CHAPTER

4 Weathering, Erosion, and Deposition

Vocabulary at a Glance

abrasion	horizontal sorting	soil
agent of erosion	humus	soil horizon
bedrock	ice age	solution
chemical weathering	leaching	sorted
deposition	mass movement	stream discharge
discharge	meander	stream velocity
erosion	mass wasting	striation
flotation	outcrop	suspension
frost action	physical weathering	till
frost wedging	precipitate	transported soil
glacial erratic	precipitation	unsorted deposit
glacier	residual soil	vertical sorting
graded bedding	sediment	weathering

WHY DO ROCKS WEATHER?

An **outcrop** is bedrock exposed at Earth's surface. When rocks that formed within Earth's crust are uplifted and exposed to wind, water, and biological processes, their new environment changes them. Rocks change in observable properties and mineral composition. The breakdown of rock due to physical or chemical changes is called **weathering**. See Figure 4-1.

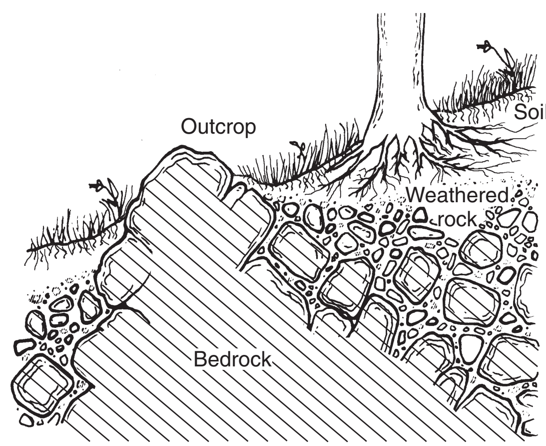


Figure 4-1. Most weathering occurs when rock is exposed to the atmosphere or groundwater. As solid rock is broken apart, weathering usually increases.

Physical Weathering

Physical weathering changes the size and/or shape of a rock without changing the rock's chemical composition. For example, the rock may be broken into smaller pieces. **Frost action** (**frost wedging**) is an important agent of physical weathering in climates that have seasonal temperature changes. In these areas the temperature is alternately above and below the freezing temperature of water, 0°C. In weathering by frost action, water seeps into cracks in rocks. As the water freezes, its volume increases. The increase in volume makes the cracks in the rock a little larger each time the water freezes. When the ice melts and the resulting liquid water evaporates, the rock is left more open than before. Over time, the freezing and melting of water in the cracks causes the rock to break apart.

Plant roots that grow in the cracks of rocks and animals that burrow beneath the ground are also agents of physical weathering. As a plant grows, its roots invade the crevices of a rock and hold them open. When animals burrow, they expose new rock surfaces to weathering.

When flowing water in a stream carries rock particles, the particles bump and rub against one another and the streambed. These collisions wear down the particles by **abrasion**, a form of physical weathering. Wind also causes particles of sediment to abrade exposed rock surfaces. Moving ice in glaciers drags, scrapes, and breaks rocks apart. Wave action constantly attacks rocks and sediment along shorelines. Even gravity alone can cause rocks to fall and break. There are five major natural agents of abrasion: flowing water, moving ice, waves, wind, and gravity.

Some rock-forming minerals are harder than others. Quartz (silica) and feldspars resist physical weathering. However, softer minerals, such as mica and clay, are quickly broken by physical weathering.

Chemical Weathering

Deep within Earth's crust, most minerals remain stable. However, when these rocks are uplifted and exposed to the atmosphere and hydrosphere, they often undergo chemical weathering. **Chemical weathering** changes the mineral composition of rock, forming new substances. The greater the exposed surface area, the faster the rate of chemical weathering.

The rusting of iron is an example of chemical weathering. Iron rusts in the presence of oxygen and water. The iron atoms combine with oxygen atoms to form rust (iron oxide). When feldspar is uplifted to Earth's surface, it weathers to clay. Figure 4-2 shows that as granite weathers, the percentage of feldspar in a sample eventually decreases dramatically. The original minerals are replaced mostly by clay and iron oxide.

Chemical weathering usually requires water to bring about mineral changes. Heat also speeds most chemical weathering. Thus, chemical weathering takes place most rapidly in warm, moist climates. See Figure 4-3.

Some minerals resist chemical weathering better than others. Quartz, a common mineral in

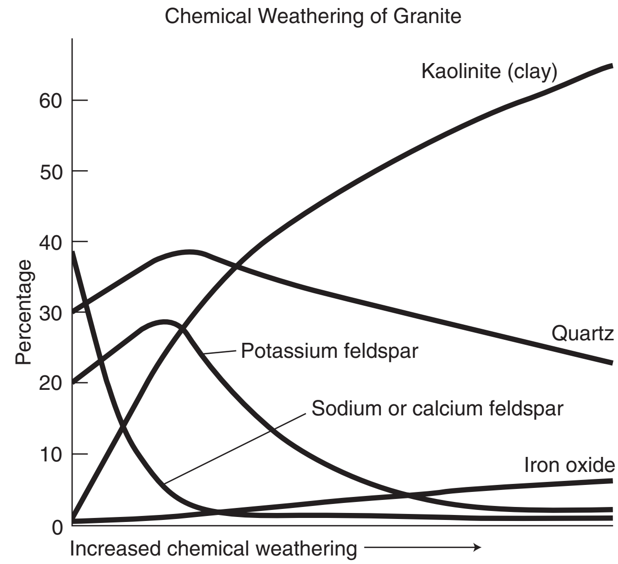


Figure 4-2. As granite weathers, the amount of the feldspars decreases as the amount of clay minerals and iron oxide increases.

beach sand, is relatively stable and resistant to chemical weathering. However, olivine, a mineral that is common deep within Earth, quickly weathers to clay when it is exposed to the atmosphere and hydrosphere. For this reason, quartz is very common in sediments but olivine is rarely found in exposed sedimentary bedrock. Limestone is a fairly hard rock that resists physical weathering; but its calcite is decomposed by

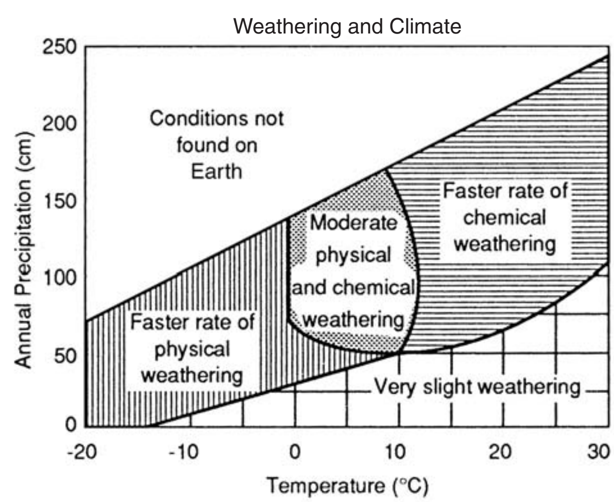


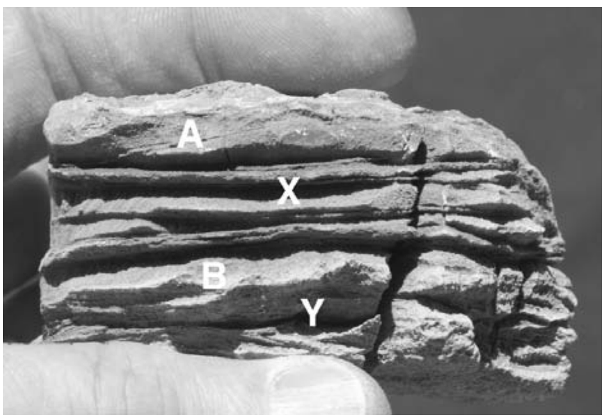
Figure 4-3. The type of rock weathering largely depends on the local climate. In general, chemical weathering dominates in warm moist climates, while cooler climates favor physical weathering (especially frost action).

exposure to acids. Rainwater absorbs carbon dioxide from the atmosphere and organic acids from soil to become slightly acidic. Atmospheric pollutants, such as the oxides of sulfur and nitrogen, can make rainwater unnaturally acidic. When limestone is exposed to these acids, the acids react with the calcite in the limestone. The product of the reaction is soluble in water and is carried away by water.

QUESTIONS

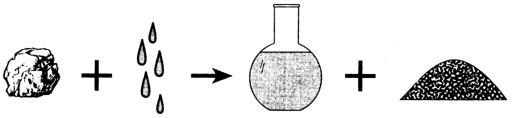
Part A

1. Chemical weathering is most active is a climate that is (1) warm and dry (2) warm and moist (3) cold and dry (4) cold and moist
2. If you leave a bottle of water outside on a cold winter night, the water may freeze, causing the bottle to break. This is an example of (1) physical weathering (2) chemical weathering (3) water erosion (4) ice erosion
3. The rock below was exposed at Earth's surface for a long time. What caused layers *A* and *B* to be different from layers *X* and *Y*?



