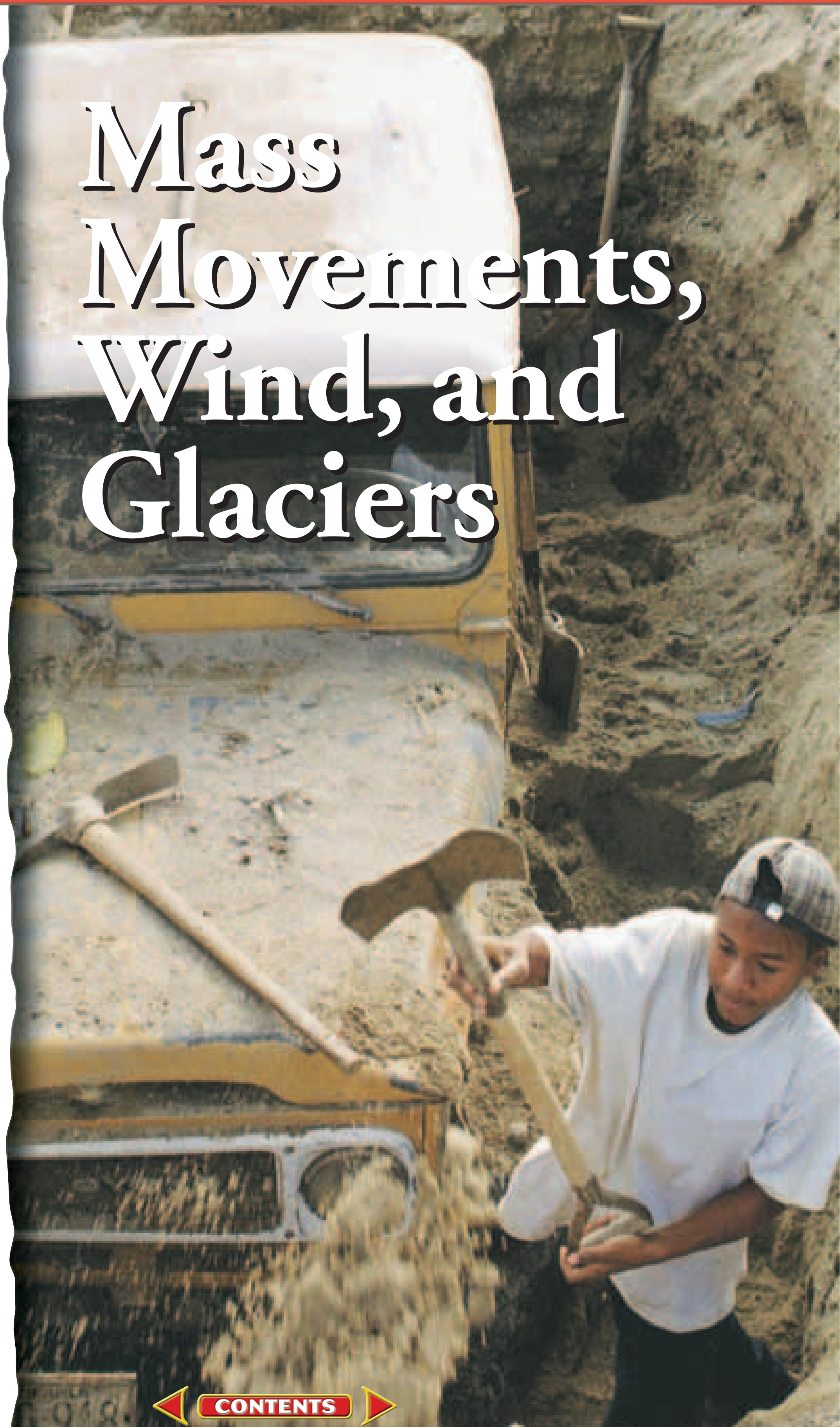
Chapter 8

Mass Movements, Wind, and Glaciers



What You'll Learn

- How the processes of mass movements, wind, and glaciation change landscape features.
- What external features on Earth's surface are caused by mass movements, wind, and glaciers.

