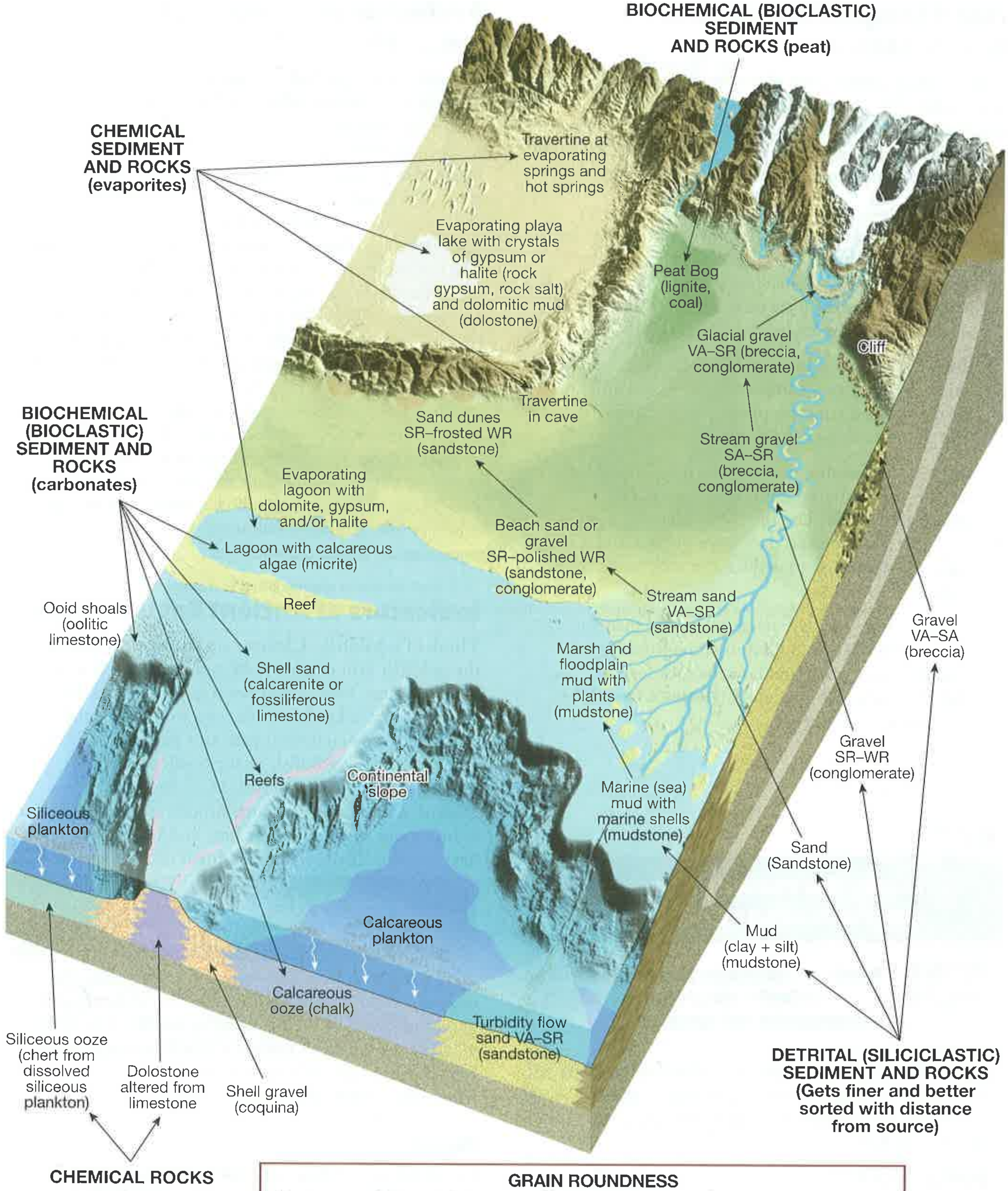
2. **Then follow your instructor's directions** for completing the worksheets.

SEDIMENTARY ROCK ANALYSIS AND CLASSIFICATION

STEP 1: Composition. What materials comprise most of the rock?		STEP 2: What are the rock's texture and other distinctive properties?			STEP 3: Name the rock based on your analysis in steps 1 and 2.		
Detrital (Siliciclastic) sediment grains: fragmented rocks and/or silicate mineral crystals	Rock fragments and/or quartz grains and/or feldspar grains and/or clay minerals (e.g., kaolinite). Detrital sediment is derived from the mechanical and chemical weathering of continental (land) rocks, which consist mostly of silicate minerals. Detrital sediment is also called terrigenous (land derived) sediment.		Mostly angular and/or subangular gravel (grains larger than 2 mm)		BRECCIA*		Detrital (Siliciclastic) sedimentary rocks (clastic rocks)
			Mostly subround and/or well rounded gravel (grains larger than 2 mm)		CONGLOMERATE*		
		 Mostly sand (1/16–2 mm grains). May contain fossils		Mostly quartz sand	QUARTZ SANDSTONE	SANDSTONE	
				Mostly feldspar sand	ARKOSE	SANDSTONE	
				Mostly rock fragment sand	LITHIC SANDSTONE	SANDSTONE	
				Sand is mixed with much mud	WACKE (GRAYWACKE)	SANDSTONE	
		 No visible grains	Mud (< 1/16 mm): Mostly silt. May contain fossils	Breaks into blocks or layers	SILTSTONE	MUDSTONE	
			Mud (< 1/16 mm): Mostly clay. May contain fossils	Fissile (splits easily into layers)	SHALE	MUDSTONE	
				Crumbles into blocks	CLAYSTONE	MUDSTONE	
Biochemical (Bioclastic) sediment grains: fragments/shells of organisms	Plant fragments and/or charcoal	Brown porous rock with visible plant fragments that are easily broken apart from one another			PEAT		Biochemical (Bioclastic) sedimentary rocks (clastic rocks)
		Dull, dark brown, brittle rock; fossil plant fragments may be visible			LIGNITE		
		Black, layered, brittle rock; may be sooty or bright			BITUMINOUS COAL		
	Shells and shell/coral fragments, and/or calcareous microfossils (rocks that effervesce in dilute HCl)		Mostly gravel-sized shells and shell or coral fragments; (Figure 6.6)		COQUINA	LIMESTONE (carbonate/calcareous rocks)	
			Mostly sand-sized shell fragments; often contains a few larger whole fossil shells		CALCARENITE (FOSSILIFEROUS LIMESTONE)	LIMESTONE (carbonate/calcareous rocks)	
			Silty, earthy rock comprised of the microscopic shells of calcareous phytoplankton (microfossils); may contain a few visible fossils		CHALK	LIMESTONE (carbonate/calcareous rocks)	
		No visible grains	No visible grains in most of the rock. May break with conchoidal fracture. May contain a few visible fossils in the micrite		MICRITE	LIMESTONE (carbonate/calcareous rocks)	
Mineral crystals (inorganic) or chemical residues (e.g., rust)	Calcite crystals and/or calcite spheres and/or microcrystalline calcite/aragonite (rocks that effervesce in dilute HCl)	Mostly spherical grains that resemble miniature pearls (< 2 mm), called ooliths or ooids			OOLITIC LIMESTONE	LIMESTONE (carbonate/calcareous rocks)	Chemical sedimentary rocks
		Masses of visible crystals and/or microcrystalline; may have cavities, pores, or color banding (Figure 6.8); usually light colored			TRAVERTINE	LIMESTONE (carbonate/calcareous rocks; evaporite rocks)	
	Microcrystalline dolomite	Effervesces in dilute HCl only if powdered. Usually light colored. (Commonly forms from alteration of limestone)			DOLOSTONE	carbonate/calcareous rocks; evaporite rocks	
	Halite mineral crystals	Visible cubic crystals, translucent, salty taste (Figure 6.7)			ROCK SALT	evaporite rocks	
	Gypsum mineral crystals	Gray, white, or colorless. Visible crystals or microcrystalline. Can be scratched with your fingernail			ROCK GYPSUM	evaporite rocks	
	Iron-bearing minerals crystals or residues	Dark-colored, dense, amorphous masses (e.g. limonite), microcrystalline nodules or inter-layered with quartz or red chert (banded iron formation)			IRONSTONE		
	Microcrystalline varieties of quartz (flint, chalcedony, chert, jasper)	Microcrystalline, may break with a conchoidal fracture. Hard (scratches glass). Usually gray, brown, black, or mottled mixture of those colors. Chert can be regarded as biochemical if its silica came from dissolution of siliceous plankton (diatoms, radiolaria).			CHERT (a siliceous rock)		