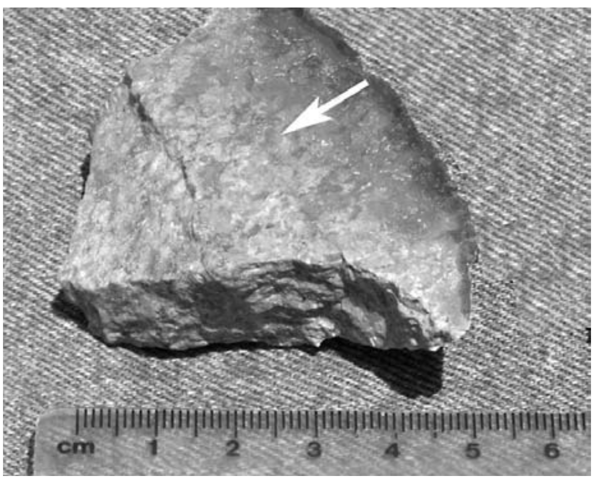
(1) Layers *A* and *B* were more exposed to the elements than layers *X* and *Y* (2) Layers *A* and *B* are composed of minerals with lower numbers on Mohs scale. (3) Layers *A* and *B* have less mineral cement than and are softer than layers *X* and *Y*. (4) Layers *A* and *B* contain minerals more resistant to weathering than layers X and *Y*.

4. Which property probably has the *least* effect on the rate at which a rock weathers? (1) how long it is exposed to the atmosphere (2) the average density of its minerals (3) the hardness of the minerals (4) how much surface is exposed
5. What is the most common form of weathering at high-latitude and high-altitude locations? (1) frost action (2) chemical weathering (3) mineral changes (4) solution in water
6. An iron nail will rust when it is left outside. What type of weathering is this? (1) frost wedging (2) rock abrasion (3) physical weathering (4) chemical weathering
7. What natural process is best represented by the diagram below?



(1) frost wedging (2) rock abrasion (3) physical weathering (4) chemical weathering

8. A student broke the piece of rock shown below from a much larger rock. The arrow points from what was the outer surface of the large rock toward the former inside. The change in color by the arrow shows a form of weathering similar to



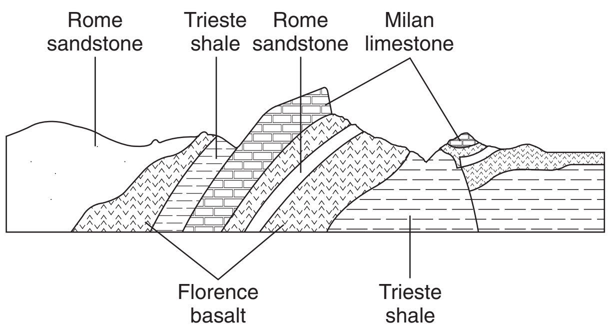
(1) water expanding when it freezes to break a metal pipe (2) a rock being rolled along the bottom of a fast-moving stream (3) the body of a car decomposing due to exposure to salt and water (4) very small par-

ticles of sediment blown around due to strong winds

9. In moist climates where temperatures alternate between warm days well above 0°C and cold nights well below 0°C, why do rocks break apart? (1) Cooling causes rocks to expand. (2) Frost forms when ice melts. (3) water expands when it freezes (4) water boils and contracts at 100° C

Part B

10. The diagram below represents a cross-sectional profile of a particular location.



Which rock type appears to best resist weathering and erosion? (1) Rome sandstone (2) Florence basalt (3) Milan limestone (4) Trieste shale

Base your answers to questions 11 through 16 on the following data table. The data are the results of an experiment in which a student shook, one type at a time, 200 grams of four types of different rocks mixed with water. The rocks were shaken with equal energy for a total of 30 minutes.

Mass of Rock Sample Remaining (g)

Rock-Shaking Time (min)	Shale	Marble	Rock Salt	Limestone
0	200	200	200	200
5	160	200	120	200
10	125	200	60	195
15	100	190	20	170
20	75	180	0	150
25	55	175	0	135
30	50	175	0	125

11. Which best explains why the mass of each rock sample remaining after 30 minutes of shaking was different? (1) Each rock was in a different container. (2) Some rocks had more initial mass than others. (3) Some rocks were shaken longer than others (4) Each rock had a different composition.

12. How did the amount of shale change through time? (1) The mass increased, but it increased most quickly at the beginning. (2) The mass increased, but it increased most quickly at the end. (3) The mass decreased, but it decreased most quickly at the beginning. (4) The mass decreased, but it decreased most quickly at the end.

13. Which rock type was most easily weathered by abrasion? (1) shale (2) marble (3) rock salt (4) limestone

14. What percent of shale remained after 30 minutes? (1) 10% (2) 25% (3) 50% (4) 100%

15. This experiment was an investigation of rock (1) weathering (2) transportation (3) erosion (4) foliation

16. Compared to the original samples, how would the appearance of rock particles have changed? The rock particles remaining would be (1) more angular (2) larger (3) more rounded (4) softer

17. In which month is physical weathering likely to be especially active and chemical weathering relatively inactive in New York State? (1) January (2) April (3) July (4) October

HOW DO SOILS FORM?

Soil is the mixture of weathered rock, microorganisms, and organic remains that usually covers bedrock. The texture of a soil depends on the size of the particles it contains. Clay-rich soils tend to feel smooth. Soils rich in sand are more likely to feel gritty. The composition of a soil depends on the rocks from which it weathered and the local climate. Under natural conditions, biological, physical, and chemical weathering processes are usually involved in the development of soils.

Physical weathering breaks solid rock into small particles. Chemical weathering changes the minerals, often increasing the clay content. Plants and animals add organic materials in the form of waste products and the remains of dead organisms. The decay of organic remains produces organic acids, which speed chemical weathering. Burrowing animals, such as earthworms, insects, and rodents, help air and water circulate through the soil and mix mineral and organic matter. Figure 4-4 shows how soil can be classified by texture. In addition to their mineral content, soils contain air, water, and organic matter in highly variable percentages. The local climate is an important factor in determining this. For example, a bog soil in a moist climate can be nearly all organic matter and water.

The slow formation of soil in place produces layers known as **soil horizons**. When soil remains where it formed, it is a **residual soil**. See Figure 4-5. The top layer is usually the best layer for growing crops because it is rich in dark-colored organic matter called **humus**. However, some important minerals may have been transported deeper into the soil by groundwater infiltration (**leaching**). The lowest layer of the soil is usually composed of broken bedrock, which may merge into solid bedrock. **Bedrock** is the solid layer of rock beneath the soil horizons.

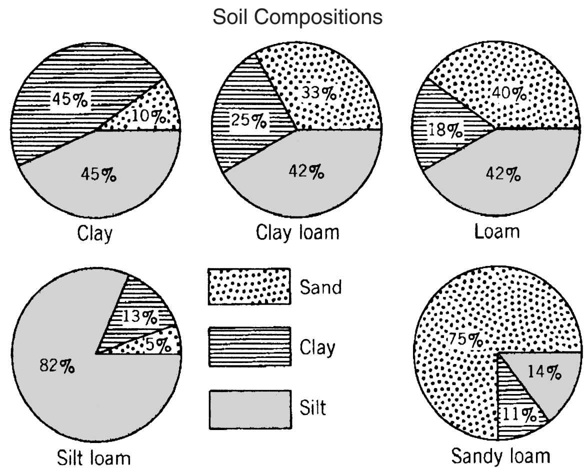


Figure 4-4. Soils can be classified according to their content of sand, silt, and clay-size particles. Each pie graph is labeled by soil type.

Most of the soils of New York State do not show the complete development of horizons. Continental glaciers from the north repeatedly covered the area that became New York. These glaciers stripped the soils from where they originally formed and moved them southward to become **transported soils**. The most recent withdrawal of continental ice sheets was only about 10,000 to 20,000 years ago. As a result, the lowest soil horizon (broken bedrock) is generally missing, and weathered soil often sits directly on top of a hard, smoothed bedrock surface as you can see in Figure 4-6 on page 100.

