Lab 5: Sedimentary Rocks

Introduction

Rock breaks down as it interacts with the surface environment. The solid particles and dissolved **ions** (charged atoms and molecules) freed by this action are transported by water, wind, gravity, and glaciers from their source (that is, the original rock) to **depositional basins** (the places where sediment accumulates). This collection of loosely packed, unconsolidated mineral or rock fragments is called **sediment**. In time, sediment is buried, compacted, and **lithified** to form **sedimentary rock**. Careful examination of the mineral composition and texture of many sedimentary rocks provides clues to the:

(1) original source of the sediment (**provenance**);
(2) type and extent of the **weathering processes** by which the source rock was broken down;
(3) agent (water, wind, gravity, or ice) that **transported** the sediment and, in some cases, 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 (**diagenesis**).

A. Sediments and the Formation of Sedimentary Rocks

Weathering, Erosion, and Transport

Weathering is the process by which rocks at the earth's surface break down. **Mechanical weathering** disintegrates rocks into progressively smaller fragments. For example, water freezes and expands in the cracks of rocks, resulting in the breakdown of the rock. During **chemical weathering**, chemical reactions cause the rock to decompose. As a result, ions of some elements, such as calcium, sodium, potassium, iron, and magnesium, are freed from the rock and carried off in solution by water. These reactions produce new minerals in the rock, principally clays and iron oxides (rust), which are more stable at surface conditions than the original mineral. Some nonreactive minerals, such as quartz (a.k.a. silica, SiO_2), can be carried in solution and re-precipitated as a cementing agent. The minerals formed by chemical weathering are those that are stable at the Earth's surface (Table 5-1).

Most Stable	Iron Oxides
	Aluminum Oxides
	Quartz
	Clay Minerals
	Muscovite
	Orthoclase
	Biotite
	Na Plagioclase
	Amphibole
	Pyroxene
	Ca Plagioclase
	Olivine
	Calcite
Least Stable	Evaporites

Table 5-1: Stability of common minerals under weathering conditions at the surface of the earth. Note that mineral stability has an inverse relationship to Bowen's reaction series (see Igneous Rock Lab).

Mechanical and chemical weathering work together to break down rock. Chemical weathering may weaken bonds, which allows the rock to break apart more easily, and cracks formed by mechanical weathering can expose more surface area to chemical weathering. As rock breaks down by weathering, the liberated material moves downhill under the influence of gravity and is **eroded** and **transported** away by water, glaciers, and/or wind.

Deposition and Lithification

When the transporting agent (whether it be water, wind, or ice) slows or melts, the particles in transport settle and accumulate. Such sediment, consisting of broken fragments of preexisting rocks (**clasts**), is called **clastic sediment**. **Chemical sediment** is deposited when the ions dissolved in water precipitate to form a solid. The solid, usually a mineral crystal, is a **chemical precipitate**, and the process of forming a solid from the ions in solution is **chemical precipitation**. **Inorganic chemical precipitation** takes place within a depositional basin when environmental conditions in the basin reduce the solubility of the water's dissolved ions. For example, evaporation of seawater causes the concentration of Na^+ (sodium) and Cl^- (chloride) ions in the remaining liquid to become so great that minerals precipitate; this is how rock salt forms. **Biochemical precipitation**, on the other hand, involves living organisms. Animals and plants extract calcium carbonate and silica from seawater to build skeletal structures such as shells or, in the case of some algae, tiny carbonate crystals that hold up their soft organic parts. When the organisms die, the skeletal parts sink and become part of the bottom sediment. **Organic sediment** forms directly from the decay of plant or, less often, animal material. The most common examples are peat and coal, which are formed from partially decayed vegetation that accumulated in a swamp or bog.

The processes by which soft sediment is **lithified** (turned to rock) are collectively termed **diagenesis** (Figure 5-1). Lithification happens in two ways:

1. the sediments can become compacted by the weight of overlying sediments, and/or
2. sediment grains can be cemented together by material that precipitates from fluids passing through them. Common cementing materials include clay, tar or oil, SiO_2 (silica), Fe_2O_3 (iron oxide) and $CaCO_3$ (calcite).

At higher temperature and pressure conditions, diagenesis merges with the lowest grades of metamorphism, which we will consider next week.

B. Classification of Sedimentary Rocks

The three types of sediment provide the basis for three categories of sedimentary rocks:

1. **Clastic** (or **detrital**), composed of clasts (broken pieces) of other rocks.
2. **Chemical** and **biochemical**, formed by the precipitation of ions.
3. **Organic**, formed from organic materials within the depositional basin.

Classification of rocks within these groups is based on texture for clastic sedimentary rocks and on mineral composition for chemical, biochemical, and organic sedimentary rocks.