Why It's Important

Earth's external processes shape its surface. Some of the processes, such as landslides and avalanches, represent hazards. Mass movements, wind, and glaciers change the landscape and have an impact on human populations in many regions.

Earth Science Online

To find out more about mass movements, wind, and glaciers, visit the Earth Science Web Site at earthgeu.com

Discovery Lab

Model Sand-Slope Activity

Water affects sediment grains on slopes. If there is too little water, the sediments may not hold together, and as a result, they may move downslope. In this activity, you will demonstrate how the addition of water affects how sediments are held together.

1. Place 225 mL of sand in each of three separate containers, such as aluminum pie plates.
2. To the first container of sand, add 20 mL of water and mix well. To the second container of sand, add 100 mL of water and mix well. To the third container of sand, add 200 mL of water and mix well.
3. Empty the three mixtures of sand and water onto a tray or piece of cardboard. Keep each mixture separate.
4. Test each mixture for its ability to be molded and retain its shape. Compare your results for the three samples.

CAUTION: Always wear safety goggles and an apron in the lab.

Observe In your science journal, describe how the addition of water affected the sand's ability to be molded in the three samples.

Section 8.1 Mass Movements at Earth's Surface

OBJECTIVES

- **Identify** *factors that affect mass movements.*
- **Relate** *how mass movements affect people.*
- **Analyze** *the relationship between gravity and mass movements.*

VOCABULARY

mass movement
creep
mudflow
landslide
slump
avalanche

Every day, the landscape around us undergoes changes. If you compared old and new photographs of the landscape around your home, you might have to look very closely to notice some of the subtle differences. Other changes, such as landslides, occur quickly and have very noticeable, immediate effects.

Mass Movements

How do landforms such as mountains, hills, and plateaus wear down and change? Landforms can change through processes involving wind, ice, and water, and sometimes through the force of gravity alone. The downslope movement of loose sediments and weathered rock resulting from the force of gravity is called **mass movement.** In the development of most of Earth's landforms, erosion is the step that follows weathering. After weathering processes weaken and break rock into smaller and smaller pieces, mass movements may occur and carry the debris downslope. Because climate has a major effect on the vegetation and the weathering activities that occur in a particular area, climatic conditions determine which materials and how much of each will be made available for mass movement.

All mass movements occur on slopes. Because very few places on Earth are completely flat, almost all of Earth's surface undergoes mass movement. Mass movements range from extremely slow motions to sudden slides, falls, and flows. The Earth materials that are moved range from fine mud to large boulders.