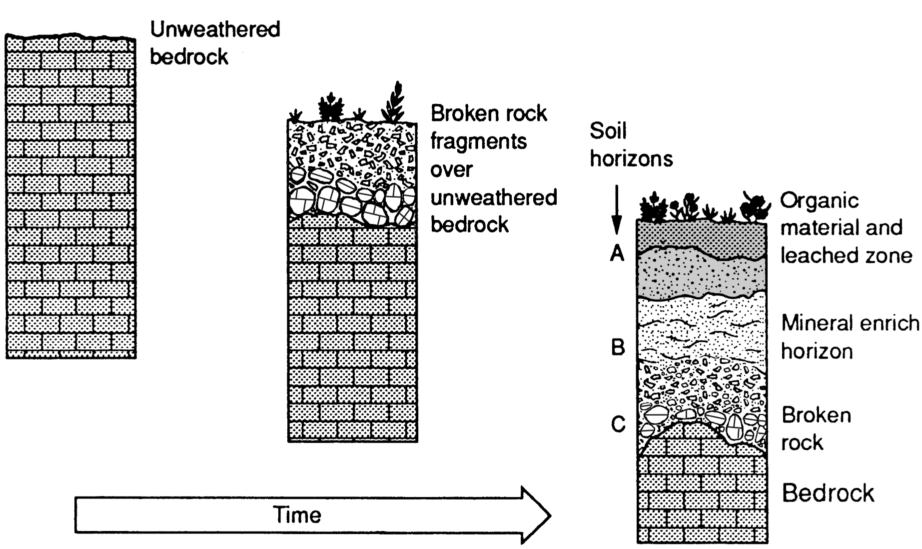


Figure 4-5. Weathering, leaching, and organic processes gradually change exposed bedrock into mature soil. These processes produce layers known as soil horizons.

Figure 4-6. In some New York State locations, glaciers have scraped away the soil and there has not been enough weathering and time for new soil to form.

Protecting the Soil

Soil is a resource that must be protected. It may take hundreds of years for just 1 centimeter of topsoil to form. Human technology has contributed to the loss of soil. For example, construction and mining projects have moved great amounts of rock and soil from their original locations. Destruction of plant cover and poor farming and forestry practices have left soil exposed and unprotected. Running water and wind quickly carry away the exposed soil.

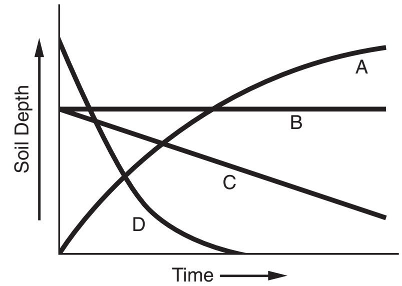
Salt used to remove ice from roads in winter is washed into the soil at the side of the road. If the concentration of salt in the soil is high enough, plants will not grow there. Without plants to hold the sediments in place, erosion can rapidly carry away the soil.

QUESTIONS

Part A

18. In many parts of western New York State, the local bedrock is the sedimentary rock shale. Yet, metamorphic minerals such as garnet are sometimes found in the soils of these areas. What do these exotic minerals tell us about the soils of New York State? (1) Shale can also be a metamorphic rock. (2) Some soils are the result of frequent meteor impacts. (3) The soils of these areas were transported from the north. (4) Physical weathering has turned clay into garnet.

19. The graph above shows four possible lines on a single set of axes. Which line best shows how the depth of a soil depends upon how long it has been forming?



(1) *A* (2) *B* (3) *C* (4) *D*

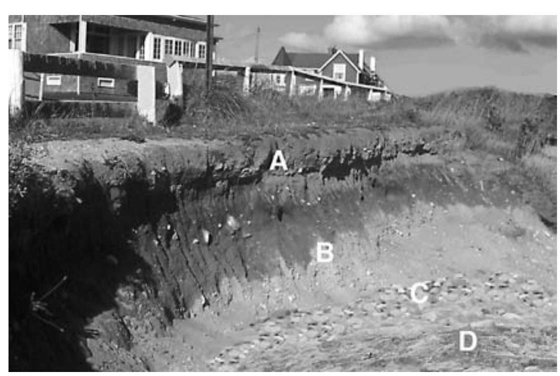
20. The composition of a soil that formed in place is primarily a function of (1) the elevation above sea level (2) the average annual temperature (3) the minerals in the bedrock (4) the age of the bedrock

21. Most plants grow best in a soil that is composed of (1) solid bedrock (2) only organic material (3) broken up fragments of bedrock (4) weathered rock and organic material

22. Which of the following changes would most likely cause the soils in New York State to become thicker? (1) frequent floods (2) dryer conditions (3) increased biological activity (4) longer winters with little snowfall

PART B

Base your answers to questions 23 and 24 on the photo below, which shows a soil profile exposed by beach erosion along a rocky shoreline. Unlike layers A, B, and C, layer D is solid bedrock.



23. Which layer in this profile has the greatest percentage of organic content? (1) *A* (2) *B* (3) *C* (4) *D*

24. How did this soil originate? (1) erosion of organic materials (2) weathering and biological activity (3) melting followed by crystallization (4) changed caused by heat and pressure deep within Earth

HOW ARE WEATHERED MATERIALS TRANSPORTED?

Rocks that have been broken into fragments, regardless of their size, are called **sediments**. The mineral composition or other characteristics of sediments may be unrelated to the properties of the underlying bedrock. In such a case, the sediments must have formed elsewhere and then been transported from their place of origin. **Erosion** is the transportation of sediments most often by water, wind, or glaciers—the **agents of erosion**. These sediments are deposited in a different location.

The force of gravity drives most forms of erosion. For example, weathering weakens a rock on a cliff. Gravity causes the weakened rock to fall to the bottom of the cliff. Piles of talus (broken rock) accumulate at the bottom of a cliff. Continued erosion, perhaps helped by wind or water, moves the sediment downslope, away from the cliff.

Erosion by Gravity Acting Alone

Have you ever seen rock debris that has fallen onto a road or to the bottom of a cliff as in Figure 4-7? The downhill movement of rock or sediment without being carried by water, wind, or ice is known as **mass movement**, or **mass wasting**. Material can slide, flow, or fall to its resting place. Although the sediment is not really carried by water, water in the sediment can act as a lubricating agent that makes mass movement more likely. Alternate freezing and thawing also accelerates this process. Mass movement includes *slow creep*, *slumping*, *landslides*, and even the falling of individual rocks.

Erosion by Water

Each year, the streams and rivers of the world carry millions of tons of sediment downstream and into the oceans. Running water, the main agent of erosion in moist areas, transports sediments in several ways. The smallest particles

Figure 4-7. This pile of rocks is the result of mass movement of the weathered rock of this cliff.

(ions) are carried in solution. **Solution** particles are so small they cannot be filtered out of the water. Sediments in suspension can be filtered out of the water. However, particles in **suspension** are too small to settle on their own. The flowing water rolls or bounces the largest and most dense particles along the streambed. Particles of low density, especially organic matter, are carried along the surface by **flotation**.

The relationship of the size of the transported particle to water velocity is shown in Figure 4-8. The graph shows that the water velocity needed

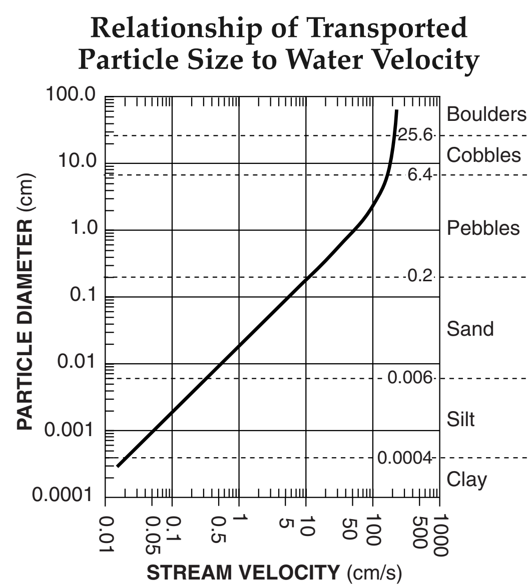


Figure 4-8. There is a direct relationship between the velocity of a stream and the size of the particles it can transport. This generalized graph shows the water velocity needed to maintain, but not start, movement of particles. This graph can be found on page 6 of the *Earth Science Reference Tables*.

to transport particles of sediment depends on the size of the mineral and rock particles. Particles in solution and suspension can be carried by slow-moving water. However, particles rolled along the bottom of the stream require faster stream velocities to move them. A convenient method to estimate the velocity of a stream is to observe the size of the sediment particles that have been carried along the bottom of the stream. Faster streams contain larger particles of sediment. Slow-moving streams can transport only the smaller particles of sediment.

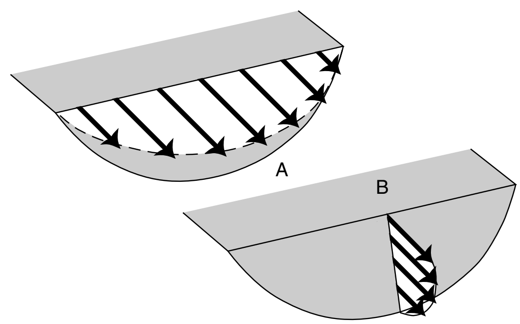


Figure 4-9. Gravity pulling water downhill and friction with the banks of the stream, the streambed, and even with the air determine the velocity of a stream. Therefore streams have the greatest velocity near the center of the stream, just below the surface.

Velocity of Streams Although the term "velocity" often includes both speed and direction, "**stream velocity**" will be used here as a synonym of stream speed. The slope (*gradient*) and the amount of water flowing in the stream (or **stream discharge**) control the stream's velocity. As the stream gradient increases, so does the velocity of the water flowing in the stream. Velocity is also increased by an increase in the amount of water flowing in the stream. Most of the erosion caused by running water takes place when streams are in flood stage. Flooding causes an increase in both the amount of water and the velocity of the water. Therefore, it usually takes a flood to move large boulders.

