ES202 Lab 4 - Introduction to Sedimentary Structures, Sedimentary Facies, and Stratigraphy

(updated Jan, 2012, 9th edition AGI lab manual)

Part 1 - Introduction to Sedimentary Structures

Examine the samples that are located at the labeled stations in the lab. Answer the associated questions. For reference, use the attached "Sedimentology Tool Kit", and p. 138-139 in your lab manual.

Station 1 - Sedimentation Patterns

Fine "muddy" sediment was mixed with water in the jar, shaken, and left to sit for 1 week. Turn on the light / illuminator, and examine the results. Pay close attention to the subtle distribution of grain size from the bottom of the jar to the top. Answer the following questions:

A. What are your initial observations of sediment size distribution?

B. Is the deposit graded or ungraded? (refer to p. 138 of the lab manual for help with these terms).

C. Where do you find the coarsest sediment? What is it's approximate grain size? (answer in both millimeters, and with the appropriate size term)

D. Where do you find the finest sediment? What is it's approximate grain size?

E. What is the implication for grain settling velocity vs. grain diameter? (i.e. which sediment sizes settle faster - or first? and which sizes settle slower - or last?).

F. Consider a natural depositional condition in which pebbles, sand, silt and clay are deposited during flood discharge in a broad river valley. What would be a likely arrangement of grain sizes that you might find in such a deposit? (based on your above observations). Draw a diagram to illustrate your answer.

G. Is the sediment sample in the jar "lithified" or "unconsolidated"?

Station 2 - Cross-Bedding

Examine the freshly broken surface of the red rock sample at Station 2A. Answer the following questions.

A. What is the grain size and rock name of this sample?

B. Is this sample well sorted or poorly sorted?

C. Is this sample graded or ungraded?

D. Is this sample best described as massive or cross-bedded? (massive is used where cross-bedding is not evident, see p. 138 of your lab manual for diagrams of cross-bedding)

Examine the sample at Station 2B and answer the following questions.

E. What is the grain size and rock name of this sample?

F. Is it well sorted, moderately sorted, or poorly sorted?

G. Is this sample massive or cross-bedded?

H. Using p. 138-139 of your lab manual for comparison, is this sample right-side up, or upside down compared to it's original depositional position?

I. Examine the north arrow taped to the top of the sample. Determine the general compass direction of paleocurrent that prevailed at the time of deposition. (north, east, northeast, or???; refer to p. 138-139 for help in your determination).

Station 3

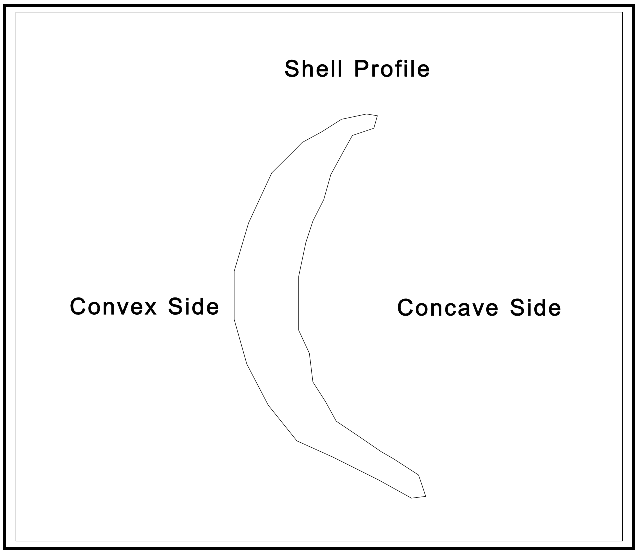
A. What is the sedimentary structure displayed in this sample?

B. Are these structures symmetric or asymmetric?

C. Can you determine the paleocurrent direction at the time of deposition? If so, what is it (note north arrow on sample).

Station 4 - Sedimentary Processes and Determining "Up Orientation"

Drop the loose shells into the tub of water, repeat 10 times and tabulate your results in the table below. Place a check on the appropriate line, determining whether the shells land convex-up, or concave-up.



Trial No.	Convex Up	Concave Up
1	____	____
2	____	____
3	____	____
4	____	____
5	____	____
6	____	____
7	____	____
8	____	____
9	____	____
10	____	____

A. What can you deduce about the position of a shell that is deposited on the sea floor, when the animal dies?

B. Given your experimental results, do you think the rock sample at this station is currently in a right-side up or upside-down position, relative to it's original depositional environment?

C. The correct answer to 1-4B above is that the rock is currently in a right-side up position. Assuming that this sample was deposited in a shallow-water, near-shore marine environment, suggest a process or processes that might provide an explanation for the discrepancy between your experimental results, and the fact that this sample is in a right-side up position.

Station 5.

Examine the glass dish of sediment at Station 5A, complete the following observations:

A. What is the grain size?

B. Is this sediment sample well, moderately or poorly sorted?

C. Is this sample graded or ungraded?

D. What is the sedimentary structure that is evident on the sediment surface?

E. How did this sedimentary structure form (what are the variables and the process?)?

Examine the display at Station 5B, answer the following:

F. What is the primary sedimentary structure observable on this sample.

G. Which of the following environments of deposition could this rock have formed in? Check all that apply, more than 1 possible. Explain your line of reasoning for each that you check.

Environment	Explanation
____ Deep Ocean Floor	
____ Submarine Fan	
____ Tidal Flat	
____ River Floodplain	
____ Shallow Lake	
____ Gravel-dominated mountain stream	

Station 6.

Examine the sample under the protective glass - fragile, do not touch!!!

A. What is the grain size (millimeters and term)?

B. Note the polygonal shape of the sample fragments, what sedimentary process might result in this pattern?

C. What are your hypotheses as to the origin of the small circular patterns on the surface of the sample?

D. Which of the following environments of deposition could this rock have formed in? Check all that apply, more than 1 possible. Explain your line of reasoning for each that you check.

Environment	Explanation
____ Deep Ocean Floor	
____ Submarine Fan	
____ Tidal Flat	
____ River Floodplain	
____ Shallow Lake	
____ Gravel-dominated mountain stream	

Station 7.

Refer to the catalog of sedimentary structures shown on p. 138-139 of your lab manual.