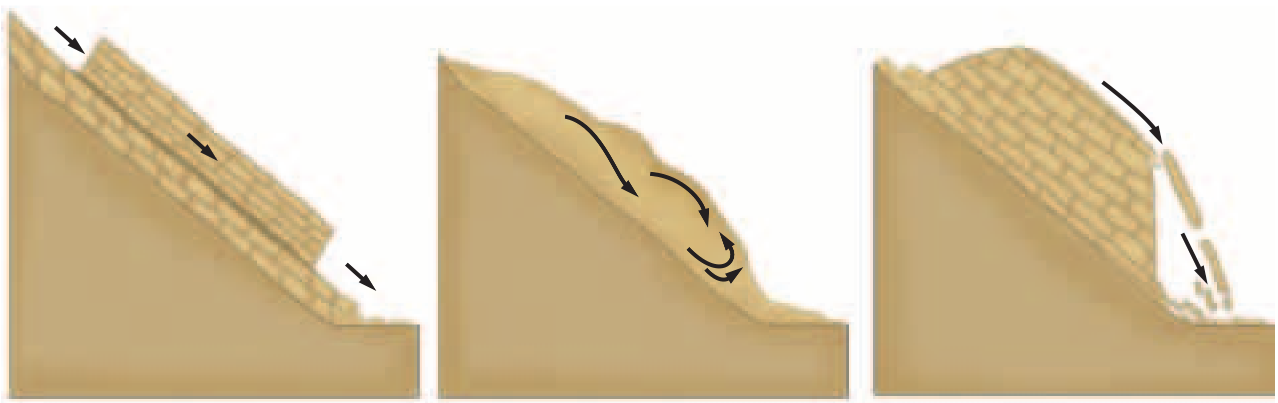
VARIABLES THAT INFLUENCE MASS MOVEMENTS

Several variables influence the mass movements of Earth's material. One variable is the material's weight resulting from gravity, which works to pull the material down a slope. A second variable is the material's resistance to sliding or flowing. A third variable can be a trigger, such as an earthquake, that works to shake material loose from a slope, as shown in ***Figure 8-1A.*** Mass movement occurs when the forces working to pull material down a slope are stronger than the material's resistance to sliding, flowing, or falling. Some common types of mass movement are illustrated in ***Figure 8-1B.***

A

Figure 8-1 Sudden mass movements can be started by a trigger, such as an earthquake, which caused this landslide in Gallatin National Forest, Montana **(A).** There are three common types of mass movement. ***How are they alike? How are they different?*** **(B)**

B



Slide
Moves as block of Earth material

Flow
Movement involves mixing of particles within moving mass

Fall
Free fall of Earth material

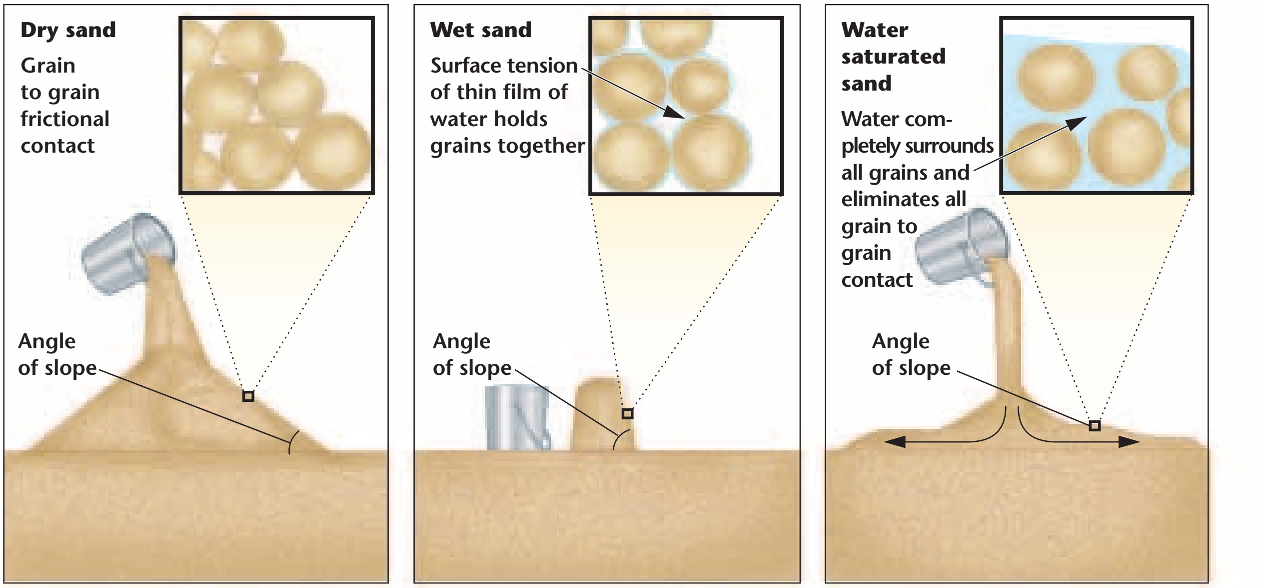


Figure 8-2 Water plays a key role in mass movements. Water acts as a lubricant between grains of sand to reduce friction between them.