*Modify name as quartz breccia/conglomerate, arkose breccia/conglomerate, lithic breccia/conglomerate, or wacke breccia/conglomerate as done for sandstones.

FIGURE 6.9 Sedimentary rock analysis and classification. See page 166 for steps to analyze and name a sedimentary rock.



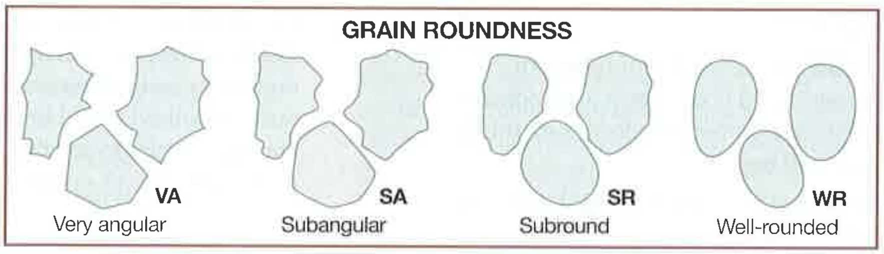


FIGURE 6.10 Sedimentary environments. Some named modern environments where specific kinds of sediments and sedimentary rocks are forming.

Hand Sample Analysis and Interpretation

The complete classification of a sedimentary rock requires knowledge of its composition, texture(s), and other distinctive properties. The same information can be used to infer where and how it formed (FIGURE 6.10). ***Follow these steps to analyze and interpret a sedimentary rock:***

Step 1: Determine and record the rock's general composition as *biochemical (bioclastic), chemical,* or *detrital (siliciclastic)* with reference to FIGURES 6.2 and 6.9, and record a description of the specific kinds and abundances of grains that make up the rock. Refer to the categories for composition in the left-hand column of FIGURE 6.9.

Step 2: Record a description of the rock's texture(s) with reference to FIGURE 6.3. Also record any other of the rock's distinctive properties as categorized in the center columns of FIGURE 6.9.

Step 3: Determine the name of the sedimentary rock by categorizing the rock from left to right across FIGURE 6.9. Use the compositional, textural, and special properties data from Steps 1 and 2 (left side of FIGURE 6.9) to deduce the rock name (right side of FIGURE 6.9).

Step 4: After you have named the rock, then you can use FIGURE 6.10 and information from Steps 1 and 2 to infer where and how the rock formed. See the example for sample X (FIGURE 6.11 and the Activity 6.7 worksheet).

ACTIVITY

6.9 Using the Present to Imagine the Past—Cape Cod to Kansas

THINK About It | **What can sedimentary rocks tell us about Earth's history and past environments and ecosystems?**

OBJECTIVE Infer characteristics of an ancient environment by comparing present-day seafloor sediments with sedimentary rock formed on an ancient sea floor.

PROCEDURES

1. **Before you begin**, read about Ancient Environments and Ecosystems and Indicators of Ancient Environments below. Also, this is **what you will need:**

   ___ Activity 6.9 Worksheet (p. 185) and pencil

2. **Then follow your instructor's directions** for completing the worksheets.

Ancient Environments and Ecosystems

Sediments are deposited in many different environments. Some of these environments are illustrated in FIGURE 6.10. Each environment has characteristic sediments, sedimentary structures, and organisms that can become **fossils** (any evidence of prehistoric life). The information gained from grain characteristics, sedimentary structures, and fossils in rocks can be used to infer the ancient environment (**paleoenvironment**) in which they formed. The process of understanding where and how a body of sediment was deposited depends on the *Principle of Uniformitarianism*—the assumption that processes that shaped Earth and its environments in the past are the same as processes operating today. This principle is often stated as, "the present is the key to the past." You can think of processes operating in modern ecosystems and then imagine how those same processes may have operated in past ecosystems with different organisms. You can also look at sediment, sedimentary structures, and fossils in a sedimentary rock and infer how it formed on the basis of where such sediment, sedimentary structures, and organisms are found together today.