A. What type of sedimentary structure is associated with this sample?

B. Are these structures molds or casts (a mold is a form, a cast is a 3-D object made from the mold)?

C. Is this sample right-side up or upside down relative to it's original depositional position? How do you know?

D. Using the north arrow, what is the paleocurrent direction represented in this sample.

Station 8.

Note the finely layered interval between points A and B on this sample. Refer to the attached Sedimentology Tool Kit, and answer the following questions.

A. Are these layers best described as bedding or laminations? What is the difference between bedding layers and lamination layers?

B. Based on your choice above, are these features thin, medium, or thick?

Refer to the contact between the light gray and dark gray strata at points A and B. Answer the following:

C. At contact A, is the break in strata sharp (smooth) or irregular (rough)?

D. At contact B, is the break in strata sharp (smooth) or irregular (rough)?

E. Based on your observations, and considering the process of erosive scour in a sedimentary environment (erosive scour = high-energy removal of previously deposited sediments), which direction do you think is depositionally right-side up? (i.e. is A toward to top, or is B toward the top?).

Station 9

Examine the stratal interval between Pt. A and Pt. B on Sample S3-39. Using your Sedimentology Tool Kit, make the following observations:

A. Grain size?

B. Sorting?

C. Grain Rounding?

D. Graded or Ungraded?

E. Referring to p. 138-139 of your lab manual, what sedimentary processes result in your answer to 1-9D above?

Station 10.

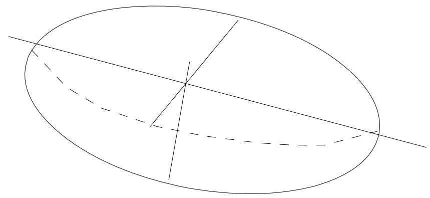
A. What does the ring structure of this sample remind you of?

B. Guess what the name of this sample is?

C. What could such a sample in rock outcrop tell you about past climate conditions, relative to ancient Earth history?

Station 11 - Clast Shape Measurements

This station consists of 5 black pebbles and 5 light-colored pebbles. Your job is to measure the length of 3 mutually perpendicular axes of diameter, as illustrated below.

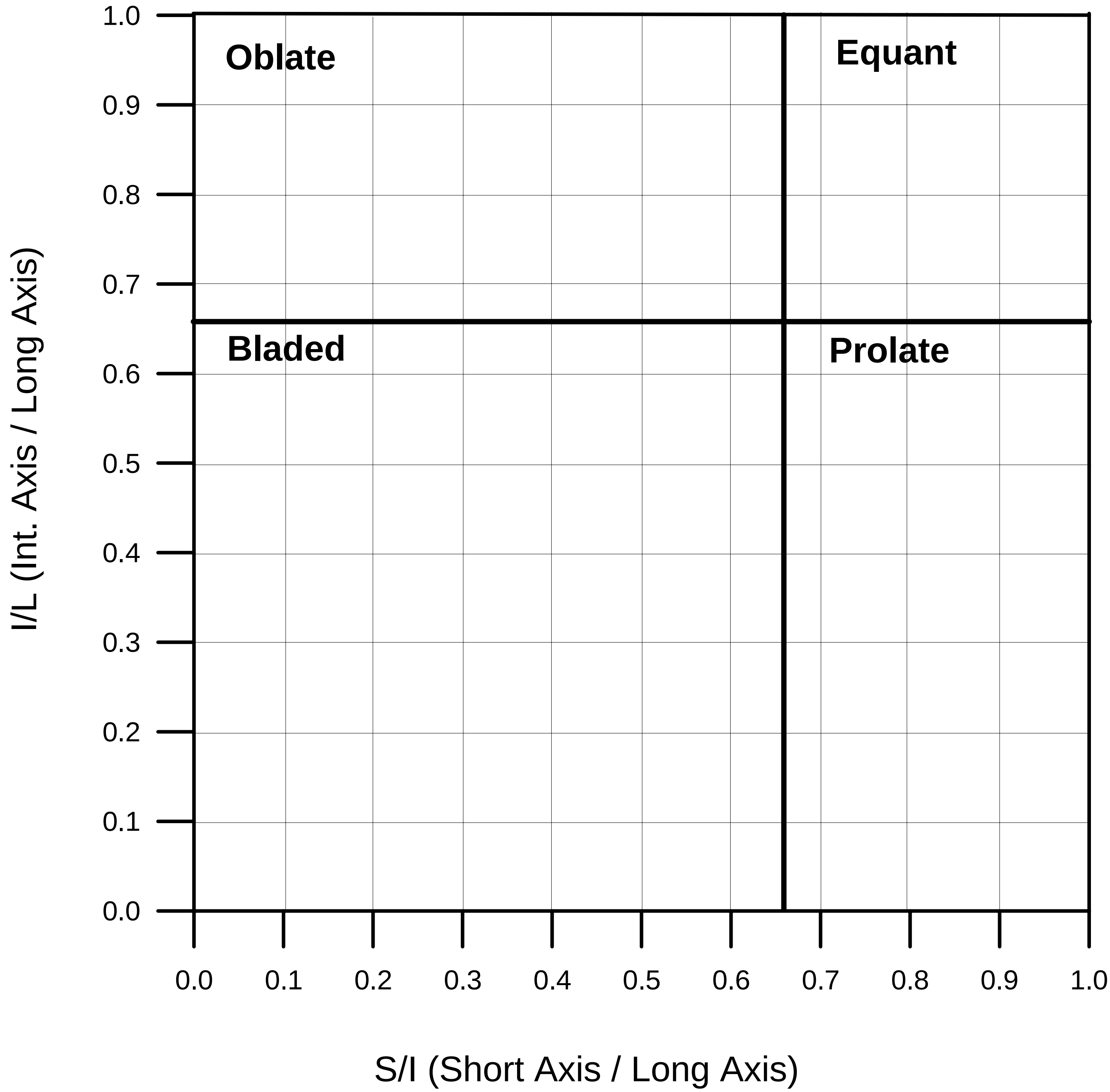


For each pebble, measure the short, intermediate, and long axis diameters in CENTIMETERS. Fill in the table below.