The speed of a stream is a balance between the force of gravity pulling the water downhill and the frictional forces slowing the stream. Water usually flows fastest near the center of the stream away from the stream banks and the streambed. There is even a small amount of friction with the air above the water. Therefore, the fastest flow is commonly found at midstream just below the water's surface as shown in Figure 4-9.

Streams with broad, flat valleys often develop S-shaped curves called **meanders**. At a bend in a stream, the fastest-flowing water swings to the outside of the bend, causing erosion along the outer bank of the meander. The slowest-moving water stays to the inside of the bend, causing deposition along the inner bank of the meander. Figure 4-10 shows where streams generally flow fastest in meanders.

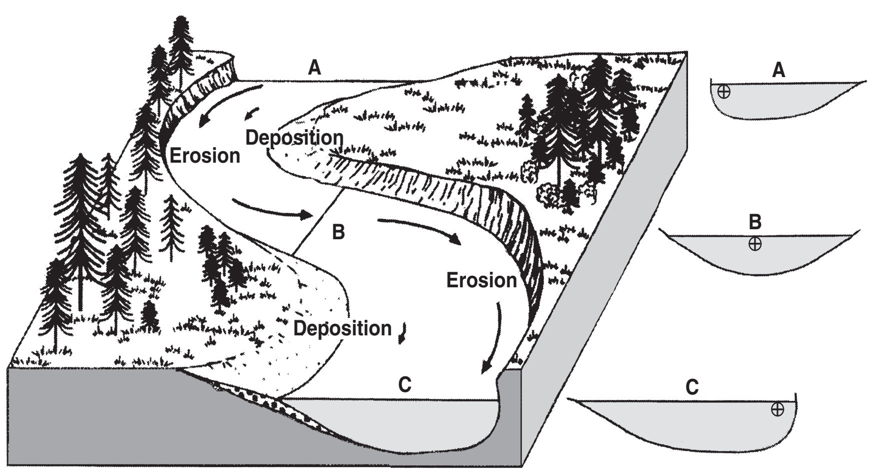


Figure 4-10. When a stream flows around a meander, or bend, the fastest current swings to the outside of the bend as shown by the longer arrows. The circles in the cross sections at A, B, and C also show there the current is fastest. Note that the stream is deepest where the current flows fastest. Therefore, erosion usually occurs on the outside banks of the meanders, while deposition takes place where the water moves slower on the inside banks. This is the way streams change their courses.

Erosion by Wind

Another agent of erosion is wind. It can pick up loose rock materials, such as sand, silt, and clay, and carry them away. Wind erosion occurs mainly in areas, such as deserts and beaches, where there is little plant life to hold soil in place.

You might think that wind is the dominant agent of erosion in desert regions such as the American Southwest. In fact, isolated areas where wind erosion is active can be found throughout the United States. But the infrequent thunderstorms that occur in most desert areas actually cause far more erosion than wind.

Erosion by Ice

During the winter, most of North America receives precipitation as snow. In most places, the snow melts long before the following winter. However, if more snow were to accumulate in the winter than melted in the summer, the snow on the bottom would turn to ice. This is most likely to occur in the Polar Regions and at high altitude. When the ice became thick enough, its weight would cause it to move under the pull of gravity.

A **glacier** is a large mass of slowly flowing ice. As a glacier moves, it carries, pushes, and drags loose rock material. The glacier, with pieces of rock embedded in its ice, acts like a huge abrasion system. It smoothes, striates (scratches), and grooves bedrock. When the ice melts, unsorted rocks and boulders are left scattered around on hilltops and the sides of valleys.

A continental glacier deepens and widens valleys parallel to its movement. It grinds down the hills, leaving them polished and rounded. As a valley glacier moves, it scours away the rock to make a U-shaped glacial valley in which the valley walls may be nearly vertical. Valleys eroded by streams are more often V-shaped with narrow valley floors. Figure 4-11 shows the erosion caused by valley glaciers.

In some ways, valley glaciers are like streams and rivers, but glaciers move much more slowly. The ice may move forward less than 1 meter (3 feet) a day. However, like the water in streams, the ice in a valley glacier moves the fastest near the center of the flowing ice.

Figure 4-11. The top photo shows a typical stream-eroded landscape with a V-shaped valley. If such a landscape were covered by a glacier, such shown in the center photo, the glacier would carve the valley into broader, U-shape. The bottom image is a glacier-eroded U-shaped valley in the western Finger Lakes region of New York State.

Characteristic Changes Caused by Agents of Erosion

Each agent of erosion causes characteristic changes in particles of sediment that can give us clues to how the material was transported. Rough and angular particles deposited at the base of a cliff usually indicate that gravity alone is responsible for transporting the rock a short distance. In this case, the rock particles often have freshly exposed surfaces, as well as older surfaces that are more weathered. Sedimentary particles carried by a stream are usually rounded and polished because the current tumbled them about in the stream. A rock exposed to the wind will develop a smooth flat surface where the wind and wind-blown sand hit it. As wind direction changes and different surfaces are exposed to wind erosion, the rock develops smooth, flat surfaces, or facets, with distinct edges. These angular rocks are called *ventifacts*. Wind-worn rocks are often pitted where softer minerals have been scoured by the wind. Rocks transported by a glacier are usually partially rounded by abrasion and are often scratched (striated) on some faces as a result of being dragged along the bottom of the glacier. See Figure 4-12.

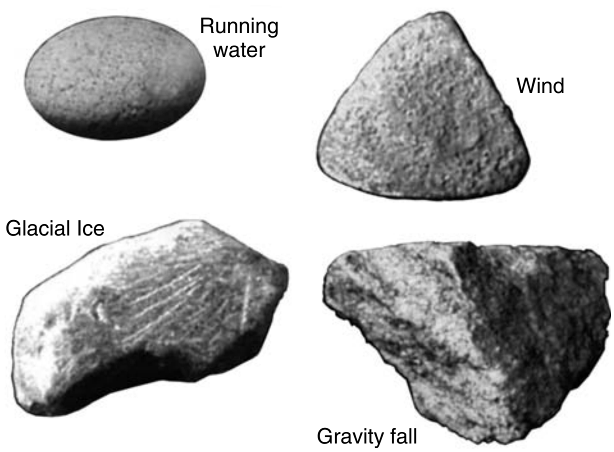


Figure 4-12. Each agent of erosion produces a characteristic shape and texture in rocks. Rocks tumbled in running water are round and smooth. Glacial rocks are often partly rounded with scratches (striations). Wind-eroded rocks (ventifacts) are smooth and angular with pitted surfaces. Talus rocks (from rock falls) are rough and angular and may show some fresh and some weathered surfaces.

QUESTIONS

Part A

25. What is the minimum rate of flow at which water can usually keep pebbles 1.0 centimeter in diameter moving downstream? (1) 50 cm/s (2) 100 cm/s (3) 150 cm/s (4) 200 cm/s

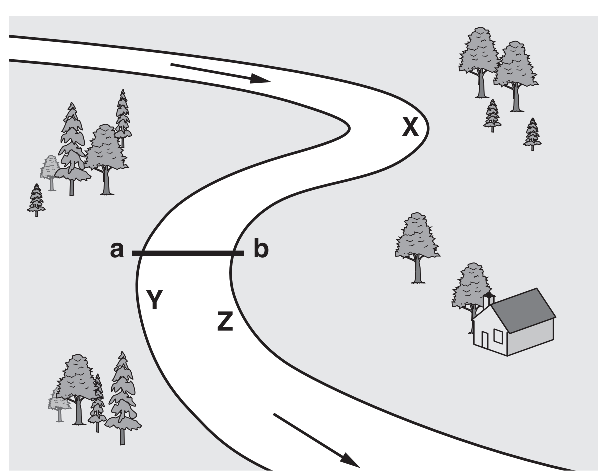
26. Which movement of Earth materials is *not* driven by the force of gravity? (1) rocks pushed and carried by a glacier (2) dissolved salt carried by a large river (3) broken rock that falls to the bottom of a cliff (4) water evaporating into the atmosphere

27. The photo below shows five natural rocks, including igneous, sedimentary, and metamorphic rocks. What do all five rocks appear to have in common?

(1) They have the same mineral composition. (2) They formed by the same geological processes. (3) They were eroded by abrasion in a stream. (4) They have the same hardness and density.

28. Which term below means almost the same as erosion? (1) weathering (2) transportation (3) chemical change (4) gravitational force

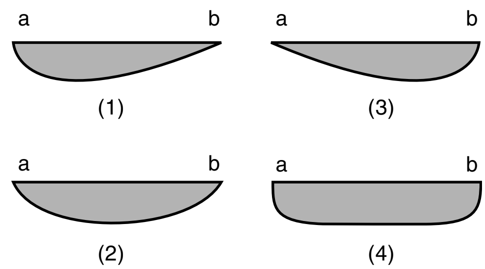
Base your answers to questions 29 through 32 on the diagram below, which represents a meandering river. Neither the gradient nor the stream volume changes within this part of the river. Arrows show the general direction in which the water is flowing.