Indicators of Ancient Environments

Think of a goldfish. Chances are that your brain put the goldfish into context, and you imagined it in a bowl of water. Now if you saw a goldfish bowl on your neighbor's kitchen table, you would probably think that the neighbor is getting a goldfish. Whether you think of the goldfish or the bowl, you cannot help but imagine the goldfish in a bowl of water—a goldfish ecosystem. The same process is used to analyze sedimentary rocks and infer how and where they may have formed. If the rock has a fossil of a freshwater fish, then the sediment must have accumulated under water, in a stream or lake. If the rock is made of rounded gravel with pieces of tree bark, then the sediment in the rock must have accumulated in an ecosystem where there were both trees and rounded gravel—like the edge of a river. Fossils and sedimentary structures are good indicators of the paleoenvironments. It is up to you, the geologist, to place the structures and fossils into context, and infer an environment or ecosystem in which they could have formed together.

Fossils

Fossils are any evidence of ancient life. **Body fossils** are fossils or the body parts of organisms. Soft body parts of organisms (skin, leaves of trees) decay easily, so they are rarely fossilized. Hard body parts like shells and bones are much easier to fossilize. **Trace fossils** are any evidence of the activities of organisms, such as their footprints and burrows or other structures that they made when living. Both kinds of fossils are useful as clues about the ancient environment of deposition. Trace fossils cannot

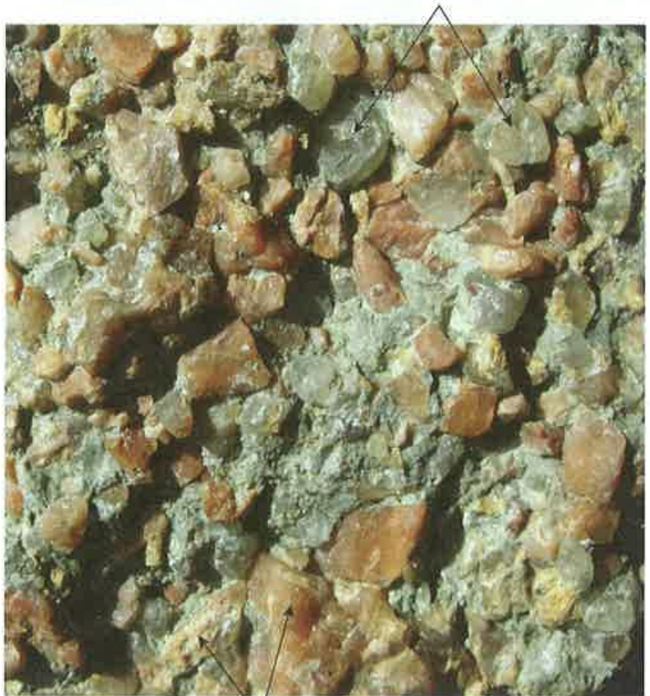


FIGURE 6.11 Photograph of hand sample X (actual size).
Refer to the first row of the Activity 6.7 worksheet to see the example of how this rock's composition, texture, and origin were described.

ACTIVITY

6.10 "Reading" Earth History from a Sequence of Strata

THINK About It **What can sedimentary rocks tell us about Earth's history and past environments and ecosystems?**

OBJECTIVE Infer Earth history by "reading" (interpreting) a sequence of strata, from bottom to top.

PROCEDURES

1. **Before you begin,** read about Stratigraphic Sequences below. Also, this is **what you will need:**

   ___ Activity 6.10 Worksheet (p. 186) and pencil

2. **Then follow your instructor's directions** for completing the worksheets.

be transported, so they are *in situ* (formed where they are found). Body fossils, even those of hard shells, are worn away quickly if transported, so they are generally *in situ* as well.

Sedimentary Structures

Sedimentary structures are things like layers of sediment and fossil burrows in the layers. They are structures made of the sediment as it accumulated or after it accumulated (FIGURE 6.12). Some are the result of physical processes, and others are the result of the activities of plants or animals.

Stratigraphic Sequences

As sediments accumulate, they cover up the sediments that were already deposited at an earlier (older) time. Environments also change through time, as layers of sediment accumulate. Therefore, at any particular location, bodies of sediment have accumulated in different times and environments. These bodies of sediment then changed into rock units, which have different textures, compositions, and sedimentary structures.

An undisturbed succession of beds of rock strata can be divided into units of different color, composition, and texture. The succession of such units, one on top of the other, is called a *stratigraphic sequence.* If you interpret each rock unit of the stratigraphic sequence in order, from oldest (at the base) to youngest (at the top), then you will know what happened over a given portion of geologic history for the site where the stratigraphic sequence is located. This order of oldest on the bottom and youngest on the top is the definition of the Law of Superposition, one of the geologic principles that will be discussed in detail in Chapter 8.

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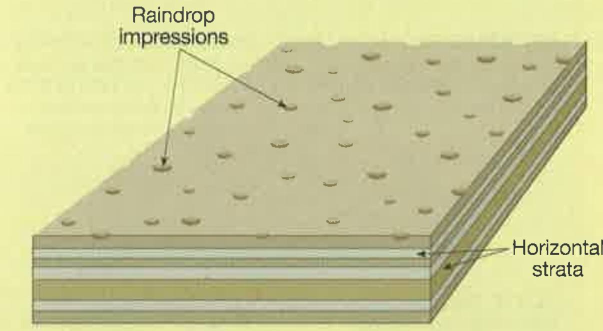
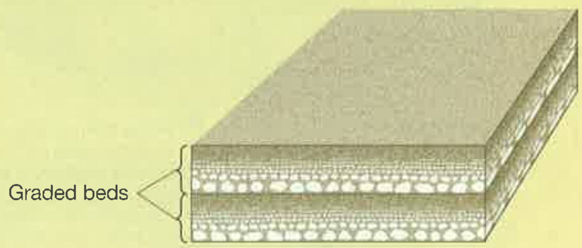
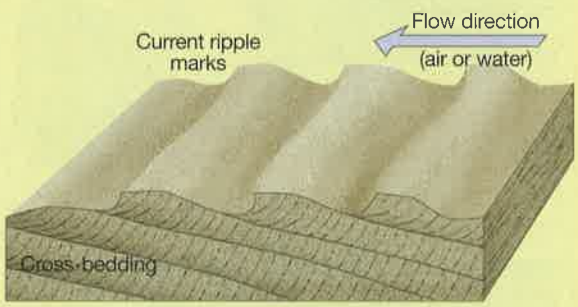
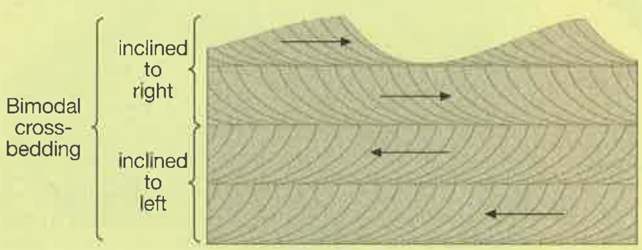
SEDIMENTARY STRUCTURES