Composition

The composition of a clastic sedimentary rock is, in part, a function of the source rock from which the original sediment was derived (its **provenance**), and in part a function of the distance that the sediment was transported. Prolonged transport allows extensive chemical and mechanical breakdown of unstable minerals. Thus, with increased distance of transport, the proportion of more stable minerals (mostly quartz and clay minerals) increases relative to the proportion of chemically unstable minerals (Table

5-1). Most chemical and biochemical sedimentary rocks are composed predominantly of one mineral and commonly contain little, if any, clastic debris. The diagnostic properties of common sedimentary rock-forming minerals are shown in Table 5-2.

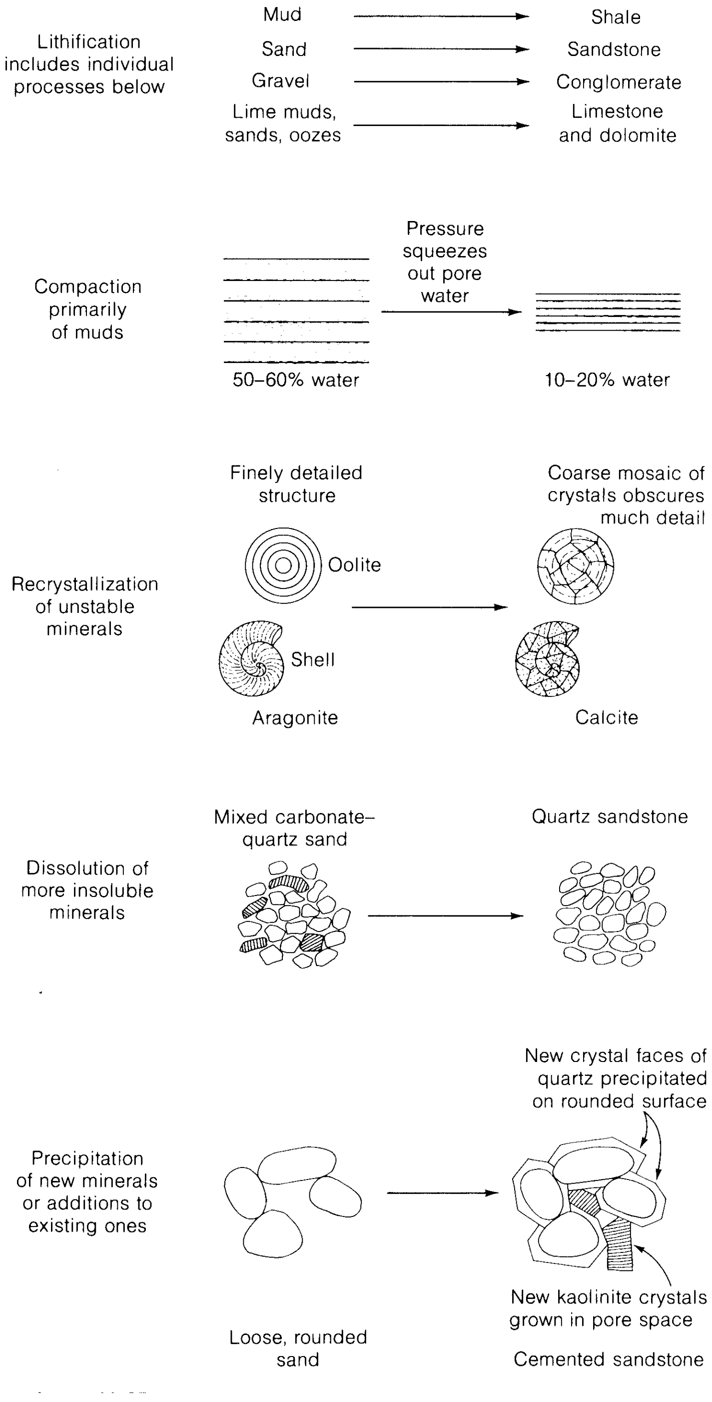

Figure 5-1: Some changes in composition and texture that are produced by diagenetic processes. Most of these changes tend to transform loose, soft sediment into hard, lithified sedimentary rock.

Mineral	Properties
Quartz	Colorless, white, or gray; exterior may be frosted, broken grains are glassy; scratches glass; can be present as cement
Orthoclase	Usually white or pink; 2 cleavages at 90°; clasts commonly angular
Biotite	Shiny, black sheets (golden if altered); one perfect cleavage, flakes easily
Muscovite	Shiny, silvery sheets; one perfect cleavage
Calcite	Generally white, gray, or black; doesn't scratch glass; reacts with acid; may be present as cement
Halite	White/light gray to colorless, may contain impurities; tastes like salt; soft, breaks into cubes
Gypsum	White to gray; can be scratched with fingernail
Iron Oxides	Yellow, orange, red or brown (rusty); usually very small particles; mainly present as cement
Clay	White, gray, green, red, black; clay-sized particles; can be scratched with fingernail; earthy feel and smell

Table 5-2: Diagnostic properties of the common sedimentary rock-forming minerals.