Pebble I.D.	Pebble Color	Short Axis (cm)	Intermed. Axis (cm)	Long Axis (cm)	S / I (divide)	I / L (divide)	Shape Type (from graph)
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

Now using the attached graph paper, plot each pebble with the ratio of S/I on the x-axis, and the ratio of I/L on the y-axis. Determine the shape type of the pebble from the graph, and write the type in the last column of the table above.

Grain Shape Plots for Station 12; ES202 Lab 4



c:wou:nssi:ns481-581:gravel.grf

Questions

A. Do the black and light pebbles plot the same or differently on the graph? How so? - explain the graph patterns that you see.

B. What is the general grain roundness of the pebbles (use your sedimentology tool kit to determine angular, subangular, rounded, etc.).

C. What does the degree of roundness tell you about the amount of sedimentary transport that the grains have been subjected to? (e.g. have they been transported... how do you know?)

D. Keeping in mind sedimentary processes, construct hypotheses to explain the patterns that you observe on your graph. What might explain the differences in grain shape between the light and black pebbles?

Station 12

A. Does this sample fizz with a drop of dilute HCl?

B. What is this sample mainly comprised of? Describe your visual observations

C. Which of the following environments of deposition could this rock have formed in? Check all that apply, more than 1 possible (refer to page 130 of lab manual for help). Explain your line of reasoning.

Environment Explanation

Yes? No.?

___ ____ Mountain River System

___ ____ Antarctic Continental Glacier

___ ____ Tropical Rainforest (nonmarine)

___ ____ Shallow, tropical marine environment

___ ____ Reef off the coast of Australia

___ ____ The deepest depths of the ocean
(e.g. ~30,000 ft below sea level)

Station 13.

Use your Sedimentology Tool Kit and lab manual to answer the following:

A. What is the name of this sedimentary rock?

B. Grain roundness of the gravel clasts?

C. What is the sorting of this sample?

D. Is this sample graded or ungraded?

E. Do you think that this rock represents a wind-blown sedimentary deposit? Explain your answer, why or why not.

Station 14.

Use your lab book and tool kit to answer the following. You know what to do...

A. What is the name of the primary sedimentary structure displayed in this sample?

B. Are these features symmetrical or asymmetrical?

C. Can you determine a paleocurrent direction in this sample? If so, use the north arrow and determine.

D. What type of sedimentary environment does this type of structure form in?

Station 15. Outcrop photograph – This photo shows a sedimentary deposit exposed at the Earth's surface. Observe and answer the following questions:

A. Is this deposit lithified bedrock or unconsolidated sediment?

B. The thin yellow stick in the photo is a jacob's staff that is approximately 1.5 m long. How thick is the deposit shown in the outcrop (answer in meters).

C. Is this deposit well sorted or poorly sorted?

D. Is this deposit in a marine or non-marine depositional environment?

E. Which is the best interpretation for the depositional environment? (deep marine, shallow marine, tidal mudflat, coal swamp, wind-blown dune, landslide, river, lake). Explain your line of reasoning.

Part 2 - Introduction to Sedimentary Facies and Stratigraphy

Sedimentary facies refer to the physical, chemical and biological aspects of sedimentary rock. The type of sedimentary facies is related back to the depositional environment that led to the formation of the rock. For example, peat and coal start out as accumulations of plant matter (trees / grasses) in terrestrial bogs or swamps. We can observe this relationship directly in modern day environments. So the implication is, if one identifies coal in the rock record, then it indicates deposition in an ancient terrestrial swamp.

Stratigraphy involves the study of rock sequences both spatially and temporally (with respect to Earth history / time). Stratigraphy is a fundamental area of study in geology as it is the foundation upon which Earth history is derived. For example, stratigraphic observations of changes in fossilized animal remains in the rock record provides a critical evidence that supports Darwin's concept of evolution through time.

Stratigraphic analysis involves the study of rock sequences with respect to their spatial and temporal distribution. Since sediments are commonly deposited under the influence of gravity in a fluid medium, sedimentary rocks are commonly layered and stacked in ***stratigraphic sequences***. Analysis of sedimentary facies and stratigraphic position permits the reconstruction of ancient sedimentary environments through geologic time.

Stratigraphy Exercise

The bookshelf at the front of the lab contains a stratigraphic sequence of sedimentary rock layers. The rock units are numbered from 1 to 11 and the thickness is listed on the note card (e.g. t = 30 m ... reads as "this bed is 30 m thick"). Your job is to construct a stratigraphic column of the "rock outcrop", and make interpretations of sedimentary environments and changes through time. Since the "outcrop" is spatially limited to one locality, you will be asked to analyze the changes that occurred at this site through time.

Step 1 - Starting at the bottom of the stratigraphic sequence, fill in the chart below.

Rock Unit Name	Rock Type (i.d. using your lab manual)	Thickness (meters)	Environment of Deposition (choose from list below).	List Key Evidence Used to Interpret Env. of Deposition
Unit 11				
Unit 10				
Unit 9				
Unit 8				
Unit 7				
Unit 6				
Unit 5				
Unit 4				
Unit 3				
Unit 2				
Unit 1				

Key to Use in Identifying Environments of Deposition (Use in Combination with p. 130 in Lab Manual)

Environment (in no particular order)	**Key Evidence**
Nonmarine (terrestrial / land-derived)	Plant Fossils, Lack of Marine Fossils
Nonmarine / volcanic	Volcanic Rock
Swamp (warm, wet environment)	Coal
Evaporating Lake or Bay (warm, dry env.)	Evaporite Deposits (e.g. rock salt / gypsum)
River Channel Deposit	Cross-bedded sandstone, no marine fossils
River Channel Gravel	Conglomerate / Rounded Gravel, no marine fossils
Tidal Flat (wetting / drying)	Mudcracks, Fine-Grained Sediments
Deep Ocean	Shale (clay, no plant fossils)
River Floodplain	Fine mudstone (plant fossils)
Beach Deposit	Coquina (shell deposits)
Shallow Marine Shelf (warm ocean water)	Fossiliferous Limestone ("calcirudite")
Offshore Marine / Intermediate Water Depth (warm)	Micrite / Microcrystalline Limestone

Questions.

2-1. What is the oldest rock unit in the stratigraphic sequence? What is the youngest rock unit?