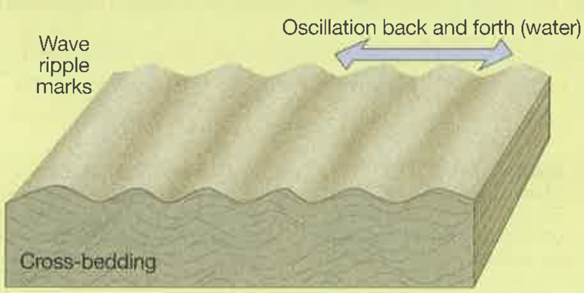
ILLUSTRATIONS









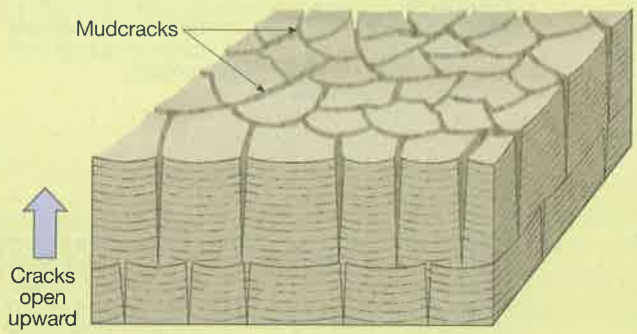


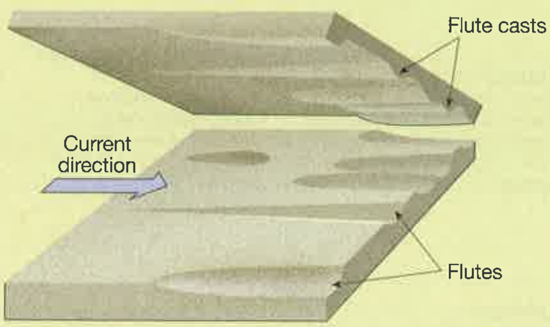
DESCRIPTIONS	ENVIRONMENTS
RAINDROP IMPRESSIONS: Tiny craters formed by raindrops as they impact bedding plane surfaces.	Raindrop impressions *occur on muddy land surfaces.*
HORIZONTAL STRATA: Relatively flat *beds* (≥ 1cm thick) and *laminations* (< 1cm thick).	Horizontal strata *occur where sediments settle from a standing body of water or air; or where currents travel parallel to the surface on which sediments are accumulating.*
GRADED BED: Stratum that contains different sizes of sedimentary grains arranged from largest at the bottom of the bed to smallest at the top.	Graded beds *form when a turbulent body of water full of sediment (flood, wave, river) suddenly loses energy and calms down. Large particles settle out before small.*
CURRENT RIPPLE MARKS: Asymmetrical ripple marks. The steep slope faces down current, and the gentle slope faces up current.	Current ripple marks *form in any environment where wind or water travels in one direction for some of the time: rivers, ocean currents, wind blowing sand dunes.*
CROSS-BEDDING: Inclined beds or laminations.	Cross-bedding *forms wherever there are wind or water currents.*
BIMODAL CROSS-BEDDING: Sequence of cross-bedding in which cross-bedding of current ripple marks is inclined in opposite directions.	Bimodal cross bedding *forms in environments where currents of wind or water flow back and forth in opposite directions. It is common in environments with tides.*
WAVE RIPPLE MARKS: Symmetrical ripple marks.	Wave (symmetrical) ripple marks *form in any body of water where gentle waves barely touch bottom, or where weak currents move back and forth (oscillate) in shallow water.*

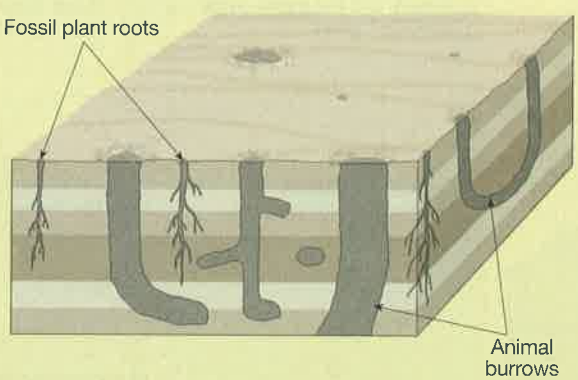
FIGURE 6.12 Sedimentary structures.