Organically-produced materials may also make up significant amounts of a given sedimentary rock. These materials may include shell fragments, teeth, bones, plant remains or other organic debris, or occasionally hydrocarbons like tar and oil.

Texture

Sedimentary rocks are said to have a **clastic texture** when they contain clasts, or grains of rock, minerals, or fossils. Clasts are not intergrown with each other, but are generally bound together or cemented by a chemical precipitate of silica, calcite, or iron oxide, or by clay or organic material. If the clastic texture results from abundant fossils or fossil fragments, the rock is **bioclastic**, and as you saw in the Igneous Rock Lab, **pyroclastic** refers to volcanic rocks with a clastic texture. When describing the texture of a clastic sedimentary rock, it is important to look at the **grain size**, **grain roundness**, and **grain sorting**.

Grain Size

Classification of clastic sedimentary rocks is based on the average diameter of constituent fragments. Grain size can be divided into four classes (Figure 5-2):

1. **Coarse-grained** (boulder-, cobble-, and pebble-sized) – larger than 2 mm.
2. **Medium-grained** (sand-sized) – between 2 mm and 0.062 mm.
3. **Fine-grained** (silt-sized) – between 0.062 mm and 0.002 mm. Individual grains may be too small to be seen, but the rock has a distinctive “gritty” feel when rubbed.

(4) **Very fine-grained** (clay-sized) – less than 0.002 mm. Individual grains are too small to be seen and the rock feels smooth when rubbed.

Grain size may vary within a single rock, especially when sorting is poor. In these cases, the grain size may be given as a range (for instance, fine to very fine).

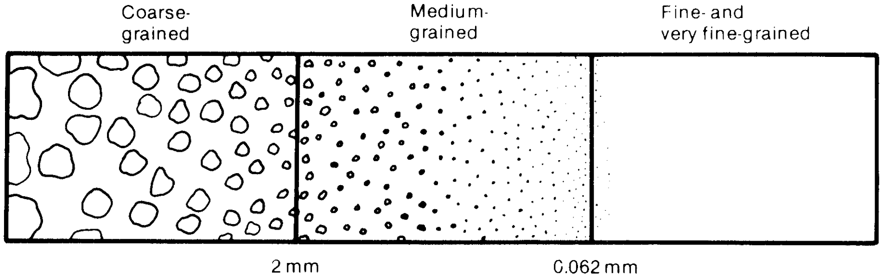

Figure 5-2: Size scale for use when describing the grain size of clastic sedimentary rocks.

Grain size is, in part, a function of the velocity of the currents that transported the sediment. The particle size that is deposited decreases as water velocity decreases. In non-flowing bodies of water, such as lakes and parts of the ocean, the movement of water is partially governed by the depth to which the motions of surface waves may reach. In these environments, sediment size generally decreases with increasing water depth. Clast size is also controlled by the nature of the transporting medium. Because of the buoyancy of water, even slow-moving streams can carry much larger particles than wind. Glaciers have a different method for transporting material than either water or wind because particles are frozen into the flowing ice. In glaciers, grains are not supported by the energy of the flow, and very large materials may be transported.

Grain Rounding

Roundness is a measure of the angularity of fragments within clastic sedimentary rocks. It ranges from **angular** to **rounded** and may be estimated by visual comparison with Figure 5-3.

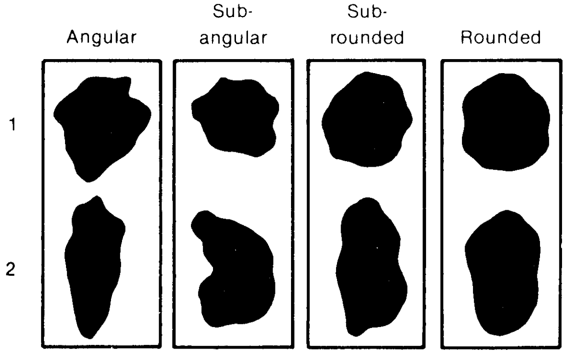

Figure 5-3: Scale for use when describing the roundness of fragments within clastic sedimentary rocks. Row 1 illustrates generally equidimensional (spherical) grains and Row 2 illustrates elongate grains.

The degree of grain rounding, in part, depends upon the distance sediment is transported. Clastic grains are mechanically abraded during wind and water transport and become more rounded the farther they are transported.

Grain Sorting

The extent of grain-size variation within a clastic rock is termed the degree of sorting (Figure 5-4). Rocks that contain grains of uniform size are **well-sorted**. If the clast size varies quite a bit, the rock is **poorly-sorted**. Terms such as **moderately sorted** may be used to describe textures intermediate between well-sorted and poorly-sorted.