2-2. Given that Unit 1 has been dated as being 60 million years old, and Unit 11 is 55 million years old. What was the sedimentation rate for this particular stratigraphic sequence (Sed. Rate = thickness of accumulation / time of accumulation). Give your answer in meters per year.

2-3. Comment on the climate change that had taken place between the time of deposition of Unit 5 and Unit 7. Give your answer in terms of relative temperature and precipitation (e.g. wetter and colder, etc.)

2-4. By examining unit 4, do you think that this rock was deposited in a tundra environment that was frozen year round? Why or why not.

2-5. Based on your stratigraphic analysis, what happened to relative sea level from the time of Unit 2 through that of Unit 11? (i.e. what happened to this area during the geologic time interval covered by the stratigraphic section?).

2-6. Hypothesize mechanisms that could result in the sea level relationships that you discussed in question 2-5 above.

G202 Lab 4
Part 3 – Outcrop interpretation from field photos.

Outcrop A: In the space below, draw a sketch of major bedding contacts and stratigraphic breaks in this section of rocks. On your diagram label, to the best of your interpretive ability, fine-grained lithofacies (mudstone/shale) and coarse-grain lithofacies (sandstone/conglomerate). In your drawing, show the geometry of the outcrop and all major bedding breaks and orientations

Outcrop B: In the space below, draw a sketch of major bedding contacts and stratigraphic breaks in this section of rocks. On your diagram label, to the best of your interpretive ability, fine-grained lithofacies (mudstone/shale) and coarse-grain lithofacies (sandstone). In your drawing, show the internal crossing bedding and all major bedding breaks and orientations

Thinking Question: How does outcrop B compare to outcrop A? Does it represent a higher-energy depositional environment? A lower depositional environment? Provide an interpretation as to where each of these deposits may form (e.g. lake, river, shallow ocean, deep ocean, desert? Explain your answer.

Outcrop B: In the space below, draw a sketch of major bedding contacts and stratigraphic breaks in this section of rocks. On your diagram label, to the best of your interpretive ability, fine-grained lithofacies (mudstone/shale) and coarse-grain lithofacies (sandstone). In your drawing, show the internal crossing bedding and all major bedding breaks and orientations.

Thinking Question: How does the scale of the cross-bedding in outcrop C compare to outcrop B? Which ones are bigger, determine the thickness of each in meters. Does it represent a higher-energy depositional environment? A lower depositional environment? Which direction(s) is (are) the paleocurrent oriented in outcrop C? To the right, to the left? to the front? to the back? Draw arrows on your sketch showing the paelocurrent directions.

Appendix A - Sedimentology Tool Kit

TABLE 5.2 Methods of measuring sediment grain size

Type of sample	Sample grade	Method of analysis
Unconsolidated sediment	Boulders Cobbles Pebbles	Manual measurement of individual clasts
	Granules Sand Silt	Sieving or settling tube analysis
	Clay	Pipette analysis, photohydrometer, Coulter counter
Lithified sedimentary rock	Boulders Cobbles Pebbles	Manual measurement of individual clasts
	Granules Sand Silt	Thin-section measurement
	Clay	Electron microscope

TABLE 5.1 Grain-size scale for sediments, showing Wentworth size classes, equivalent phi (ϕ) units, and sieve numbers of U.S. Standard Sieves corresponding to various millimeter and ϕ sizes

	U.S. Standard sieve mesh	Millimeters		Phi (ϕ) units	Wentworth size class
GRAVEL		4096		−12	
		1024		−10	Boulder
		256	256	− 8	
		64	64	− 6	Cobble
		16		− 4	Pebble
	5	4	4	− 2	
	6	3.36		− 1.75	
	7	2.83		− 1.5	Granule
	8	2.38		− 1.25	
	10	2.00	2	− 1.0	
SAND	12	1.68		− 0.75	
	14	1.41		− 0.5	Very coarse sand
	16	1.19		− 0.25	
	18	1.00	1	0.0	
	20	0.84		0.25	
	25	0.71		0.5	Coarse sand
	30	0.59		0.75	
	35	0.50	½	1.0	
	40	0.42		1.25	
	45	0.35		1.5	Medium sand
	50	0.30		1.75	
	60	0.25	¼	2.0	
	70	0.210		2.25	
	80	0.177		2.5	Fine sand
	100	0.149		2.75	
	120	0.125	⅛	3.0	
	140	0.105		3.25	
	170	0.088		3.5	Very fine sand
	200	0.074		3.75	
	230	0.0625	1/16	4.0	
MUD — SILT	270	0.053		4.25	
	325	0.044		4.5	Coarse silt
		0.037		4.75	
		0.031	1/32	5.0	
		0.0156	1/64	6.0	Medium silt
		0.0078	1/128	7.0	Fine silt
		0.0039	1/256	8.0	Very fine silt
MUD — CLAY		0.0020		9.0	
		0.00098		10.0	Clay
		0.00049		11.0	
		0.00024		12.0	
		0.00012		13.0	
		0.00006		14.0	