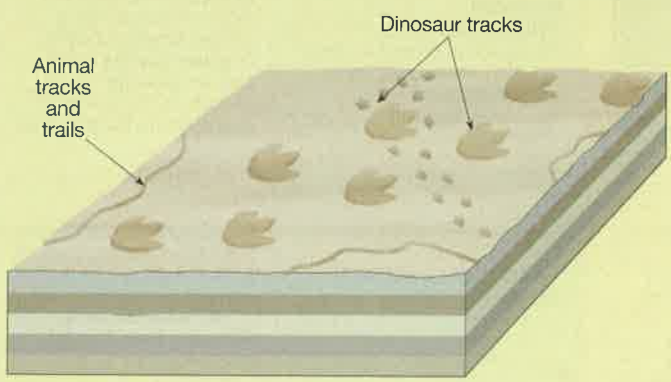
SEDIMENTARY STRUCTURES

ILLUSTRATIONS









DESCRIPTIONS	ENVIRONMENTS
MUDCRACKS: Polygonal patterns of cracks that develop in mud as it dries.	Mudcracks *form in muddy environments that are wet sometimes and dry at other times, like tidal mudflats or land surfaces exposed to rain.*
FLUTE CASTS: Natural molds formed when mud or sand fill up flutes.	Flute casts *form when sediment is deposited on current-scoured surfaces. Thus, flute casts develop in environments that have strong currents sometimes, but relatively calm conditions at other times.*
FLUTES: U-shaped or V-shaped scrapes and gouges in mud or sand that were scoured out by currents. The opening of a V or U points in the downstream direction. The mud and sand may have turned to mudstone or sandstone, preserving the flutes.	Flutes *form wherever water or wind scours away mud or sand from land or submerged surfaces. Strong currents are required to do the scouring.*
FOSSIL PLANT ROOTS: Root-shaped fossils that narrow away from the main branch.	Fossil plant roots *indicate ancient soil zones where plants once grew.*
ANIMAL BURROWS: All sizes of tunnels or tubes that cut into or across strata and maintain constant diameters with circular cross sections.	Animal burrows *occur wherever burrowing animals live, in water or on land. The shape of the burrow may be characteristic of a particular kind of animal that lives only in a specific environment.*
ANIMAL TRACKS, TRACKWAYS, AND TRAILS: Footprints or grooves left on bedding plane surfaces by animals.	Animal tracks and trails *occur wherever animals live. Some are diagnostic of specific kinds of animals that live in specific environments.*

FIGURE 6.12 (continued)

ACTIVITY 6.1 Sedimentary Rock Inquiry

Name: ______________________ **Course/Section:** ______________________ **Date:** __________

A. Analyze the sedimentary rocks below (and actual rock samples of them if available). Beside each picture, write words and phrases to describe the rock's **composition** (what it is made of) and **texture** (the size, shape, and arrangement of its parts). Use your current knowledge, and complete the worksheet with your current level of ability. Do not look up terms or other information.

1

2

3

4

5

6

B. REFLECT & DISCUSS Reflect on your observations and descriptions of sedimentary rocks in part A. Then describe how you would classify the rocks into groups. Be prepared to discuss your classification with other geologists.

ACTIVITY 6.2 Mount Rainier Sediment Analysis

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. These are images of rocks on or near Mount Rainier, WA, an andesitic volcano. Image A was taken at an outcrop of the andesite near the top of the volcano, and Image B was taken near the middle of the volcano's slope. Image C was taken in the Nisqually River that drains away from the base of the volcano. Image C was taken 30 km downstream, at a delta where the river enters Alder Lake. All images are 1/3 of actual size. Note how the sediment changes from A to D.

B. Mount Rainier slope, 5600 feet above sea level.
45 47 23.5N, 121 44 23.4W in Google Earth™
2 kilometers from Location A

A. Mount Rainier outcrop, 6600 feet above sea level.
46 48 15.2N, 121 43 57.8W in Google Earth™

C. Nisqually River, near Longmire, southwest of Mount Rainier, 2600 feet above sea level.
46 44 26.4N, 121 49 27W in Google Earth™
9 kilometers downhill from Location B

D. Alder Lake delta, at Elbe, southwest of Mount Rainier, 1200 feet above sea level.
46 45 52N, 122 11 45W in Google Earth™
30 kilometers downstream from Location C

1. What is the grain size of the sediment at each location, expressed as one or more Wentworth size classes?

A.

B.

C.

D.

2. What is the grain roundness at each of the following locations?

A.

B.

C.

3. In general, would you describe the sediment in these images as detrital (siliciclastc), biochemical, or chemical? Why?

4. Name the kind of rock that the sediment in each image would form if it became lithified (**FIGURE 6.9**, Step 3).

A.

B.

C.

D.

5. Notice the yellow-orange color of the sedimentary grains at Location B. What is the yellow-orange material and where did it come from?

6. Each image is a photograph of materials that are the product of chemical and physical sedimentary processes. For each image, list the processes that must have occurred to form the sediment.

A.

B.

C.

D.

B. **REFLECT & DISCUSS** Based on your work, write a sentence that describes what happens to detrital (siliciclastic) sediment with distance from its source. Then describe how you could use your statement to interpret detrital (siliciclastic) rocks.

ACTIVITY 6.3 Clastic and Detrital Sediment

Name: ______________________ **Course/Section:** ______________ **Date:** ________

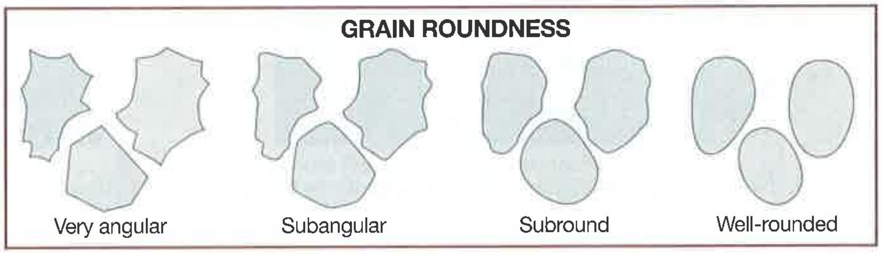
A. Obtain two pieces of granite or diorite. Hold one in each hand and tap them together over a piece of paper. As you do this you should notice that you are breaking tiny sedimentary grains from the larger rock samples. These broken pieces of rocks and minerals are called **clasts** (from the Greek *klastós*, meaning "broken in pieces").

1. Using a hand lens or microscope, observe the tiny clasts that you just broke from the larger rock samples. Describe what minerals make up the clasts and whether or not the clasts are fragments of mineral crystals, rock fragments, or a mixture of both.

2. Geologists commonly refer to several different kinds of clastic sediment. Circle the one that you just made.

- **pyroclastic sediment**—volcanic bombs and/or volcanic rocks fragmented by volcanic eruption
- **bioclastic sediment**—broken pieces of shells, plants, and/or other parts of organisms
- **siliciclastic sediment**—broken pieces of silicate mineral crystals and/or rocks containing them

3. **Roundness** is a measure of how much the profile of a grain of sediment resembles a circle. It is most often visually estimated using a chart like this one. Re-examine your clasts from Part A1 and sketch the outline of several of them. Compared to the chart, what is the roundness of the clasts that you sketched?



4. Using a grain size scale (from GeoTools 1 or 2 at the back of your manual), circle the Wentworth size class(es) of the clastic sediment that you made above.

gravel	sand	silt	clay
(grains > 2 mm)	(grains 1/16 to 2 mm)	(grains too small to see but you can feel them)	(grains too small to see or feel; like chalk dust)

5. Obtain a piece of quartz sandpaper and lay it flat on the table. Find a sharp corner on one of the granite/diorite samples that you used above and sketch its outline in the "before abrasion" box below. Next, rub that corner against the quartz sandpaper for about 10 seconds. Sketch its profile in the "after abrasion" box. What did this abrasion process do to the sharp corner?