Erosion and the undermining of soil at the foot of a slope increase the potential of Earth materials to move downhill, as does the increased weight from torrential rainfall. An important force that determines a material's resistance to downhill movement is friction between the material and the slope.

Water Water is a fourth variable that influences mass movements, as illustrated in ***Figure 8-2.*** On a slope, too little water may prevent sediment grains from holding together at all, thereby increasing the material's potential for movement. You could demonstrate this concept by trying to form dry, loose soil into a ball. It would be difficult to get the particles to hold together. However, if you added small amounts of water, the particles of soil would cling together and remain in the shape in which you formed them. Similarly, the addition of water to sediments on a slope helps to hold the grains together and makes the material more stable. On the other hand, too much water can make a slope unstable. Saturation by water greatly increases the weight of soils and sediments. In addition, as the water fills the tiny open spaces between grains, it may act as a lubricant between the grains to reduce the friction between them. Thus, the force of gravity is more likely to pull the saturated material downhill. While water is very important to the process of mass movement, it is important to note that water is not involved as a transport agent. In mass movements, water moves along with Earth materials. This is in contrast to stream transport, in which sediment moves along with the water.

Types of Mass Movements

Mass movements are classified as creep, flows, slides, and falls. Mass movements can move different types of materials in various ways. Let's investigate the different types of mass movement.

Creep The slow, steady, downhill flow of loose, weathered Earth materials, especially soils, is called **creep.** Because movement may be as little as a few centimeters per year, the effects of creep usually are noticeable only over long periods of time. One way to tell whether creep has occurred is to observe the positions of structures and objects. As illustrated in ***Figure 8-3,*** creep can cause the tilting of once-vertical utility poles, fences, and gravestones, the bending of trees, the cracking of walls, and the breaking of underground pipelines. Loose materials on almost all slopes, even the very gentlest, undergo creep. Soil creep moves huge amounts of surface material each year.

The slow, downhill movement of loose, water-logged materials that occurs in regions of permafrost is called solifluction. The material moved in solifluction is a mudlike liquid that is produced when water is released from melting permafrost during the warm season. The water saturates the surface layer of soil and is unable to move downward through the underlying permafrost. As a result, the surface layer can slide slowly down a slope. Solifluction may also occur in humid regions where the ground remains saturated year-round.