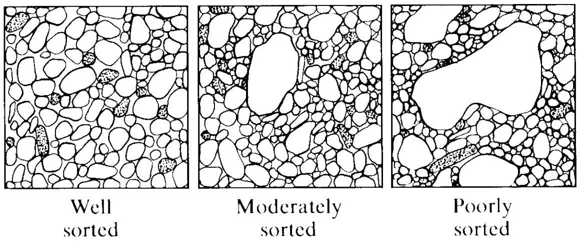

Figure 5-4: Diagram illustrating grain-size sorting in clastic sedimentary rocks.

The degree of sediment sorting is influenced by the rate of deposition and the energy within the depositional environment. Sediment deposited rapidly in areas of little current or wave action is usually poorly-sorted, because there is little chance for the removal of fine-sized grains. There is more opportunity for size sorting when sediment slowly accumulates in a high-energy environment. Therefore, to a certain degree, size sorting can be a measure of sediment reworking within a depositional environment.

Crystalline textures

Chemical and biochemical sedimentary rocks commonly exhibit a **crystalline texture**. A **primary crystalline texture**, like that of rock salt, forms during or shortly after deposition. **Secondary crystalline textures** result from recrystallization of existing minerals or replacement of existing minerals by new ones after lithification. Some sedimentary rocks, such as chert, are so fine-grained or dense that it is impossible to see much detail within them. These rocks are typically **microcrystalline**; that is, they are made of crystals so small that they can be seen only with a microscope.

1. Identify the six common sedimentary rock-forming minerals in your tray (specimens M-1 through M-6). You identified many of these minerals in the Minerals Lab. Refer to your mineral identification charts (Appendices A-1, A-2, and A-3) and the diagnostic properties of sedimentary rock-forming minerals (Table 5-2).

Specimen #	Mineral Name	Specimen #	Mineral Name
M-1		M-4	
M-2		M-5	
M-3		M-6	

2. Samples A and B are igneous rocks you saw last week. Sample C is a partially weathered igneous rock. Sample D is a sandy beach sediment.
   (a) Use the Igneous Rock ID Chart (Appendix B-1) to identify the igneous rock samples A and B.

   (b) Identify the minerals present in the clasts breaking off of sample C.

   (c) Which sample, A or B, did sample C start out as (circle one)?

   (d) Look at sample D with a hand lens. Could these sediments have come from the same source as sample C?

   (e) What would you call a sedimentary rock made up of Sample D? (Use Table B-2)

   (f) How does the texture of the sediments differ between sample C and sample D?

3. Look at rock specimens R-1 and R-2. Identify the minerals that are present as cement in each sample. Remember that cement usually consists of silica/quartz, calcite, clay, tar or other organics, or iron oxides/rust.

Specimen #	**Minerals Present as Cement**
R-1	
R-2	

4. Look at rock specimens R-2, R-3, and R-4. Identify the most common mineral present in each sample.

Specimen #	**Mineral Present**
R-2	
R-3	
R-4	

5. Compare rock specimens R-1 and R-2.
   (a) Which sample contains the most stable mineral clasts at the surface of the Earth?

   (b) Which sample has the rounder grains?

   (c) Which sample is more well-sorted?

   (d) Based on your observations above, which sample was deposited furthest from its source?

6. The energy of a system can be inferred from the size of the particles transported within that system. High-energy systems can carry big particles; low-energy systems carry small particles. Examine the rock specimens R-2, R-5, and R-6 and rank them from high-energy to low-energy.

Energy	**Rock Specimen #**
High	
Intermediate	
Low	

11. Some limestones are dense, fine-grained, and black. How would you distinguish between such a limestone and a basalt?

12. How did rock specimen R-4 form?

7. Using your mineral ID charts and the table of diagnostic properties of sedimentary rock-forming minerals, determine the composition of the rock specimens R-1 to R-9 and write your answer in the column labeled "composition" on the Sedimentary Rock ID Chart (Question 10). Where possible you should list what minerals make up the rock. If the rock is composed of fragments of other rocks write "rock fragments". *Note that "clay minerals" is an appropriate answer for fine-grained clastic rocks.*

8. Determine the texture of the rock specimens R-1 to R-9 and write your answer in the column labeled "texture" on the Sedimentary Rock ID Chart. First determine if the rock is chemical or clastic. *If it is chemical, write one term describing its texture:* crystalline, microcrystalline, or fossiliferous. *If the rock is clastic, you must write three descriptive terms:* grain size, sorting, and, if the clasts are visible, grain rounding.

9. Under the column labeled "fossils present", write whether the rock contains any fossils or organic material. If not, write "N/A" for not applicable.

10. Use your sedimentary rock ID charts (Table B-2 and Table B-3) to name the 9 rock specimens in your tray (R-1 to R-9). Write this in the column labeled "rock name".