Before abrasion

After abrasion

6. The sediment that you just made by wearing down the corner of a rock clast is called **detrital sediment** (from the Latin *detritus*, participle of *detero*, meaning "to weaken, wear away, rub off"). The term is also used to refer to all sediment that is terrigenous (from the land)—worn and transported away from landscapes (rock fragments, mineral grains, and rock material that has been weakened and decomposed by chemical weathering).

The Mississippi River carries detrital sediment that has been weathered from bedrock and worn away from the landscape of much of the United States. The river flows downhill under the influence of gravity and eventually flows into the Gulf of Mexico, where its load of detrital sediment temporarily accumulates at the mouth of the river on the edge of the Mississippi Delta. On this NASA satellite image of the Mississippi Delta, write a "D" to indicate where the main load of terrigenous detrital sediment is being deposited at the edge of the delta. How do you think the roundness of sediment in the river will change from a place upstream where it was broken from bedrock to the location where you placed your "D" on the image?

29 39 45N, 90 33 48W in Google Earth™ (© Google Earth)

B. Sediment falls and slides (rockslides) downhill under the influence of gravity and is transported by flowing agents like water, wind, and ice (glaciers). As grains are transported, they scrape, chip, brake, and generally increase in roundness.

1. Glacial ice holds detrital grains of sediment in its firm grip while the weight of the glacier exerts tremendous downward force and gravity pulls the glacier downhill. You can model this process and see what it does to grains of sediment. Place a piece of sandpaper flat on the table. Next, firmly grip (like glacial ice) a piece of shale with a somewhat flat side pointing down. In one motion press the shale firmly against the sandpaper and push it forward one time. Then use a hand lens to observe the shale surface that you just scraped over the sandpaper. To the right of this paragraph, draw the pattern of scratches that you observe. What would happen to the shale surface if you kept grinding it straight ahead on a 10-meter-long strip of sandpaper?

2. Grains of sediment carried by water and wind move generally in one main direction but are free to quickly change direction and roll about so that all of their sides scrape and impact other grains often. Imagine that the piece of shale above has been dropped from a melting glacier and is being transported by a melt water stream. To model what might happen to the shale grain, place it onto the sandpaper, grip it lightly, and move it about against the sandpaper in multiple directions. Turn the shale to a different side and repeat. Now observe the newly scraped surfaces with a hand lens. To the right of this paragraph, draw the pattern of scratches that you observe.

C. **REFLECT & DISCUSS** Based on your work above, how could you tell a grain of sediment that was abraded and shaped in a glacial environment from one that was abraded and shaped while being transported by water or wind?

ACTIVITY 6.4 Biochemical and Chemical Sediment and Rock

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. Seashells are grains of sediment made by the biochemical processes of organisms, so they are grains of biochemical sediment. When you find a rock with a fossil seashell, then you have found evidence that the rock contains sediment deposited where the sea animal lived (i.e., in the ocean, in a marine environment). Some limestone is entirely made of the seashells or broken pieces of seashells. Obtain a seashell (e.g., hard clam shell) and draw it to the right of this paragraph. It may be easiest to trace it, then fill in the outline with details of what the shell looks like inside or out. Next, place the shell into a plastic sandwich bag and take the bag to the hammering station in your lab. Lightly tap the bag with the hammer to break up the shell into pieces. Return to your table and view the broken pieces of shell with a hand lens.

1. The shell fragments that you just made are called **clasts** (from the Greek *klastós*, meaning "broken in pieces"). Geologists commonly refer to several different kinds of clastic sediment. Circle the one that you just made.
   - **pyroclastic sediment**—volcanic bombs and/or volcanic rocks fragmented by volcanic eruption
   - **bioclastic sediment**—broken pieces of shells, plants, and/or other parts of organisms
   - **siliciclastic sediment**—broken pieces of silicate mineral crystals and/or rocks containing them

2. Compared to FIGURE 6.3, what is the roundness of your clasts? ______________________

3. What is the roundness of the clasts in this picture (× 1 scale)? ______________________ Explain how and in what environment the shell clasts could have attained their roundness.

4. Some limestone is made of shells that are calcareous (calcite or aragonite), like visible seashells, but they are microscopic and cannot even be seen with a hand lens. Chalk is such a limestone. Some chalk used with modern blackboards is clay or plaster-of-Paris, rather than real chalk. Obtain a piece of chalk from your lab room or instructor. Explain how dilute HCl (hydrochloric acid) can be used to help you test your chalk and find out if it is real chalk or not. Then conduct your test and report the results of your test.

5. Based on FIGURE 6.10 (page 165), how and where does chalk form?

B. Place a charcoal briquette into a plastic sandwich bag and take it to the hammering station in your lab. Lightly hammer the bag enough to break apart the briquette. Return to your table with the bag of charcoal.

1. View the broken pieces of charcoal with a hand lens. Describe what kinds of grains you see and their texture.

2. Charcoal is made by allowing wood to smolder just enough that an impure mass of carbon remains. In the presence of oxygen, the charcoal briquette will naturally combine with oxygen to make carbon dioxide. Over a period of many years, it will all react with oxygen and chemically weather to carbon dioxide. When you burn charcoal in your grill, you are simply speeding up the process. However, if plant fragments are buried beneath layers of sediment that keep oxygen away from them, then they can slowly convert to a charcoal-like rock (peat, lignite, or coal) and remain so for millions of years. Obtain a piece of coal and compare it to your charcoal. How is it different? Why?

C. **REFLECT & DISCUSS** Based on your observations in this activity, write a definition of biochemical sedimentary rock in your own words.

D. Bedrock can remain buried underground for millions to billions of years. However, when it is exposed to water and air at Earth's surface it weathers chemically and physically. For example, acidic water reacts with potassium and plagioclase feldspars to make clay minerals plus water containing dissolved silica (hydrosilicic acid) and metallic ions (K, Na, Ca). This is one of the main sources of clay found in soil and worn away into rivers and the ocean. The metals in many minerals oxidize (combine with oxygen) to form metal oxides like limonite ("rusty" iron) and hematite. Obtain and observe samples of both.