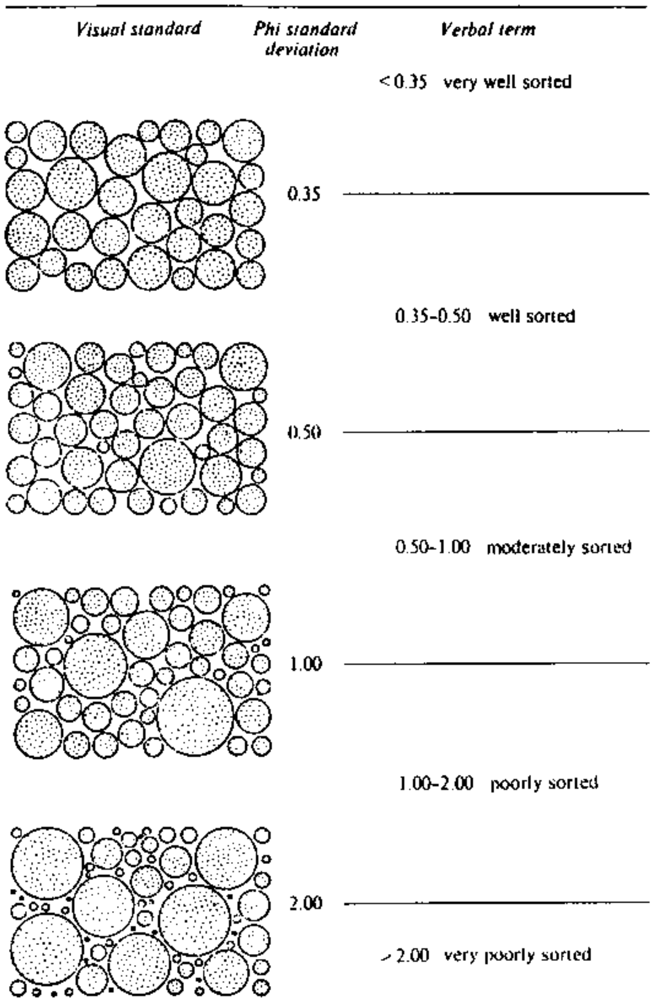


Figure 6.4 Chart for the field estimation of sorting (modified from Folk 1968).

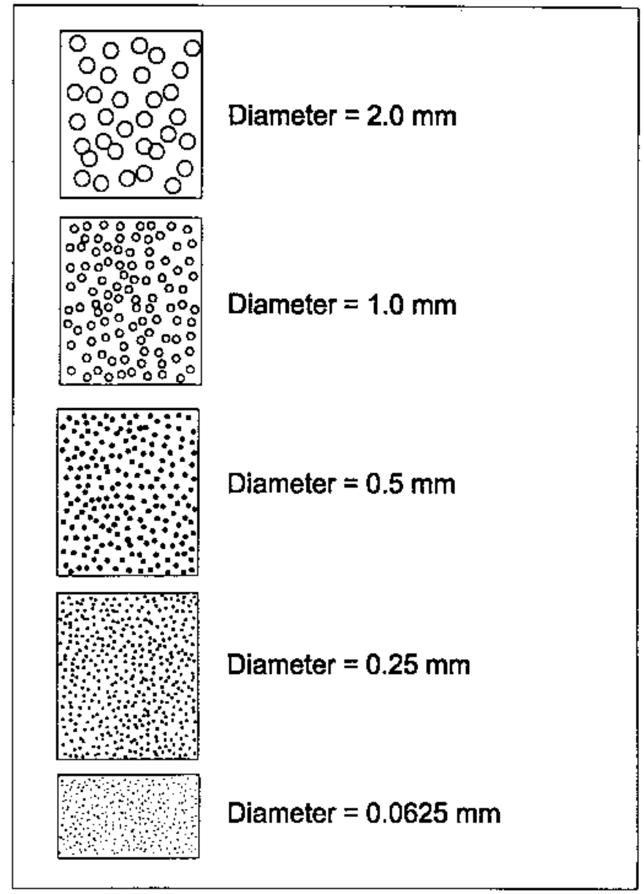
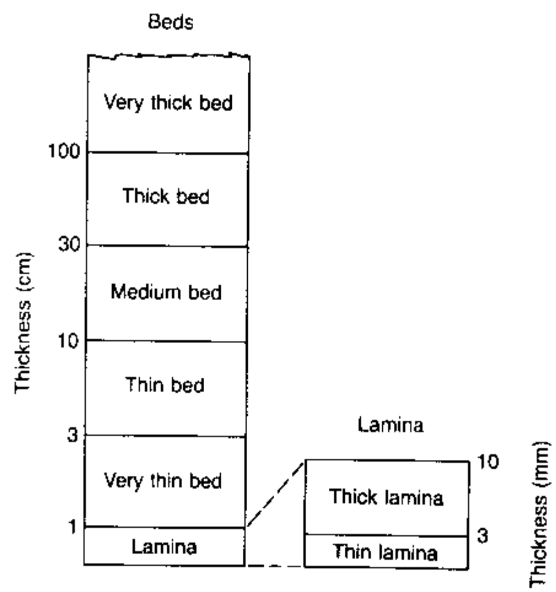


FIGURE 6.1 Terms used for describing the thickness of beds and laminae. (Modified from McKee, E. D., and G. W. Weir, 1953, Terminology for stratification and cross-stratification is sedimentary rocks: Geol. Soc. America Bull., v. 64, Table 2, p. 383; and Ingram, R. L., 1954, Terminology for the thickness of stratification and parting units in sedimentary rocks: Geol. Soc. America Bull., v. 65, Fig. 1, p. 937.)



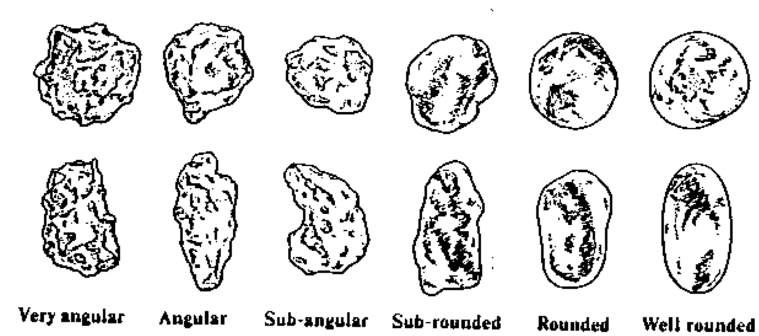


Figure 6.6 Images for the visual assessment of sand grain roundness (based upon Powers 1953).