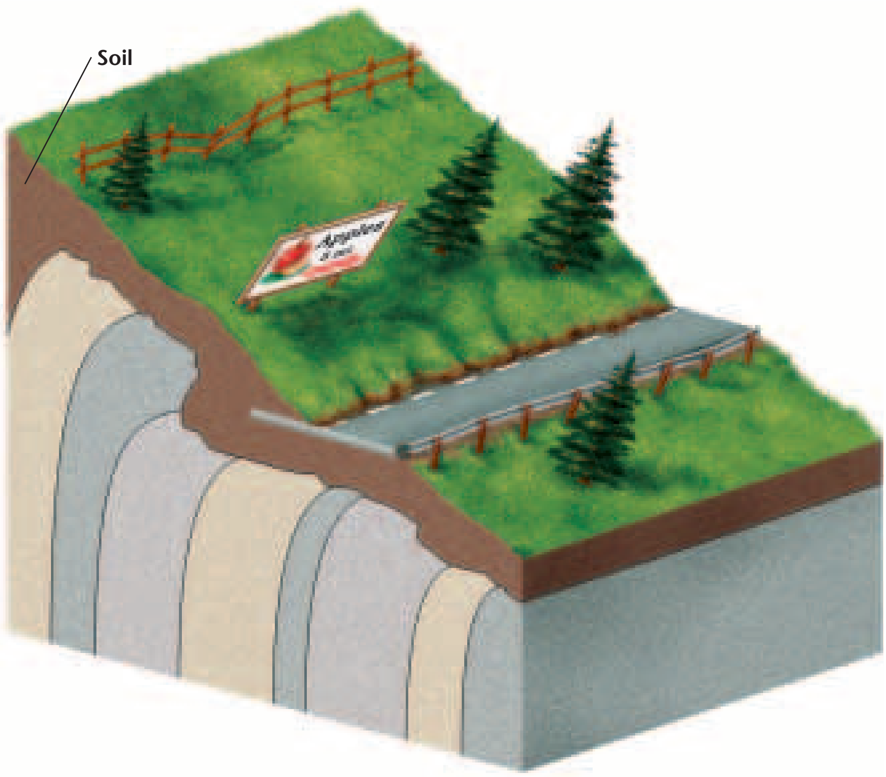


Figure 8-3 Creep can cause the slow tilting of various objects on slopes. ***Is there any evidence of creep in your area?***

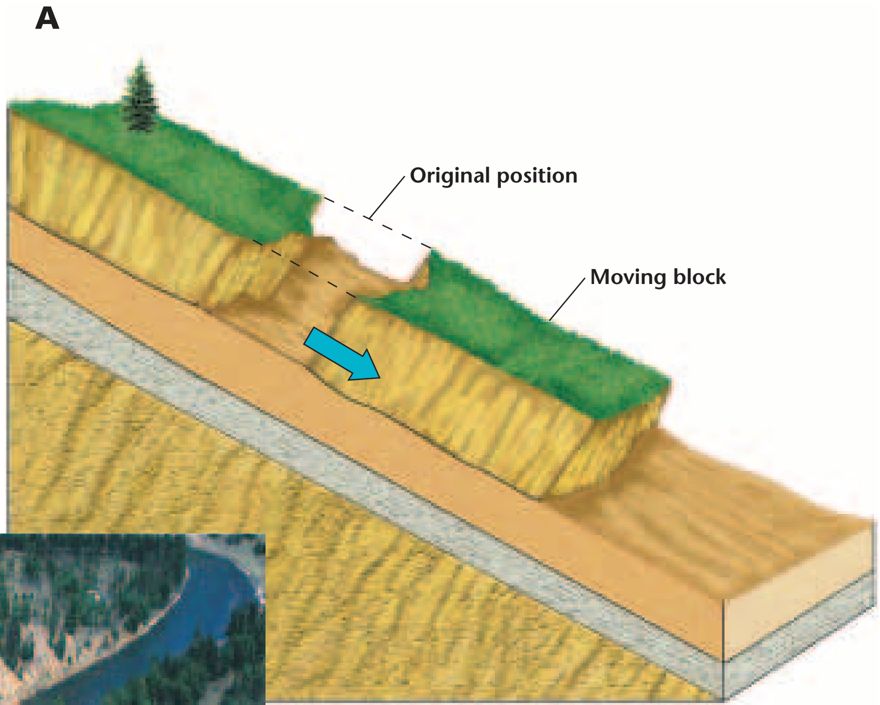
Figure 8-4 Major mudflows occurred after the eruption of Mount St. Helens in 1980 **(A).** In 1998, a mudflow in Sarno, Italy, caused the deaths of 135 people and the destruction of many buildings **(B).**

Flows In some mass movements, Earth materials flow as if they were a thick liquid. The materials can move as slowly as a few centimeters per year or as rapidly as hundreds of kilometers per hour. Earth flows are moderately slow movements of soils, whereas **mudflows** are swiftly moving mixtures of mud and water. Mudflows can be triggered by earthquakes or similar vibrations and are common in volcanic regions where the heat from a volcano melts snow on nearby slopes that have fine sediment and little vegetation. The meltwater fills the spaces between the small particles of sediment and allows them to slide readily over one another and move down the slope. As shown in ***Figure 8-4A,*** when Mount St. Helens erupted in 1980, it triggered mudflows that traveled downhill at speeds of over 30 km/h. Although the area was sparsely populated, the mudflows damaged or destroyed more than 200 homes. In 1998, a mudflow in Italy caused many deaths and much destruction, as shown in ***Figure 8-4B.***

Mudflows are also common in sloped, semi-arid regions that experience intense, short-lived rainstorms. The Los Angeles Basin in southern California is an example of an area where mudflows are common. In such areas, periods of drought and forest fires can leave the slopes with little protective vegetation. When heavy rains eventually fall in these areas, they can cause massive, destructive mudflows. Mudflows are destructive in areas where urban development has spread to the bases of mountainous areas.