29. At which letters is deposition most likely taking place? (1) X, only (2) Y, only (3) Z, only (4) X and Y, but not Z

30. Where is the stream most likely flowing the fastest? (1) X, only (2) Y, only (3) Z only (4) X and Y, but not Z.

31. Which figure below best represents a cross section of the river along line *a–b*?



32. The photo below shows a bend in the Susquehanna River near Oneonta in central New York State. What letter on the stream diagram on page 104 best represents the position that the arrow is pointing to?

(1) X, only (2) Y, only (3) Z, only (4) X and Y, but not Z.

33. An observer notes that in a particular part of a stream, the water transports clay, silt, sand, pebbles and cobbles, but not boulders. What is the approximate stream velocity? (1) 50 cm/sc (2) 100 cm/s (3) 250 cm/s (4) 400 cm/s

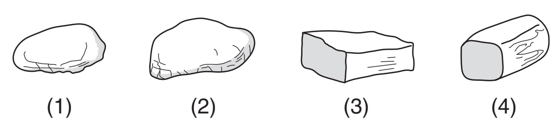
34. The photo above shows two rocks. Each coin in this photo is approximately 1 cm across. How are these rocks best classified?

(1) silt (2) sand (3) pebbles (4) cobbles

35. What change is most likely to cause a river to flow faster? (1) an increase in discharge (2) a decrease in gradient (3) temperatures well below freezing (4) an increase in sediment load

Part B

36. The rock particles in the diagram below were nearly the same shape when they were dropped into a fast-flowing stream. They are all the same kind of rock. They were later taken from the stream at different places downstream. Which rock was recovered from a location closest to where they were dropped into the stream?



37. If a river is flowing at a speed of 50 centimeters per second, what kind of sediments can it transport? (1) silt and sand (2) silt, sand, and pebbles (3) silt, sand, pebbles, and cobbles (4) silt, sand, pebbles, cobbles, and boulders

38. How are particles of sand and pebbles that are less dense than water carried by a stream? (1) by bouncing along the bottom in traction (2) by solution in water (3) by chemical weathering (4) by floating on the surface

WHAT IS DEPOSITION?

When an agent of erosion deposits, or stops transporting, particles of earth materials (sediments), the process is called **deposition**. Deposition is also called *sedimentation*. Agents of erosion, such as gravity, water, ice, and wind, are also agents of deposition.

Factors That Affect Deposition

The rate at which sediments are deposited by water and wind depends on the size, shape, and density of the sediment particles and the speed of the transporting medium.

Particle Size Smaller particles, such as clay and silt, settle more slowly than cobbles and boulders. Very small particles (less than 0.001 millimeter in size) may be held in solution or suspension indefinitely. The smallest particles do not settle out of a water solution unless the solution becomes saturated. For example, in some parts of the Persian Gulf, evaporation leaves the remaining water so rich in salt that the water becomes saturated. This means that it can hold no more salt in solution. If more water evaporates, salt crystallizes and settles to the bottom. The salt crystals that form and settle out of solution are called **precipitates**, and the process is called **precipitation**.

Particle Shape Friction between water and the surfaces of particles slows the settling process. Therefore, flat, angular, and irregularly shaped particles that have more surface area settle more slowly than smooth, rounded particles.

Particle Density Among particles of the same average size and shape, denser particles settle faster, while less dense particles take longer to settle.

Settling Rate and Settling Time There is an inverse relationship between the rate of settling and the settling time. Sediments that settle at a faster rate require less settling time. Thus, as the rate of settling increases, the settling time decreases.

Sorting of Sediments

The velocity of a transporting medium plays a major role in determining when the deposition of particles will occur. Deposition is usually the result of a reduction in the velocity (slowing) of

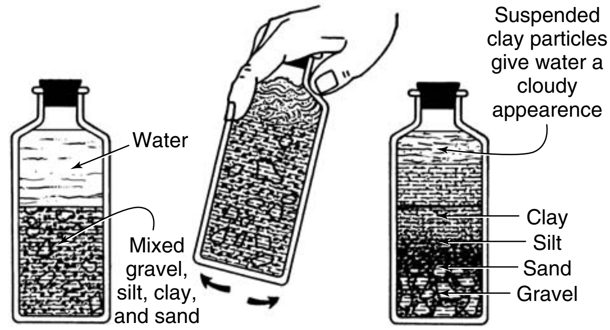


Figure 4-13. When a jar of water and sediments of mixed sizes is shaken, the largest, roundest, and most-dense particles tend to settle to the bottom first. The gradual change in sediment size from bottom to top is known as vertical sorting.

a transporting medium. For example, when a stream enters a large body of water, such as an ocean, the stream's velocity decreases as it mixes with the still water. Particles of sediment begin to settle. The largest, roundest, and densest particles are deposited first near the ocean's shoreline. The smallest, flattest, and least-dense particles are carried farthest from shore. The separation of particles, in this case, is called **horizontal sorting**. Figure 4-14 shows a similar pattern of deposition at the end of a steep canyon where floodwater slows.

When particles settle in calm water, the roundest, largest, and densest particles quickly settle at the bottom of a layer, while the flattest, smallest, and least-dense particles settle later at the top of the same layer. This kind of **vertical sorting** may occur when a landslide suddenly dumps particles of many sizes into still water. Figure 4-13 shows a procedure you can use to watch this process.

A series of depositional events, such as a succession of underwater landslides in deep water, can cause a type of vertical sorting known as **graded bedding**. An abrupt change in the particle size—from coarse sediments upward to very fine sediments—separates one graded bed from another. Each graded bed represents a period of deposition or a single, distinct depositional event, such as one landslide as shown in Figure 4-15.

Deposition by Gravity

When gravity acts alone as the agent of erosion, the sediments deposited are not sorted. Where

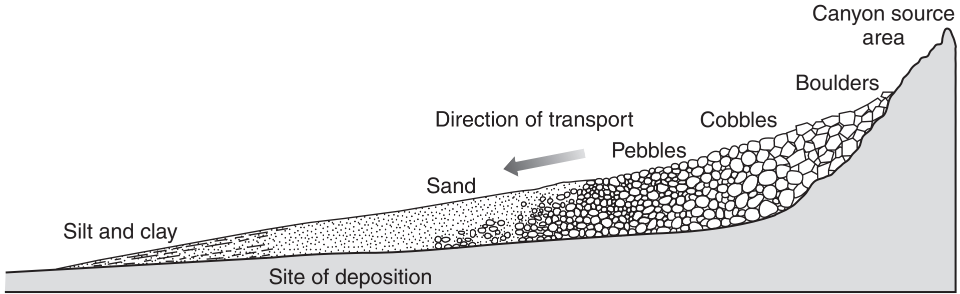


Figure 4-14. Horizontal sorting occurs at the end of a steep canyon. Larger particles are deposited first. The smaller sediments can be carried a greater distance from the end of the canyon. Also notice that the thickness of the sedimentary layer decreases downhill.

pieces of weathered rock have fallen, you will find a talus pile of angular rocks of many different sizes mixed together. Figure 4-12 on page 104 shows characteristics that can help you decide what agent of erosion and deposition has shaped particles of sediment.

Deposition in Water

The size of sediment particles carried by a stream indicates the stream's velocity. Large boulders and cobbles are generally found in the fastest parts of streams. Finer sediments indicate a slower current. As a river slows, it drops some of the sediment it carries. To keep the slower sections of a river deep enough for boats to pass, sediments that accumulate in those sections must be dredged out.

Where a river or stream enters a lake or ocean, the water slows and drops its load of sediment, often in a fan-shaped deposit. This deposit is called a delta because it resembles the Greek letter delta (Δ), an ancestor of our letter D. The land around New Orleans, Louisiana, is a delta deposited by the Mississippi River as it slows upon entering the Gulf of Mexico.

Deposition by Wind

Wind-blown sediments tend to be finer than those deposited by other agents of erosion. Air is less dense than water, so the wind usually does not have enough force to move the largest particles, such as pebbles. You can see hills of wind-blown sand, called dunes, at some beaches as well as in certain desert valleys. Sand is blown up the windward side of the dune and deposited along a steeper slope on the leeward (downwind) side as you can see in Figure 4-16.

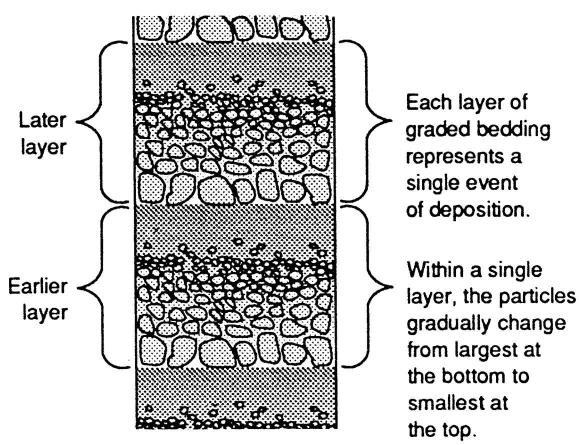


Figure 4-15. Layers of graded bedding represent a series of depositional events each of which shows vertical sorting.