Specimen #	Composition	Texture	Fossils Present	Rock Name
R-1				
R-2				
R-3				
R-4				
R-5				
R-6				
R-7				
R-8				
R-9				

C. Sedimentary Structures and Environments of Deposition

Sedimentary Structures

Sedimentary structures are features in clastic sedimentary rocks that formed during or after deposition of the sediment, but before lithification. They are important because they provide information about the transporting agent and the environment in which the sediments were deposited. The most common sedimentary structures are described below.

Stratification, the layering of sediment, is the most obvious type of sedimentary structure. Most sediment accumulates in horizontal layers called **strata** or **beds**. The top or bottom surface of a bed is called a **bedding plane**, and it represents an exposed surface that existed between sedimentary depositional events.

Inclined stratification is referred to as **cross-bedding**. Cross-bedding in a sedimentary rock indicates that the sediment was transported by a current (wind or water) when it was deposited. Cross-bedding can be used to tell the direction of current, as shown in Figure 5-5 below.

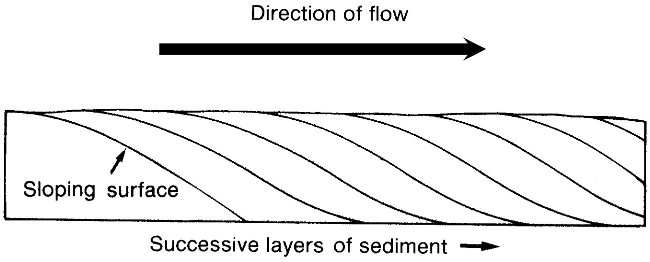

Figure 5-5: Figure showing cross-beds and their relationship with current flow direction.

Ripple marks are wave-like features found on bedding planes. **Oscillation ripple marks** are symmetrical and commonly form where the back-and-forth motion of water waves shaped the bottom sediment (Figure 5-6A). These typically form in relatively shallow water: less than 10 meters depth for normal waves and up to 200 meters depth for storm waves. **Current ripple marks** form when wind or water currents shape the loose sediment into asymmetrical wave forms whose gentle slope is on the side from which the current came (Figure 5-6B).

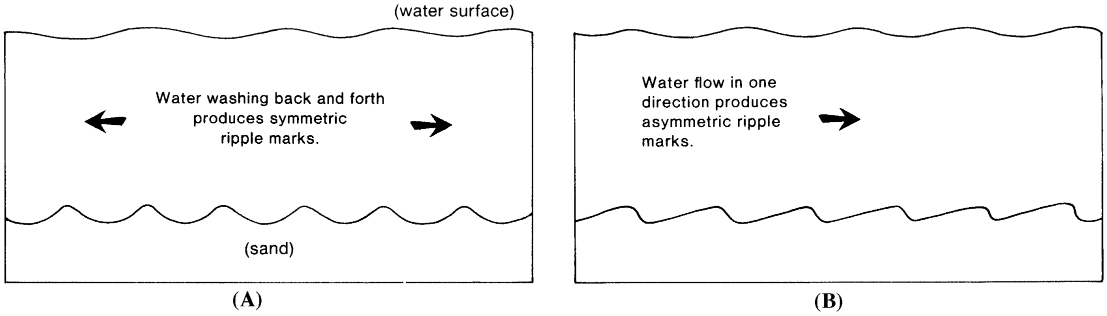

Figure 5-6: Diagrams showing the formation of (A) oscillatory ripples and (B) current ripples.

In **graded beds** (Figure 5-7), larger grains on the bottom usually grade upwards into finer grains on the top. Graded beds form when a sediment-laden (**turbidity**) current slows after flowing down an underwater slope; larger grains settle out first, smaller ones last.

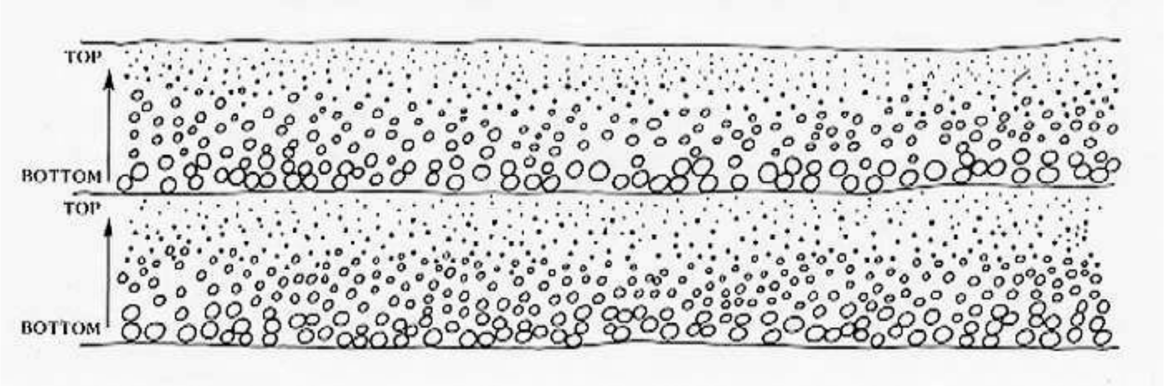

Figure 5-7: Diagram showing two graded beds. The coarsest grains are on the bottom; the finest grains are on top.