Figure 8-5 A landslide occurs when a sheet of loose Earth materials separates from the bedrock and moves quickly downslope **(A).** In March of 1998, a landslide caused about 120,000 m^3 of dirt and debris to flow into the Blackfoot River in Ovando, Montana. The river became well known after its portrayal in the movie *A River Runs Through It* **(B).**

A



B

Slides A rapid, downslope movement of Earth materials that occurs when a relatively thin block of loose soil, rock, and debris separates from the underlying bedrock is called a **landslide,** illustrated in ***Figure 8-5A.*** The material rapidly slides downslope as one block, with little internal mixing. Some landslides may reach speeds of 200 km/h. As shown in ***Figure 8-5B,*** a landslide mass eventually stops and becomes a pile of debris at the bottom of a slope, sometimes damming rivers and causing flooding. Landslides are common on steep slopes, especially when soils and weathered bedrock are fully saturated by water. This destructive form of mass movement causes almost $2 billion in damage and several deaths per year in the United States alone. You will explore the movement of a landslide in the *Mapping GeoLab* at the end of this chapter.

A rock slide is a type of landslide that occurs when a sheet of rock moves downhill on a sliding surface. During a rock slide, relatively thin blocks of rock are broken into smaller blocks as they move downslope. Often triggered by earthquakes, rock slides can move large amounts of material.

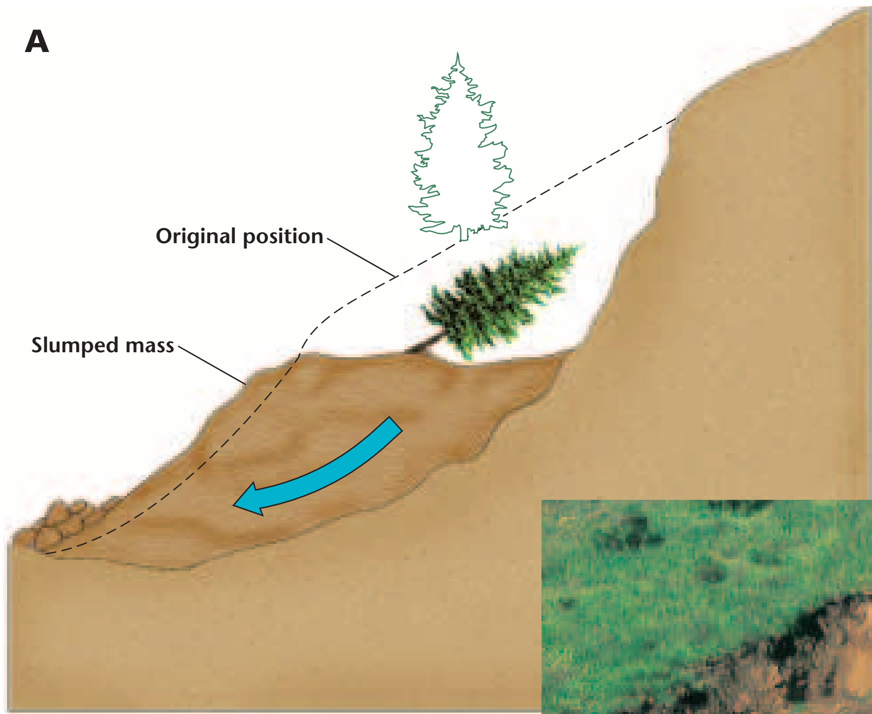


Figure 8-6 A slump occurs when Earth materials in a landslide rotate and slide along a curved surface **(A).** This slump, which occurred in Santa Barbara, California, was triggered by heavy rains **(B).**