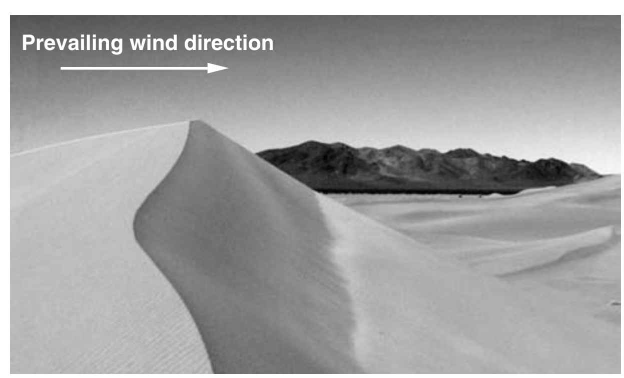


Figure 4-16. In the formation of a sand dune, wind usually carries the sand up the gentler windward slope and drops it on the steeper down-wind slope that is more shielded from the wind. This dune is being formed by winds blowing left to right.

Layers that meet at different angles, a feature known as cross-bedding, are common in sediments deposited by wind. Most desert areas, however, are dominated by rocky soils that were deposited by flash floods in occasional thunderstorms.

Deposition by Glaciers

Throughout Earth's history there have been **ice ages**, long periods when glacial ice covered large parts of the continents. Ice has advanced over Eastern North America at least four times over just the past 2 million years. Geologists have learned about this from the sediments the ice transported southward and the features it left on the land. In New York, transported soils are more common than residual soils. The Pleistocene (10,000 to 2 million years ago) ice sheets that covered mountains as well as valleys in New York State have left rounded mountaintops and polished, grooved, and striated bedrock.

Glaciers produce two kinds of deposits. Material deposited directly by moving ice contains a wide range of particle sizes that are not sorted or layered. Sediments deposited by streams of meltwater, on the other hand, usually contain layers in which sediments are **sorted** by particle size. When we see ice-age sediments, we can usually tell whether they were deposited by the advancing ice or deposited by meltwater.

Deposition directly by glacial ice occurs when a glacier melts and sediments are released. Unlike water deposits, sediment left by melting glacial ice usually contains clay, sand, cobbles, and boulders mixed together. These **unsorted deposits** (**till**) left by glacial ice are often found in ridges and mounds. **Glacial erratics** are large rocks that were transported by glacial ice without being broken into small particles. They often rest high above stream valleys, which shows that they could not have been deposited by running water. Partial rounding and **striations** (scratches) on smooth surfaces also indicate transport by glaciers. Erratics, as with other glacial deposits, commonly differ in composition from the bedrock on which they rest.

QUESTIONS

Part A

39. Which statement best describes sediments deposited by the ice in glaciers and rivers? (1) Glacial deposits and river sediments are both sorted into layers. (2) Glacial deposits are sorted into layers, while river sediments are unsorted. (3) Glacial deposits by ice are unsorted and river sediments are sorted into layers. (4) Glacial deposits and river sediments are both unsorted and not layered

40. As a stream slows, which sediments are deposited first? (1) the largest and most-dense particles (2) the largest and least-dense particles (3) the smallest and most-dense particles (4) the smallest and least-dense particles

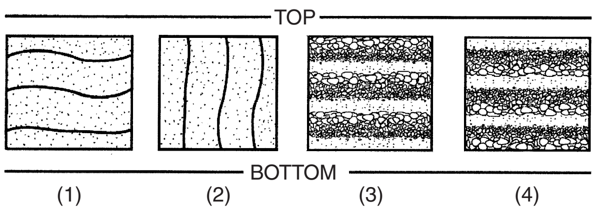
Base your answers to questions 41 through 44 on the image below, which is a satellite photograph of Taughannock Falls State Park near Ithaca, New York. In this image, Taughannock Creek flows toward the northeast. Use this image to answer the following four questions.

41. What is the depositional landform seen at the end of the creek? (1) tributary (2) stream (3) deposition (4) delta

42. Why does the creek deposit sediments in the lake? (1) Large waves on the lake cause deposition. (2) The creek slows as water enters the lake. (3) The sediments become waterlogged. (4) Water stirs up pebbles on the bottom of the lake

43. Where would you find particles of clay with no sand or pebbles? (1) in the bottom of the creek bed (2) in the middle of the delta (3) at the bottom of the high stream banks (4) in the deepest parts of the lake

44. Taughannock Creek transports most of its sediment load in occasional floods. Which diagram below best represents sediments deposited in the lake by flood events.



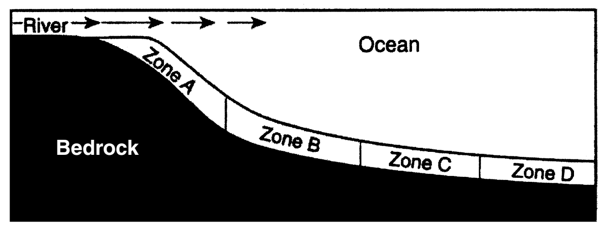
45. How many floods are represented by the sediments in choice (4) above? (1) 1 (2) 2 (3) 3 (4) 4

Part B

46. The photograph below is a view of Amargosa Dunes in California. The camera was pointing west.

Most likely, the winds have been blowing from the (1) north (2) south (3) east (4) west

Base your answers to questions 47 through 49 on the diagram below, which is a cross-sectional profile of a river entering an ocean. Arrows show the direction of the current. The data table describes the sediments in zones A–D.



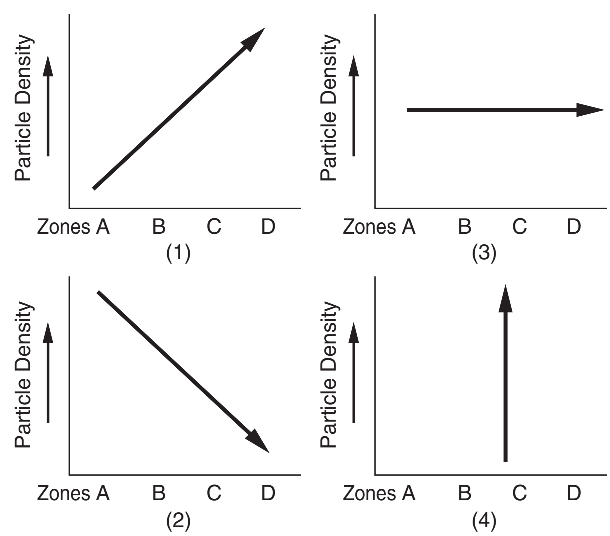
Data Table

Zone	Major Sediment Sizes
A	0.04 cm to 6 cm
B	0.006 cm to 0.1 cm
C	0.0004 cm to 0.006 cm
D	Less than 0.0004 cm

47. How is this pattern of horizontal sorting produced? (1) Larger particles are generally deposited first. (2) Rounded particles generally settle more slowly. (3) Dissolved minerals are generally deposited first. (4) High-density sediments generally settle more slowly.

48. The sedimentary rock siltstone is most likely to form for sediments in which zone? (1) *A* (2) *B* (3) *C* (4) *D*

49. Which graph below best shows the relationship between the density of particles and their positions on the diagram above?

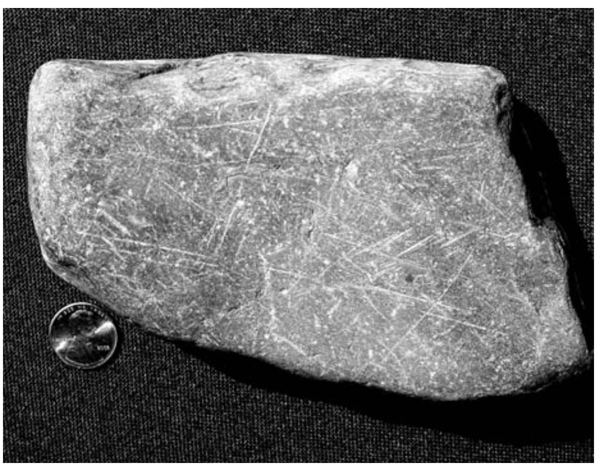


Chapter Review Questions

PART A

1. A stream deposits sediments as it enters a lake. As the distance from the mouth (end) of the stream toward the center of the lake increases, the average diameters of the particles along the bottom of the lake (1) decreases (2) increases (3) decreases and then increases (4) increases and then decreases

2. What agent most likely transported the rock shown in the image below? (A coin is shown for scale)



   (1) a river (2) the wind (3) a glacier (4) gravity acting alone

3. Rocks transported in which way are likely to be *less* weathered than those transported by the other three methods? (1) running water (2) gravity falls (3) strong winds (4) glacial ice

4. If a river flows at a rate of 500 centimeters/second, what is the largest rock it can transport? (1) sand (2) pebbles (3) cobbles (4) boulders

5. Which agents of erosion and deposition generally sort sediments by grain size? (1) wind, water, and glaciers (2) wind and water, but not glaciers (3) wind, but not water and glaciers (4) not wind, not water, and not glaciers

6. The photo below shows a marble gravestone in a remote part of the Adirondack Mountains of New York State.

   What has been the major cause of changes in this gravestone over the past 50 years? (1) wind abrasion (2) chemical weathering (3) water erosion (4) metamorphism

7. Which two factors are most likely to affect the amount of erosion done by a stream? (1) direction of flow and water temperature (2) elevation and the wind direction (3) longitude and mineral content of sediments (4) gradient and discharge volume

Base your answers to questions 8 and 9 on the photo below, which was taken in Southern California.