Mud cracks form when mud dries and shrinks. When sediment is deposited on top of cracked mud, some of the sediment falls into the cracks, allowing preservation during subsequent lithification. The presence of mud cracks indicates a depositional environment in which periodic wetting and drying occurred. Some shales also preserve ancient **raindrop impressions**.

Environments of Deposition

One of the most important goals in studying rocks ("petrology") is to learn how, and under what conditions, a particular rock formed. If we know the environmental conditions at the time of deposition, we can reconstruct the geologic past, predict where we might find ore deposits or fossil fuels, reconstruct how climate conditions have varied through time, and even formulate hypotheses about the future.

We can learn how and under what conditions ancient sediments formed by studying the environments in which modern sediments accumulate. The most important **depositional environments** are shown in Figure 5-8 and the rock types that are characteristic of those environments are described in Table 5-3.

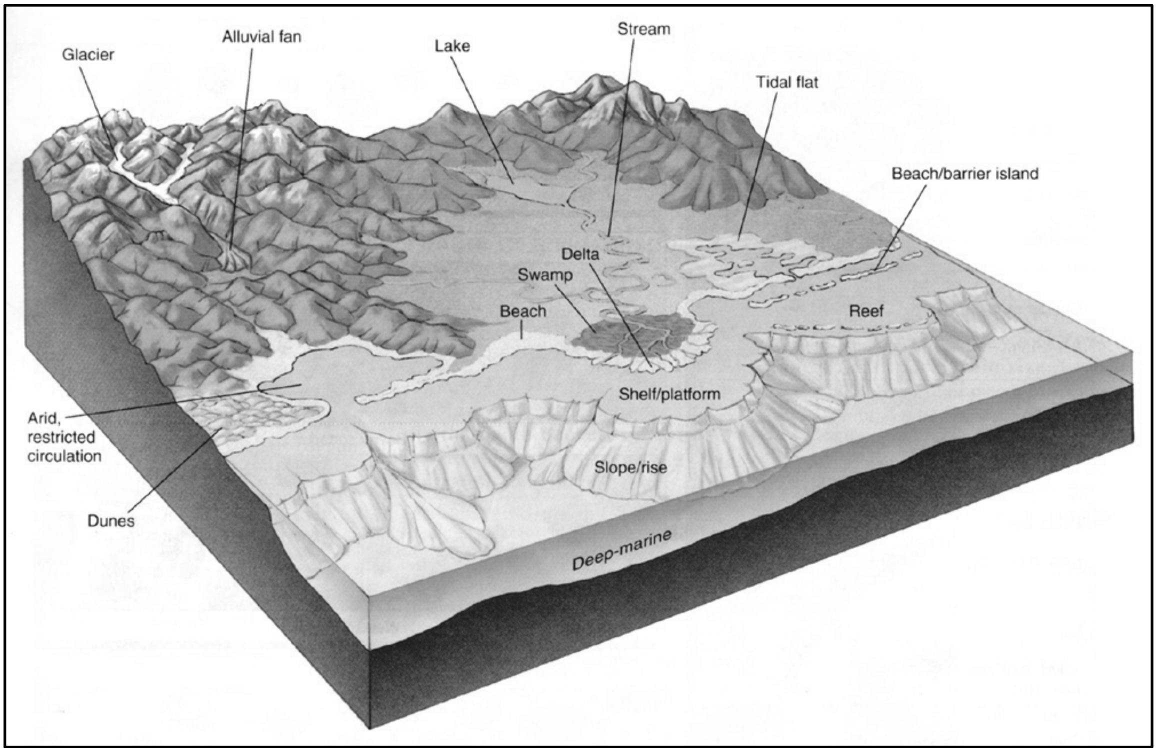

Figure 5-8: Modern environments of sediment accumulation and deposition.

15. Which rock specimens from the nine specimens in your tray could have formed on a continental shelf?

16. What is a possible depositional environment for rock specimen R-9?

13. Examine Rock E on the side table to answer the following questions.
    (a) What kind of sedimentary structure is most prominent in this rock sample?

(b) Sketch these features below. Show which direction is north. On your sketch, also show what direction the water that formed these structures was flowing.

(c) Describe a likely environment of deposition for this sediment.

14. Examine Rock F on the side table.
    (a) What kind of sedimentary structure is most prominent in this sample?

    (b) How does this structure form?

    (c) Describe a likely environment of deposition for this sample.

17. Your TA will give each group a sedimentary rock. Each group should carefully examine the sample and fill out the following description.