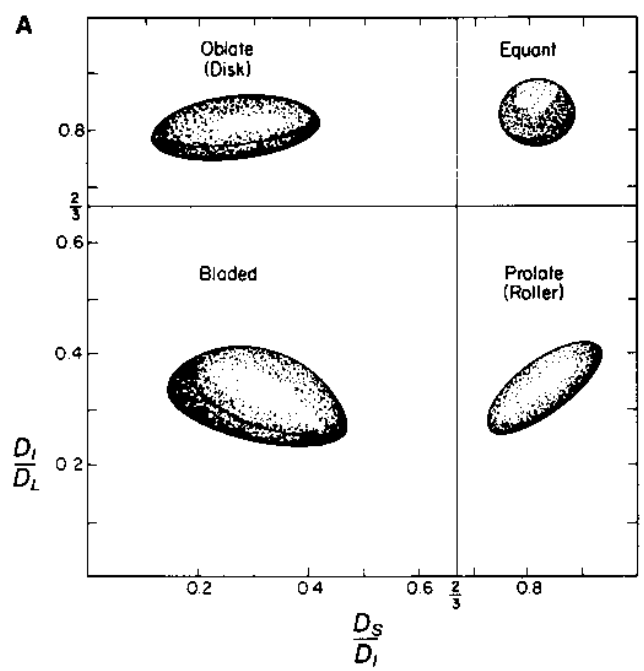
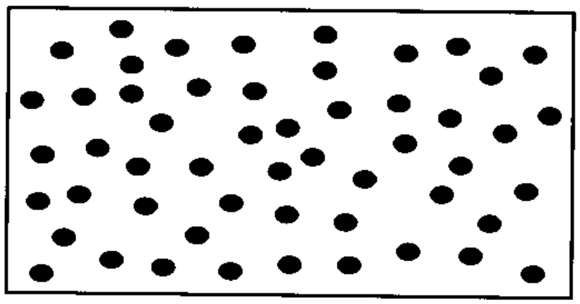


TABLE 5.6 Relation of Powers' verbal rounding classes to Wadell roundness and Folk's rho (ρ) scale

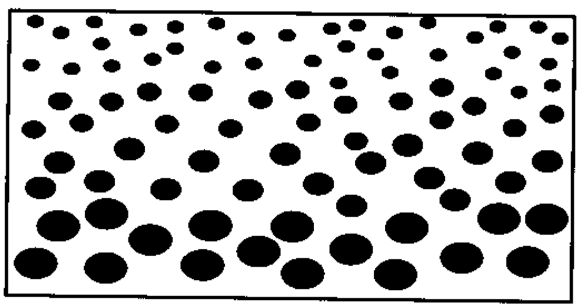
Powers verbal class	Corresponding Wadell class interval	Folk's rho (ρ) scale
Very angular	0.12–0.17	0.00–1.00
Angular	0.17–0.25	1.00–2.00
Subangular	0.25–0.35	2.00–3.00
Subrounded	0.35–0.49	3.00–4.00
Rounded	0.49–0.70	4.00–5.00
Well rounded	0.70–1.0	5.00–6.00

Source: Powers, M. C., 1953, A new roundness scale for sedimentary particles: Jour. Sedimentary Petrology, v. 23, p. 117–119. Folk, R. L., 1955, Student operator error in determination of roundness, sphericity, and grain size: Jour. Sedimentary Petrology, v. 25, p. 297–301.

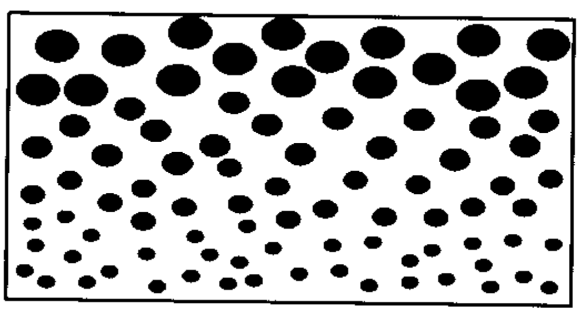
Styles of Vertical Grain Size Grading
in Sedimentary Deposits



Massive (Ungraded)



Normal Grading
(Fining Upwards)



Reverse Grading
(Coarsening Upwards)

PART 6C: SEDIMENTARY STRUCTURES AND ENVIRONMENTS

A variety of structures occur in sedimentary rocks (Figure 6.11). Some form by purely physical processes, and others form as a result of the activities of plants or animals. Therefore, the specific kinds of sedimentary structures can be used as indicators of environments where they normally form today.

Sedimentary Structures

One of the most obvious sedimentary structures is layering of sediments. Most layers of sediment, or **strata** (plural of *stratum*, a single layer), accumulate in nearly horizontal sheets. Strata less than 1 cm thick are called *laminations*; strata 1 cm or more thick are called *beds* (see Figure 6.11).

Surfaces between strata are called **bedding planes.** These represent surfaces of exposure that occurred between sedimentary depositional events. To illustrate, imagine a series of storms, each of which causes sediment to be deposited in puddles. Each storm is a sedimentary depositional event. Between storms, deposition stops, and the surface of the sediment in the puddles (bedding plane surface) becomes exposed to the sorting action of water in the puddles or to the processes of weathering as dry surfaces after the puddles evaporate.

Most strata are deposited in nearly horizontal sheets. However, some stratification is inclined and is referred to as **cross-stratification** or **cross-bedding** (see Figure 6.11). Sediment transported in a single direction by water or air currents commonly forms **current ripple marks** or sand dunes. Sediment transported by back-and-forth water motions or very gentle waves skimming the bottom of a lake or ocean commonly forms **oscillatory ripple marks** (Figure 6.11). Both types of ripple marks are internally cross-stratified, and the cross-strata are inclined in the direction of water/air flow. This information is useful for interpreting the kinds of environments in which the strata formed. For example, cross-strata inclined in just one general direction indicate flow of air or water in just one direction (downstream or downwind). If a sequence of cross-strata is inclined in opposite directions (**bimodal cross-bedding** in Figure 6.11), then the environment in which the sequence formed must have water/wind that changed direction back and forth. An example would be water currents associated with tides.

Individual strata also may be **graded** (Figure 6.11). Normally, graded beds are sorted from coarse at the bottom to fine at the top. This feature is caused when sediment-laden currents suddenly slow as they enter a standing body of water, or as current flow terminates abruptly.

Flutes (Figure 6.11) are scoop-shaped or V-shaped depressions scoured into a sediment surface by the erosional, winnowing action of currents. Natural casts of flutes are called **flute casts.** Flutes and flute casts indicate current direction, because they flare out (widen) in the down-current direction.

Many sedimentary rocks also contain structures that formed shortly after deposition of the sediments that compose them. For example, **mudcracks** often form while moist deposits of mud dry and shrink, and **raindrop impressions** may form on terrestrial (land) surfaces (Figure 6.11). Animals make tracks, trails, and burrows (Figure 6.11) that can be preserved in sedimentary rocks. Such traces of former life are called **trace fossils.**

Sedimentary Environments

Sediments are deposited in many different environments. Some of these environments are illustrated in Figure 6.12. 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 can be used to infer what ancient environments (**paleoenvironments**) were like in comparison to modern ones.