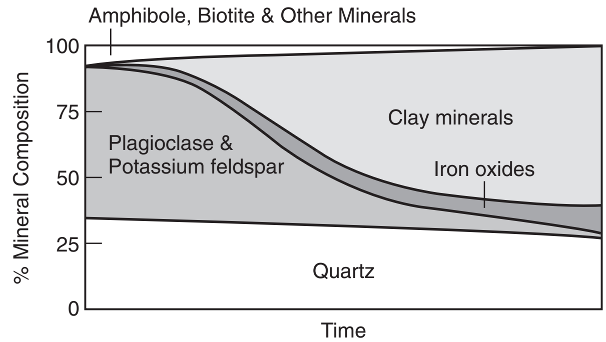
8. What was the major event that formed this sand dune? (1) wind erosion (2) water erosion (3) wind deposition (4) water deposition

9. What is the most likely direction of the prevailing winds in this location? (1) left to right (2) right to left (3) foreground to background (4) background to foreground

10. When is physical weathering most active in New York State? (1) winter (2) spring (3) summer (4) autumn

PART B

Base your answers to questions 11 through 13 on the graph above, which shows how the mineral composition of a sample of rock that was exposed to the atmosphere changed over time.



11. What process does this graph best illustrate? (1) erosion (2) weathering (3) recrystallization (4) deposition

12. Which mineral seems to be the most resistant to change? (1) quartz (2) the feldspars (3) amphibole (4) biotite

13. It appears that over time plagioclase and potassium feldspar can change mostly to (1) quartz (2) iron oxides (3) amphibole and biotite (4) clay

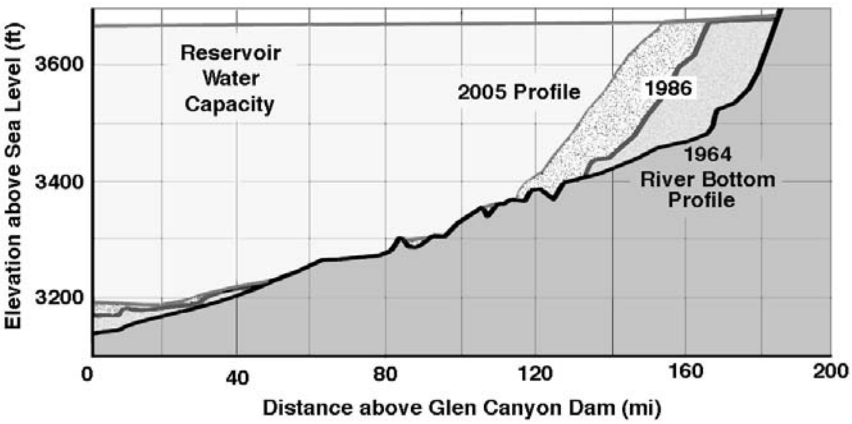
Base your answers to questions 14 through 24 on the map, lake profile, photograph, and the text below.

Unintended Consequences at Lake Powell

We want carbon-free sources of energy. Hydroelectric power is an attractive alternative. However, every form of energy comes at an environmental price. Sedimentation, or silting, is the environmental price of dams built to provide hydroelectric power.

The Glen Canyon Dam on the Colorado River was completed in 1964. Lake Powell formed behind the dam. Sedimentation occurs in Lake Powell because the Colorado River is very rich in sediments. Since 1964, the Colorado's nearly 100-million-ton average annual sediment load has collected at the upper end of Lake Powell. The sediments sinking to the lake's bottom will gradually fill the submerged canyon. Scientists estimate that sediment accumulation will force the closing of the dam within 200 years.

Sediment fill at the upper end of Lake Powell—2008



Sedimentation of Lake Powell 1964–2005

Another problem is that the water released from the dam is sediment-free. This causes beaches to wash away in the Grand Canyon. Before the dam was built, sand that washed away from the beaches was replaced by sediment carried by the river. This kept the sandy banks in equilibrium. The loss of the beaches will adversely affect rafting and camping down river as shores erode away to bare rock.

14. What geological process is filling Lake Powell? (1) erosion (2) weathering (3) deposition (4) crystallization

15. What is the major source of most of the sediments flowing into Lake Powell?

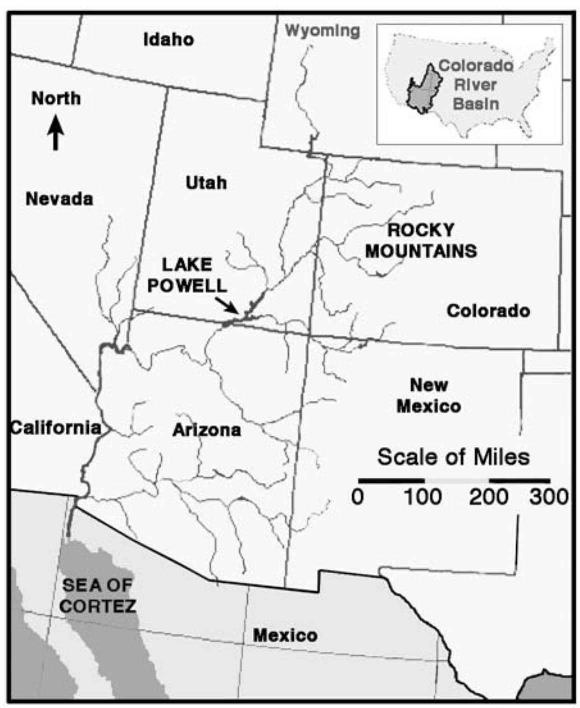
(1) Sea of Cortez (3) State of Arizona
(2) Rocky Mountains (4) Mexico

16. In what general direction does the Colorado River flow? (1) southwest (2) southeast (3) northwest (4) northeast

17. What is the straight-line distance from the most northerly source of the Colorado River to the place where it ends at the Sea of Cortez? (1) 300 miles (2) 600 miles (3) 850 miles (4) 950 miles

18. The Glen Canyon Dam is contributing to what problem downstream in the Grand Canyon? (1) flooding (2) warm water (3) deposition (4) erosion

19. What is the greatest depth of sediments deposited in Lake Powell in the period between 1964 and 2005? (1) 100 feet (2) 200 feet (3) 300 feet (4) 400 feet

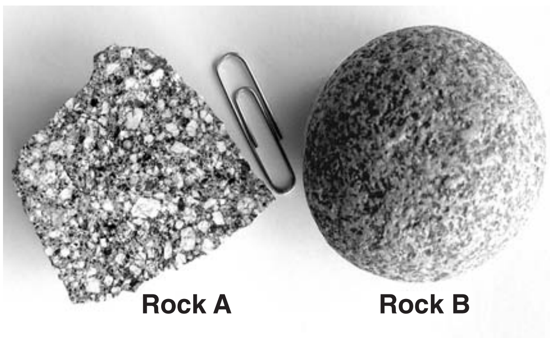


The Colorado River and Its Tributaries

20. How many US states contain tributaries of the Colorado River or border the river? (1) 1 (2) 3 (3) 5 (4) 7

21. What is the approximate distance from the Glen Canyon Dam to the place where the photo of sediment fill was taken? (1) 40 miles (2) 80 miles (3) 120 miles (4) 160 miles

22. The photo below shows two samples of granite from the same part of the Rocky Mountains. One of them was collected along the Colorado River in the state of Colorado. The second sample was collected about 500 miles downstream in Arizona.



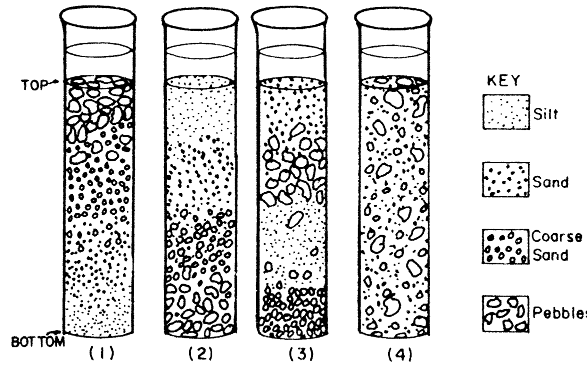
Where were these two rocks found?
(1) Rock *A* was recovered from Colorado and *B* was from Arizona. (2) Rock *A* was recovered from Arizona and *B* was from Colorado. (3) Rock *A* was found at the center of Lake Powell and *B* was at its source. (4) Rock *A* was found in a riverbank and *B* was found in a sand dune.