    Grain size:

    Composition:

    Sorting:

    Degree of rounding:

    Fossils:

    Sedimentary structures:

    Original depositional environment based on the above information:

Depositional Environment	Characteristic Sedimentary Rocks
CONTINENTAL	
Stream Channel	Conglomerate and sandstone with current ripple marks, cross-beds, and discontinuous beds/erosional surfaces.
Stream Floodplain	Shale, some mud cracks, and siltstone; coal may also be present.
Alluvial Fan	Conglomerate and feldspar-rich sandstone with poor sorting and cross-beds.
Deserts	Well-sorted sandstone with large cross-beds.
Glacier	Poorly sorted, unstratified conglomerate; constituent clasts angular to rounded and may have striations. (Glacial streams are similar to stream channel deposits.)
Swamp	Coal.
Lake	Shale; sandstone and conglomerate near shore.
TRANSITIONAL (COASTAL)	
Delta	Complex association of marine and nonmarine sandstone, siltstone, and shale, possibly with cross-beds and ripple marks; coal common.
Beach/Barrier Island	Fine- to medium-grained, well-sorted sandstone; cross-beds common.
Tidal Flat	Shale, siltstone, and fine-grained sandstone, with ripple marks, cross-beds, and/or mud cracks; evaporites possible.
MARINE	
Continental Shelf	Sandstone with cross-beds and ripple marks common; shale; various limestones.
Reef	Fossiliferous limestone; coral and algae fossils common.
Continental Slope/Rise	Shale and muddy sandstones; graded bedding common.
Deep Marine	Chert, chalk, crystalline limestone, and shale.
Arid, hot, restricted circulation	Evaporites (ie. rock salt and rock gypsum)

Table 5-3: Common depositional environments.

Appendix B-1. **Igneous Rock Identification Chart**

Composition (Minerals present) → ↓ **Texture**		***Felsic*** Quartz Orthoclase Biotite Na-Plagioclase	***Intermediate*** Na-Plagioclase Amphibole Pyroxene Biotite	***Mafic*** Ca-Plagioclase Pyroxene Olivine
Coarse-grained*		**GRANITE**	**DIORITE**	**GABBRO**
Fine-grained*		**RHYOLITE**	**ANDESITE**	**BASALT**
Glassy		**OBSIDIAN**		▨
Vesicular		**PUMICE**		**SCORIA**
Fragmental (pyroclastic)	Coarse	**VOLCANIC BRECCIA**		
	Fine	**TUFF**		

*Some igneous rocks have a porphyritic texture, which means it has mineral of at least two distinctive sizes. If a rock is predominantly fine-grained and mafic, it is a basalt. If phenocrysts (the larger mineral grains) are present in the fine-grained matrix, this rock is called a porphyritic basalt. Note both pumice and scoria can have intermediate compositions.

Appendix B

TABLE B-2. Clastic Sedimentary Rocks

GRAIN SIZE	OTHER PROPERTIES	ROCK NAME
Coarse-Grained	Rounded grains; moderately to poorly sorted	**CONGLOMERATE**
	Angular grains; moderately to poorly sorted	**BRECCIA**
Medium-grained	Often consists of quartz, feldspar, rock fragments, and/or clay	**SANDSTONE***
Fine-grained	Commonly massive; feels gritty on teeth	**SILTSTONE***
Very fine-grained	Commonly laminated or massive; feels smooth on teeth; often can be scratched with fingernail	**SHALE***

TABLE B-3. Chemical, Biochemical, and Organic Sedimentary Rocks

COMPOSITION	OTHER PROPERTIES	ROCK NAME
Calcite (reacts with acid)	white to gray to black; may contain fossils or be crystalline	**LIMESTONE***
Silica (Quartz) (scratches glass)	Dense, microcrystalline texture; white to black; sometimes shows choncoidal fracture	**CHERT**
Gypsum	Massive, crystalline; white to yellow; can be scratched with fingernail	**ROCK GYPSUM**
Halite	Massive, crystalline; clear to white; tastes like salt	**ROCK SALT**
Plant debris (mostly carbon)	Plant fossils may be present; combustible black and nonporous	**COAL**

***Descriptive adjectives should be added to the rock name if the rock contains fossils (e.g., fossiliferous limestone) or if it is predominantly composed of a single mineral. (For example, a rock made of quartz sand would be called a quartz sandstone.)**

Appendix A-1

Metallic Mineral Identification Chart

Luster	Streak	Hardness	Cleavage	Color	Specific Gravity	Other Properties	Name
Metallic	Dark Gray to Black	6.0-6.5	No	brass yellow	5.0	cubic crystals (with striations) common	**PYRITE**
		6.0	No	dark gray to black	5.2	strongly magnetic	**MAGNETITE**
		3.5-4.0	No	golden yellow	4.2	may tarnish to bronze or purple; massive	**CHALCOPYRITE**
		2.5	Yes	silvery gray	7.5	perfect cubic cleavage (3 planes at 90°)	**GALENA**
		1.0	Yes-d	gray to black	2.5	marks paper and fingers; greasy feel	**GRAPHITE**
	Red to Red-Brown	5.0-6.5	No	silver to gray to red	5.0	may be tiny glittering flakes	**HEMATITE**
	Yellow-Brown	3.5-4.0	Yes-d	yellow-brown to dark brown	4.0	submetallic to resinous luster; 6 cleavage planes	**SPHALERITE**
	Copper	2.5-3.0	No	copper to dark brown	8.9	malleable	**NATIVE COPPER**