1. What is the color and chemical formula for hematite? (Refer to Minerals Database, page 95)

2. What is the color and chemical formula for limonite? (Refer to Minerals Database, page 96)


sandstone ×1

3. As iron oxides form, they act like glue to cement together grains of sediment, like the "sandstone" above. Which iron oxide mineral has cemented together this sandstone? How can you tell?

4. Powder some limonite in a mortar and pestle, and note its true streak color (yellow-brown). Put on safety goggles. In a fume hood or behind a glass shield, heat some of the powder in the Pyrex test tube over the Bunsen burner. Be sure to point the test tube at an angle, away from people. After about a minute of heating, pour the hot limonite powder onto the foil on the table. What happened to the yellow-brown limonite? Why?

5. **REFLECT & DISCUSS** The *rapid* chemical change that you observed above can occur quickly only at temperatures like those above the Bunsen burner. However, some modern desert soils do contain hematite and appear red. How can that be?

ACTIVITY 6.5 Sediment Analysis, Classification, and Interpretation

Name: ______________________ **Course/Section:** ______________ **Date:** __________

Complete parts 1 through 6 for each sample below. Refer to FIGURES 6.2 and 6.3 as needed.

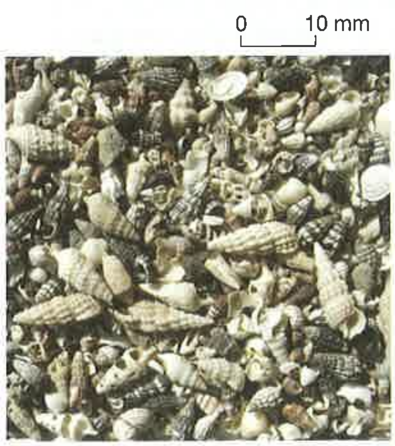
SAMPLE A

1. Grain size range in mm: ______________________
2. Percent of each Wentworth size class:
   clay ______ silt ______ sand ______ gravel ______
3. Grain sorting (circle):
   Poor Moderate Well
4. Grain roundness (circle):
   Angular Subround Well-rounded
5. Sediment composition (circle):
   Detrital Biochemical (Siliciclastic) Chemical (Bioclastic)
6. Describe how and in what environment (FIGURE 6.10) this sediment may have formed.

SAMPLE B

1. Grain size range in mm: ______________________
2. Percent of each Wentworth size class:
   clay ____ silt ____ sand ____ gravel ____
3. Grain sorting (circle):
   Poor Moderate Well
4. Grain roundness (circle):
   Angular Subround Well-rounded
5. Sediment composition (circle):
   Detrital (Siliciclastic) Biochemical (Bioclastic) Chemical
6. Describe how and in what environment (FIGURE 6.10) this sediment may have formed.

SAMPLE C



1. Grain size range in mm: ______________________
2. Percent of each Wentworth size class:
   clay ______ silt _____ sand ____ gravel ____
3. Grain sorting (circle):
   Poor Moderate Well
4. Grain roundness (circle):
   Angular Subround Well-rounded
5. Sediment composition (circle):
   Detrital (Siliciclastic) Biochemical (Bioclastic) Chemical
6. Describe how and in what environment (FIGURE 6.10) this sediment may have formed.

D. REFLECT & DISCUSS Imagine that these sediments are rocks. Which of the samples do you think would be the least diagnostic of a specific ancient environment? Why?

ACTIVITY 6.6 Hand Sample Analysis and Interpretation

Name: ______________________ Course/Section: ______________ Date: __________

SEDIMENTARY ROCKS WORKSHEET

Sample Number or Letter	Composition (Figures 6.2 and 6.9)	Textural and Other Distinctive Properties (Figures 6.3 and 6.9)	Rock Name (Figure 6.9)	How Did the Rock Form? (See Figure 6.10)
Fig. 6.11	Detrital (Siliciclastic): • Mostly orange feldspar grains (~85%) • Some quartz (~10%) • Green silty matrix (~5%)	• Mostly (~95%) angular to subangular gravel-sized grains • Poorly sorted (The gravel is mixed with some sand and green silt)	Breccia (Arkose breccia)	Preexisting rock exposed on land (probably granite) was weathered. Grains were not rounded or sorted much, so they were not transported very far from their source. Grains were mixed with some green silt, deposited, and hardened (compaction?) into rock.