Questions

7. Complete the questions in Figure 6.13.

8. Complete the questions in Figure 6.14.

9. Complete the questions in Figure 6.15.

PART 6D: INTERPRETATION OF A STRATIGRAPHIC SEQUENCE

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.

SEDIMENTARY STRUCTURES

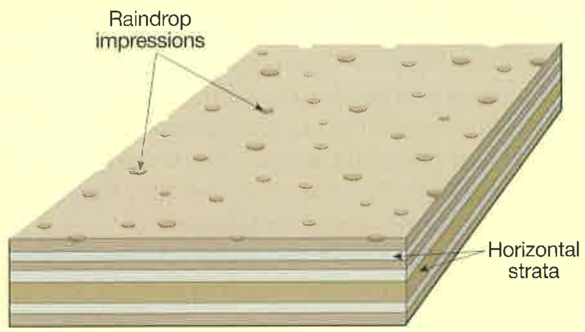
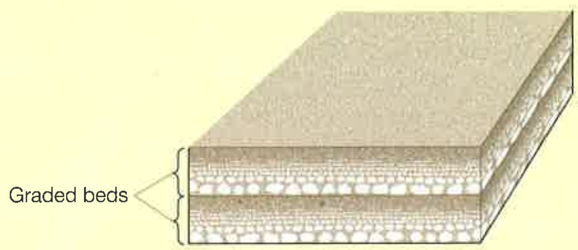
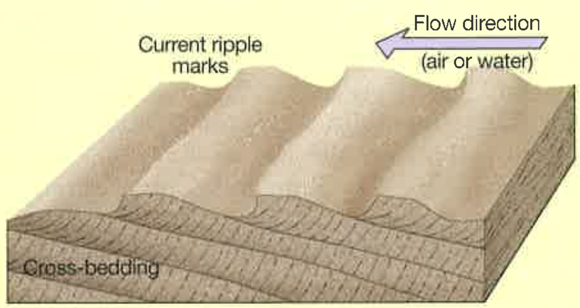
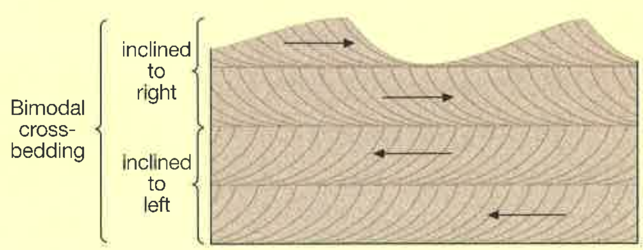
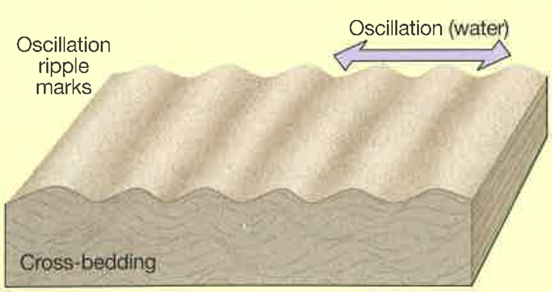
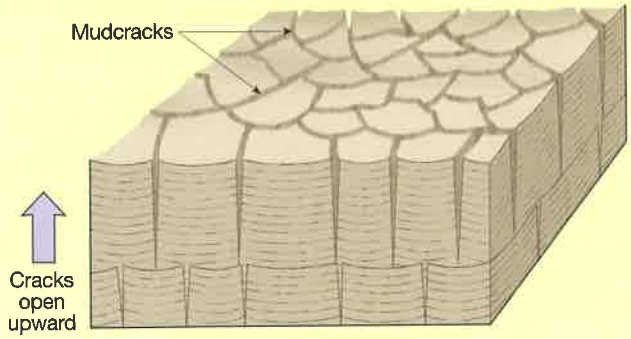
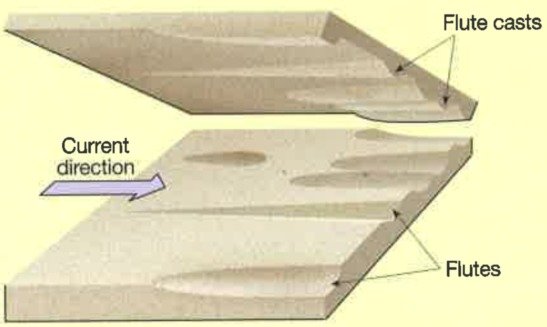
ILLUSTRATIONS	DESCRIPTIONS	ENVIRONMENTS
	**RAINDROP IMPRESSIONS:** Tiny craters formed by raindrops as they impact bedding plane surfaces.	Raindrop impressions *occur on muddy land surfaces.*
	HORIZONTAL STRATA: Relatively flat *beds* (≥ 1cm thick) and *laminations* (< 1cm thick).	Horizontal strata *occur 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 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.*
	**OSCILLATION RIPPLE MARKS:** Symmetrical ripple marks.	Oscillation 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.*

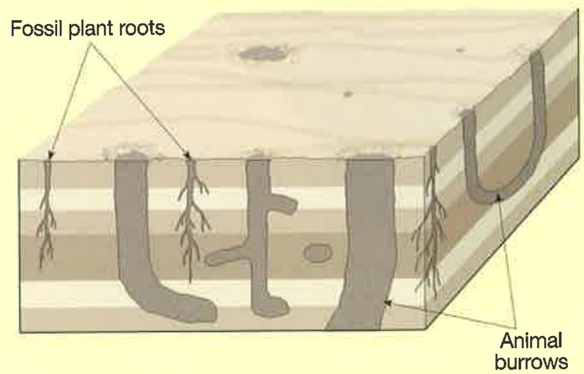
FIGURE 6.11 Sedimentary structures.