Note: Yes-d means cleavage is present but may be difficult to see

Appendix A-2. Light Colored Non-metallic Mineral Identification Chart

Luster & Color	Relative Hardness	Hardness	Cleavage	Color	Specific Gravity	Other Properties	Name
Non-Metallic Light Colored	Harder than Glass	7.0	Yes-d	pistachio green	3.3-3.6	surface coatings, or massive	**EPIDOTE**
		7.0	No	variable	2.7	vitreous luster; conchoidal fracture; massive but also occurs as 6-sided crystals	**QUARTZ**
	Similar to Glass	6.0	Yes	pinkish-orange (variable)	2.5	vitreous luster; banding; 2 cleavages at 90°	**ORTHOCLASE** (Potassium Feldspar)
		6.0	Yes	white to gray	2.6-2.8	vitreous luster; 2 cleavages at 90°; striations common on cleavage faces	**PLAGIOCLASE** (Na & Ca Feldspar)
		5.0-7.0	Yes-d	bluish-gray	3.5	vitreous luster; blade shaped crystals	**KYANITE**
	Softer than Glass	4.0	Yes	clear, purple, yellow (variable)	3.2	vitreous luster; 4 perfect cleavages forming octahedrons	**FLUORITE**
		3.0	Yes	white to clear (variable)	2.7	reacts with HCl; rhombic cleavage; 3 perfect cleavages not at 90°	**CALCITE**
		2.5	Yes	clear to milky white	2.2	3 perfect cleavages at 90° (cubes); salty taste	**HALITE**
		2.0-2.5	Yes-d	white to tan	2.6	dull luster, powdery; earthy odor; white streak	**KAOLINITE**
		2.0-2.5	Yes	clear to light yellow	2.5-3.0	vitreous luster; perfect cleavage in 1 dir.;forms flexible, transparent, thin sheets	**MUSCOVITE**
		2.0	Yes	clear, white, yellow (variable)	2.3	vitreous to pearly luster; brittle flakes; perfect cleavage in 1 direction	**GYPSUM**
		1.5-2.5	No	yellow	2.0	yellow streak; distinctive sulfurous odor	**SULFUR**
		1.0	Yes-d	apple green to silvery white	2.7	pearly luster; greasy feel	**TALC**

Note: Yes-d means cleavage is present but may be difficult to see.

Appendix A-3. Dark Colored Non-metallic Mineral Identification Chart

Luster & Color	Relative Hardness	Hardness	Cleavage	Color	Specific Gravity	Other Properties	Name
Non-Metallic Dark Colored	Harder than Glass	9.0	No	brown (variable)	4.0	six-sided prismatic crystals	**CORUNDUM**
		7.0	Yes-d	brown	3.8	vitreous to dull luster; prismatic to cross-shaped crystals	**STAUROLITE**
		7.0	No	red or brown	3.5-4.3	twelve-sided crystals common; vitreous luster	**GARNET**
		7.0	No	variable	2.7	vitreous luster; conchoidal fracture; massive but also occurs as 6-sided crystals	**QUARTZ**
		6.5-7.0	No	olive green	3.3-4.4	vitreous luster; granular	**OLIVINE**
	Similar to Glass	6.0	Yes	gray to white	2.6-2.8	vitreous luster; 2 cleavages at 90°; striations common on cleavage faces	**PLAGIOCLASE**
		5.0-6.0	Yes-d	dark green to black	3.3	vitreous to dull luster; 2 poor cleavages at 90°	**PYROXENE**
		5.0-6.0	Yes	dark green to black	3.3	vitreous luster; splintery appearance; 2 perfect cleavages at 120° and 60°	**AMPHIBOLE**
		5.0-6.0	No	reddish-brown to black	5.0	red-brown streak; dull luster; massive	**HEMATITE**
		5.0	Yes-d	green, brown, blue, black	3.2	vitreous luster; six-sided crystals common	**APATITE**
	Softer than Glass	3.5-4.0	Yes-d	grass green	4.0	occurs as surface coatings, masses, or tiny crystals; green streak	**MALACHITE**
		2.5-3.0	Yes	brown to black	2.8-3.0	vitreous luster; perfect cleavage in 1 direction; forms flexible thin sheets	**BIOTITE**
		2.0-2.5	Yes-d	dark or light green	2.6-2.9	flexible crystal flakes; crystal aggregates common	**CHLORITE**

Note: Yes-d means cleavage is present but may be difficult to see.