Name: ______________________ Course/Section: ______________ Date: __________

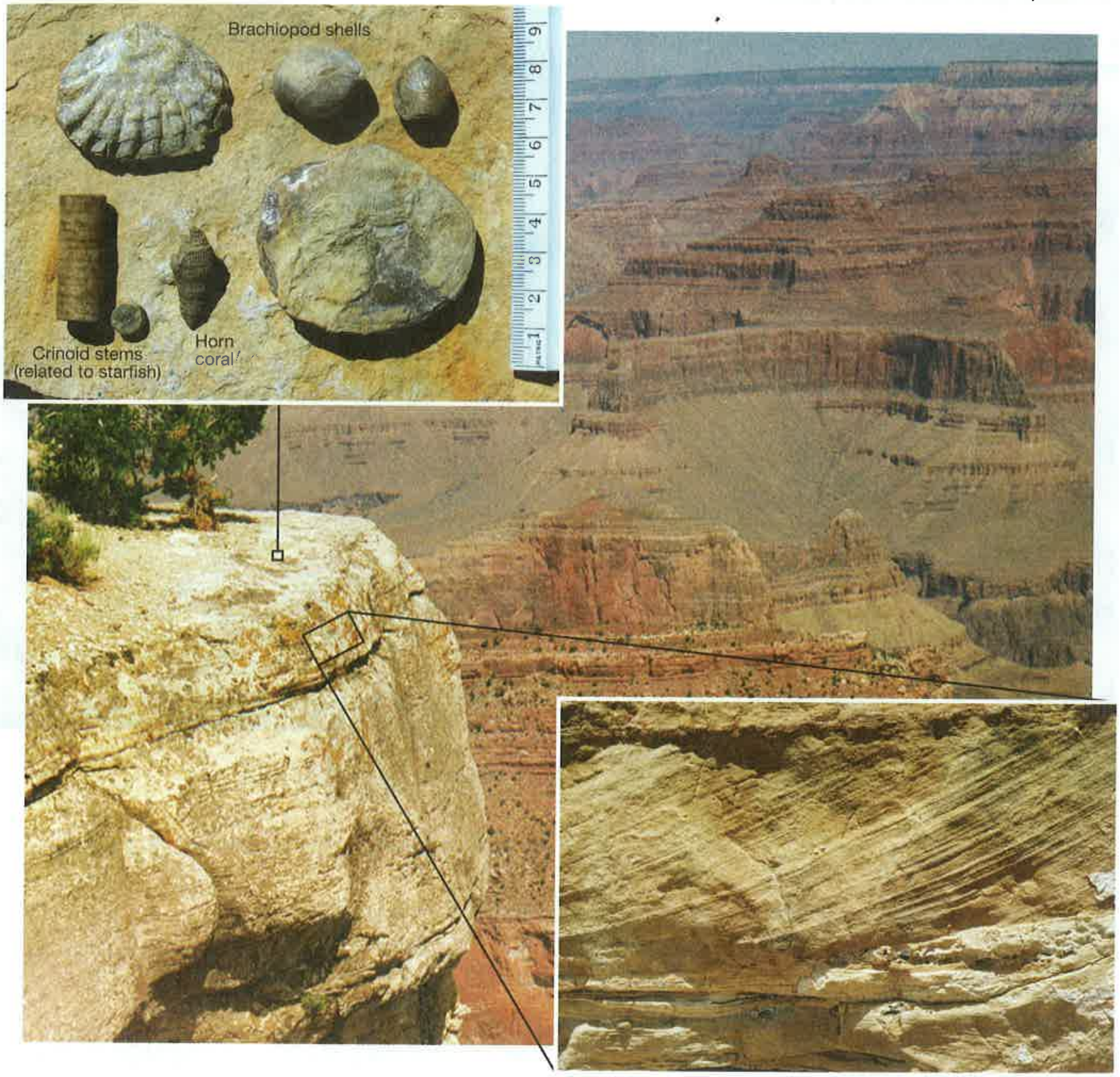
SEDIMENTARY ROCKS WORKSHEET

Sample Number or Letter	Composition (Figures 6.2 and 6.9)	Textural and Other Distinctive Properties (Figures 6.3 and 6.9)	Rock Name (Figure 6.9)	How Did the Rock Form? (See Figure 6.10)

ACTIVITY 6.7 Grand Canyon Outcrop Analysis and Interpretation

Name: ______________________ **Course/Section:** ______________ **Date:** ________

A. Analyze the images above, from the South Rim of the Grand Canyon, near Grand Canyon Village. The edge of the canyon here is made of a Permian calcarenite (sand–sized fossilifereous limestone) called the Kiabab Limestone. It is about 270 million years old.



1. Notice that some of the beds in the outcrop are cross-bedded. Draw an arrow on the picture to show the direction that the water moved here to make this cross bedding. Refer to **FIGURE 6.12** as needed.

2. Which kind of cross bedding is this? (**FIGURE 6.12**)? ______________________________

3. **REFLECT & DISCUSS** Describe (as well as you can) what the environment was like here about 270 million years ago and the evidence and logic that you used to reach your conclusion.

ACTIVITY

6.8 Using the Present to Imagine the Past—Dogs and Dinosaurs

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. Analyze photographs X and Y below.

X. Modern dog tracks in mud with mudcracks on a tidal flat, St Catherines Island, Georgia (x1)

Y. Triassic rock (about 215 m.y. old) from southeast Pennsylvania with the track of a three-toed *Coelophysis* dinosaur (x1)

1. How are the modern environment (Photograph X) and Triassic rock (Photograph Y) the same?

2. How are the modern environment (Photograph X) and Triassic rock (Photograph Y) different?

3. Describe what the Pennsylvania ecosystem (environment + organisms) was like when *Coelophysis* walked there about 215 million years ago.

B. **REFLECT & DISCUSS** Use what you learned about sediment and sedimentary rocks. Develop a hypothesis about how the dinosaur footprint in Photograph Y was preserved.

ACTIVITY 6.9 Using the Present to Imagine the Past—Cape Cod to Kansas

Name: ______________________ **Course/Section:** ______________________ **Date:** __________

A. Analyze photographs A and B below of a Kansas rock and the modern-day seafloor near Cape Cod.

A. Pennsylvanian-age rock from Kansas (290 m.y. old)

B. Modern sea-floor environment, 40 m (130 ft) deep, near Massachusetts (10 miles north of Cape Cod). Detrital (siliciclastic) sediment:

- **1% gravel**
- **90% sand**
- **9% mud**

1. How are the modern environment (Photograph B) and Kansas rock (Photograph A) the same?

2. How are the modern environment (Photograph B) and Kansas rock (Photograph A) different?

3. Today, this part of Kansas is rolling hills and farm fields. Describe what the Kansas ecosystem (environment + organisms) was like when the sediment in this rock sample (Photograph A) was deposited there about 290 million years ago.

B. REFLECT & DISCUSS What would have to happen to the sediment in Photograph A to turn it into sedimentary rock?

ACTIVITY 6.10 "Reading" Earth History from a Sequence of Strata

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. Permian strata (about 270 million years old) exposed along Interstate Route 70 in northeastern Kansas. Describe the paleoenvironment (pink column), then apply it to infer the record of change (purple column).

OUTCROP

HAND SAMPLE Bedding plane surface	DESCRIPTION OF ROCK UNIT	DESCRIPTION OF PALEOENVIRONMENT REPRESENTED BY THE ROCK UNIT	RECORD OF CHANGE: ocean (marine)	muddy bay/estuary	evaporating bay	peat bog or swamp	land
	7. Tan skeletal limestone with shells of many kinds of marine organisms, bimodal cross-bedding, oscillation ripple marks, animal burrows, flutes, flute casts, and chert.						
	6. Gray silty mudstone (shale) with animal burrows, fossil clams, fossil plant fragments, and current ripple marks.						
	5. Red and gray silty mudstone with raindrop impressions, fossil roots, and mudcracks.						
	4. Gray silty mudstone with abundant gypsum layers and crystals.						
	3. Tan skeletal limestone with bimodal cross-bedding.						
	2. Coal.	peat bog or swamp					
	1. Gray silty mudstone with mudcracks and fossil ferns.	Probably moist muddy land where ferns grew; mudcracks formed in dry periods.					

B. **REFLECT & DISCUSS** What could have caused the sea level to rise and fall in this way about 270 million years ago?