Slumps As illustrated in ***Figure 8-6A,*** when the mass of material in a landslide rotates and slides along a curved surface, a **slump** results. Slumps, such as the one shown in ***Figure 8-6B,*** may occur in areas that have thick soils on moderate-to-steep slopes. Sometimes, slumps occur along highways where the slopes of soils are extremely steep. Slumps are common after rains, when water reduces the frictional contact between grains of soil and acts as a lubricant between surface materials and underlying layers. The weight of the additional water pulls material downhill. As with other types of mass movement, slumps can be triggered by earthquakes. Slumps leave crescent-shaped scars on slopes.

Avalanches Landslides that occur in mountainous areas with thick accumulations of snow are called **avalanches.** Avalanches usually occur on slopes of at least 35°. About 10 000 avalanches occur each year in the mountains of the western United States alone. Radiation from the Sun can melt surface snow, which then refreezes at night into an icy crust. Snow that falls on top of this crust can eventually build up, become heavy, slip off, and slide down a slope as an avalanche.

Another type of weak snow layer forms in early winter as the ground, which is still warm, melts the overlying snow. The snow then refreezes into a layer of jagged, slippery snow crystals. A vibrating trigger, even from a single skier, can send such an unstable layer sliding down a mountainside at speeds of up to 300 km/h. As shown in ***Figure 8-7,*** avalanches pose particular risks in places such as Switzerland, where more than 50 percent of the population lives in avalanche terrain. In the 1998–1999 season, for example, hundreds of major avalanches swept down the Swiss Alps.

Figure 8-7 In February of 1999, a deadly avalanche occurred in Switzerland. Several people were killed and many homes were destroyed. The damage was estimated at $100 million.

Rock Falls Rock falls commonly occur at high elevations, in steep road cuts, and on rocky shorelines. On high cliffs, rocks are loosened by physical weathering processes, such as freezing and thawing, and by plant growth. As rocks break up and fall directly downward, they may bounce and roll, ultimately producing a cone-shaped pile of coarse debris, called talus, at the base of the slope. On human-made rock walls, such as road cuts, rock falls are particularly common. "Falling Rock" warning signs can often be seen along highways that run through steep, rocky areas, as shown in ***Figure 8-8.*** Rock falls are less likely to occur in humid regions, where the rock is typically covered by a thick layer of soil, vegetation, and loose materials.

Figure 8-8 These rocks on a highway in Colorado were deposited by a rock fall. In areas where rock falls are common, signs are posted to warn motorists.

Mass Movements Affect People

While mass movements are natural processes, human activities often contribute to the factors that cause mass movements. Activities such as constructing heavy buildings, roads, and other structures can make slope materials unstable. In addition, poor maintenance of septic systems, which often leak, can trigger slides.

Environmental Connection

Dangerous Mudflows Human lives are in danger when people live on steep terrain or in the path of unstable slope materials. For example, in December of 1999, northern Venezuela experienced the heaviest rains that had fallen there in 100 years. Within several days, between 30 to 48 cm of unseasonal rainfall occurred in this area. The sudden saturation of sediments, combined with the area's steep topography and widespread deforestation, resulted in severe mudflows and landslides, as shown in ***Figure 8-9.*** Tens of thousands of people died, more than 114 000 people were left homeless, and 23 000 homes were destroyed. Entire villages were buried in mud, rock, and debris. The widespread loss of human life was primarily a result of the location of villages both high up in steep terrain and at the foot of unstable, saturated slopes.

Reducing the Risks

Catastrophic mass movements are most common on slopes greater than 25° that experience annual rainfall of over 90 cm. The best way to minimize the destruction caused by mass movements is to avoid building structures on such steep and unstable slopes.

Figure 8-9 Deadly mudflows that occurred in Venezuela in 1999 caused extensive damage in Los Corales.