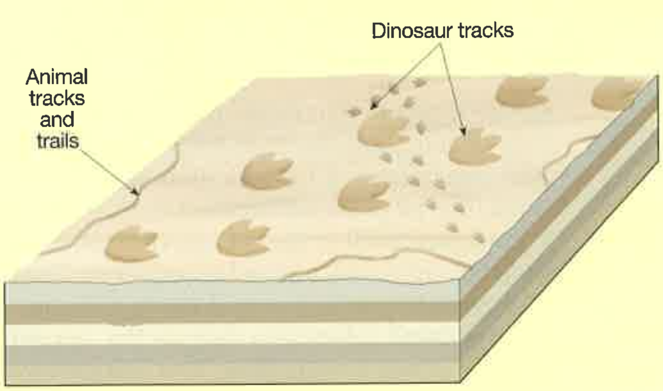
SEDIMENTARY STRUCTURES

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 6.11 (CONTINUED)

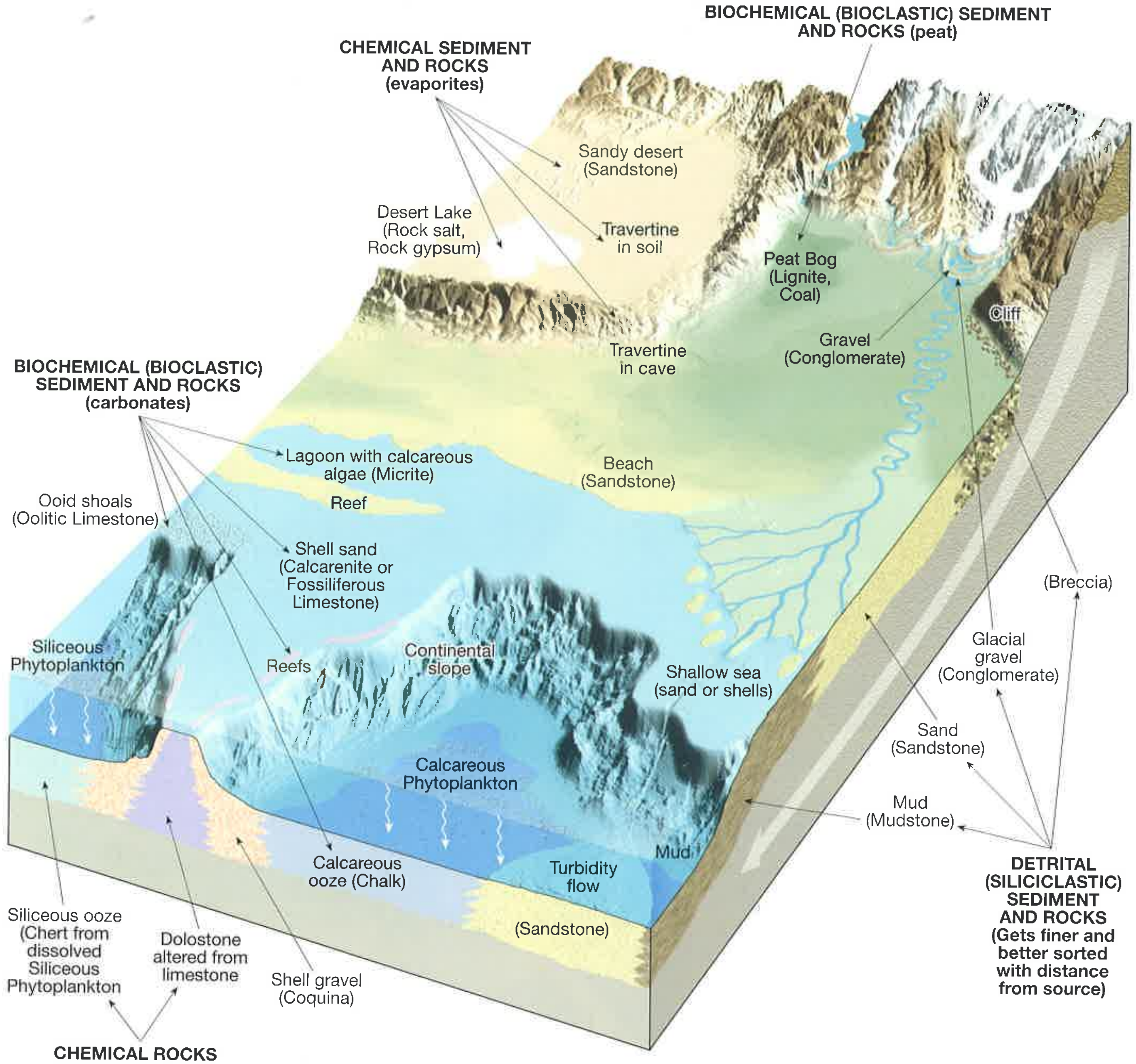


FIGURE 6.12 Some named modern environments where sediments and sedimentary rocks are forming now.

A succession of rock strata or 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.

Question

10. A stratigraphic sequence of Permian rocks (approximately 270 million years old) from northeast Kansas is pictured in Figure 6.16. Close-up pictures of hand samples from the rock units and field descriptions of the rock units are also provided. Use all of the information that is provided in the figure to fill in the paleoenvironment represented by each rock unit in the sequence. Then work from bottom to top, and shade in the narrow righthand columns to indicate the "record of change." When you are done, you will see how environments changed in Kansas over about 400,000 years of the Permian Period.

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
		Tan skeletal limestone with shells of many kinds of marine organisms, bimodal cross-bedding, oscillation ripple marks, animal burrows, flutes, flute casts, and chert.						
		Gray silty mudstone (shale) with animal burrows, fossil clams, fossil plant fragments, and current ripple marks.						
		Red and gray silty mudstone with raindrop impressions, fossil roots, and mudcracks.						
		Gray silty mudstone with abundant gypsum layers and crystals.						
		Tan skeletal limestone with bimodal cross-bedding.						
		Coal	peat bog or swamp				(shaded)	
		Gray silty mudstone with mudcracks and fossil ferns.	Probably moist muddy land where ferns grew; mudcracks formed in dry periods.					(shaded)

FIGURE 6.16 See Question 10. Permian stratigraphic sequence (approximately 270 million years old, exposed along Interstate Route 70 in eastern Kansas) to analyze and evaluate. Write a concise description of the paleoenvironment represented by each rock unit (pink column). Then shade in the narrow Record of Change columns to infer how the environments changed over the time that these sediments were deposited.