23. If the original shape of rock *B* was similar to rock *A*, what process changed rock *B*?
(1) wind abrasion (3) metamorphism
(2) abrasion in water (4) crystallization

24. What major river-deposited landform is shown in the photo of the upper end of Lake Powell? (1) a glacial deposit (2) a sand dune (3) a delta (4) a soil profile

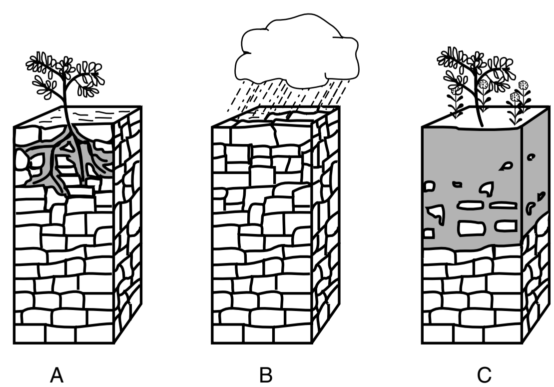
25. Paved roads in the Adirondack Mountains of New York State need more frequent repairs than roads built to the same standards on Long Island, New York. Why do the Adirondack roads break down more quickly? (1) Long Island roads get more traffic than the roads in the Adirondacks. (2) Winter snows last longer on Long Island. (3) Long Island is north of the Adirondacks. (4) The Adirondacks have more freeze-thaw cycles.

26. A student quickly dumped the contents of a beaker filled with particles of mixed sizes into a tall transparent column filled with water. Which diagram below best shows how the sediments settled?



PART C

Base your answers to questions 27 through 30 on the diagram below, which shows changes in the bedrock of a location in New York State.



27. What is the correct sequence of the changes shown in these three diagrams?

28. According to the symbols in the *Reference Tables*, what is the mineral composition of this rock?

29. What kind of bedrock weathering is probably dominant in this location?

30. What is the end product of the weathering and biological activity shown in this diagram?

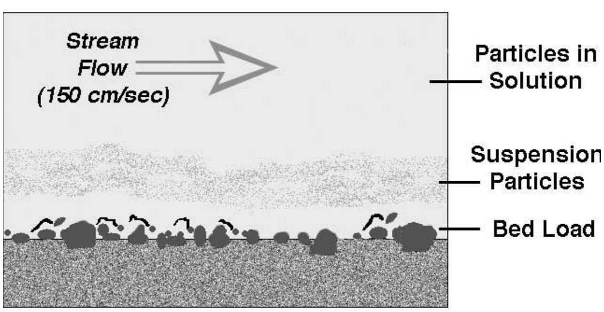
Base your answers to questions 31 and 32 on the image below, which was taken along an ocean shoreline.

31. How did the large rocks get to the bottom of the cliff?

32. State two ways in which the particles of sediment along the beach have changed since they were eroded from the steep area above the beach.

33. Draw one layer of graded bedding.

Base your answers to questions 34 and 35 on the diagram below, which represents sediments being carried by a fast-moving stream.

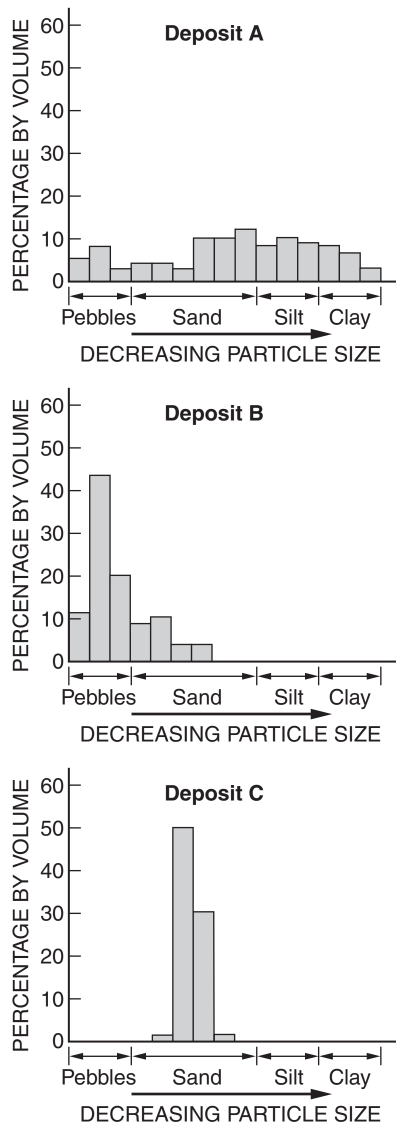


34. According to the information in this diagram, what is the largest type of particle that the stream can transport?

35. Specify three characteristics of the dark particles bouncing along the bottom of the stream that make them different from the particles carried at midstream.

36. Give two characteristics of steam deposits that are not usually found in sediments deposited by glaciers.

Base your answers to questions 37 through 40 on the three graphs below, which show the particle sizes of sediments found in three locations in New York State. Each was deposited by a different agent of erosion and deposition. One location is a sand dune near the shoreline on eastern Long Island. One is a small hill composed entirely of sediments. The third is from the bottom of a fast-moving stream in the Catskill Mountains of New York State.



37. Which sediment sample is probably from the Catskill stream? How can you tell?

38. What is the most likely agent of erosion and deposition for Deposit *A*?

39. Name two characteristics of Deposit *C* that help you identify it as a sand dune deposit.

40. What is the approximate average diameter of the sediments in Deposit *C*? (Express your answer in quantity and units.)

Base your answers to questions 41 through 43 on the passage below.

Muck Soil

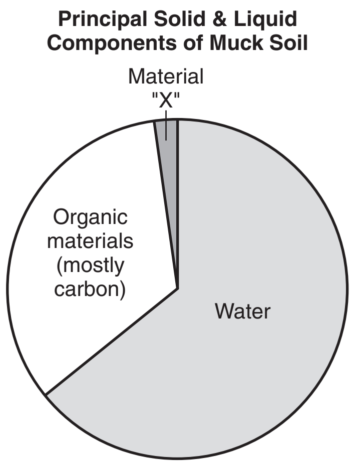
Muck, or bog soil, is a soil made up mostly of humus from drained swampland. It is used in the United States for growing specialty crops such as onions, carrots, celery, and potatoes. These crops can tolerate the poor drainage and lack of minerals. Farming on drained bogs is an important part of agriculture in southeastern New York State, primarily in Orange County. The soil is deep, dark-colored, and crumbles easily. It is often underlain by clay.

Muck has been hyped as miracle soil, capable of supporting vast yields. However, this does not hold up in reality. It is prone to problems, such as the fact that it is very light and usually windbreaks must be provided to keep it from blowing away when dry. It also can catch fire and burn underground for months. Oxidation also removes a portion of the soil each year, so it becomes more and more shallow.

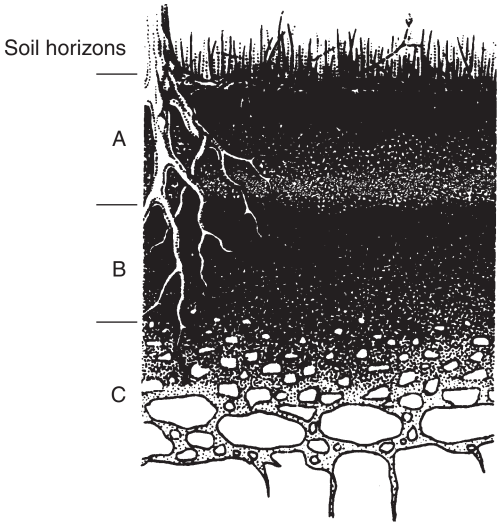
41. What is humus?

42. The graph below represents a typical composition of muck soil. (Air is not included.)

The portion of the graph labeled Material *X* is a substance very common in most soils but mostly absent in muck. What is substance *X*?



43. The figure below shows the soil horizons of a typical soil. Muck has a much thicker *A* horizon than typical soils. What is the nature of the material below the bottom of the *C* horizon in the figure?



Base your answers to questions 44 through 47 in the photo below of three girls walking in a nature preserve.

44. What is the agent of erosion that deposited the sediment the girls are walking near?

45. Why does the size of the sedimentary particles decrease from boulders to clay in the direction of the arrow?

46. What name is given to the kind of change in the size of the sediments that you see in the photo?

47. You can see boulders in the distance. If the smallest boulder has a diameter of 25.6 centimeters, how fast was the stream moving that carried it?