Figure 8-10 This steel net was installed along Route 101 near Quilcene, Washington, to protect motorists from rockslides **(A).** In Wolf Creek Pass, Colorado, a fence was built along this highway to protect motorists from rock slides **(B).**

Preventive Actions Although preventing mass-movement disasters is not an easy task, some actions can help to avoid the potential hazards. For example, a series of trenches can be dug to divert running water around a slope and control its drainage. Other approaches to controlling landslides include covering steep slopes with materials such as steel nets, and constructing protective fences along highways in areas where rock slides are common, as shown in ***Figure 8-10.*** Still other approaches involve the installation of retaining walls to support the bases of weakened slopes and prevent them from falling. Most of these efforts at slope stabilization and prevention of mass movements, however, are generally successful only in the short run. The best way to reduce the number of disasters related to mass movements is to educate people about the problems of building on steep slopes.

Section Assessment

1. Identify and describe one type of rapid mass movement and one type of slow mass movement.
2. Describe the underlying force behind all forms of mass movement and explain its role in the process of mass movement.
3. How does water affect the process of mass movement?
4. What precautions can humans take to avoid the dangers associated with mass movements?
5. **Thinking Critically** Explain how one particular human activity can increase the risk of mass movement and suggest a solution to the problem.

Skill Review

6. **Making Tables** Design a data table that shows the similarities and differences among the forms of mass movement discussed in this section. For more help, refer to the *Skill Handbook*.

SECTION 8.2 *Wind*

Moving air can pick up and transport Earth materials in the process of erosion. Unlike water, wind can transport sediments uphill as well as downhill. As an erosional agent, wind can modify and change landscapes in arid and coastal areas.

OBJECTIVES

- **Describe** *conditions that contribute to the likelihood that an area will experience wind erosion.*
- **Identify** *wind-formed landscape features.*
- **Describe** *how dunes form and migrate.*
- **Explain** *the effects of wind erosion on human activities.*

VOCABULARY

deflation
abrasion
ventifact
dune
loess

WIND EROSION AND TRANSPORT

A current of rapidly moving air can pick up and carry sediments in the same way that water does. However, except for the extreme winds of hurricanes, tornadoes, and other strong storms, winds generally cannot carry particles as large as those transported by moving water. Thus, the relative ability of wind to erode materials is less than that of other erosional agents, such as water and ice.

Winds transport materials by causing their particles to move in different ways. For example, wind can move sand on the ground in a rolling motion. A method of transport by which strong winds cause particles to stay airborne for long distances, as shown in ***Figure 8-11A,*** is called suspension. Another method of wind transport, called saltation, causes a bouncing motion of particles. Saltation accounts for most sand transport by wind. Both suspension and saltation are shown in ***Figure 8-11B.*** Most areas where wind transport and erosion occur experience limited amounts of precipitation, which helps to hold down sediments and allows plants to grow.

Figure 8-11 Dust storms, caused by suspension, are common in the Arizona desert **(A).** Strong winds can transport sediments by suspension and saltation **(B).**

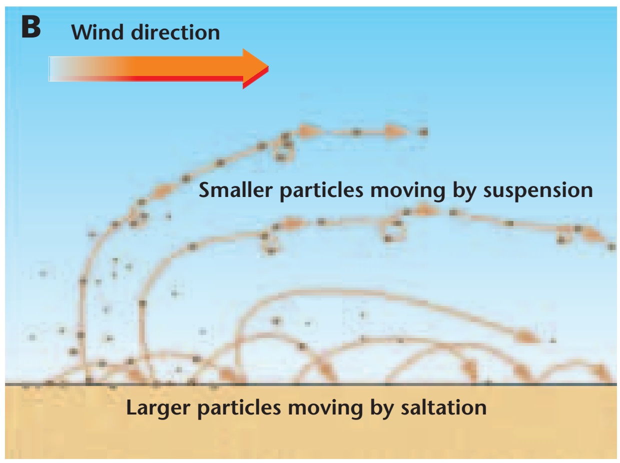


Figure 8-12 *What areas in the United States are subject to wind erosion? Why is wind erosion a problem in those areas?*

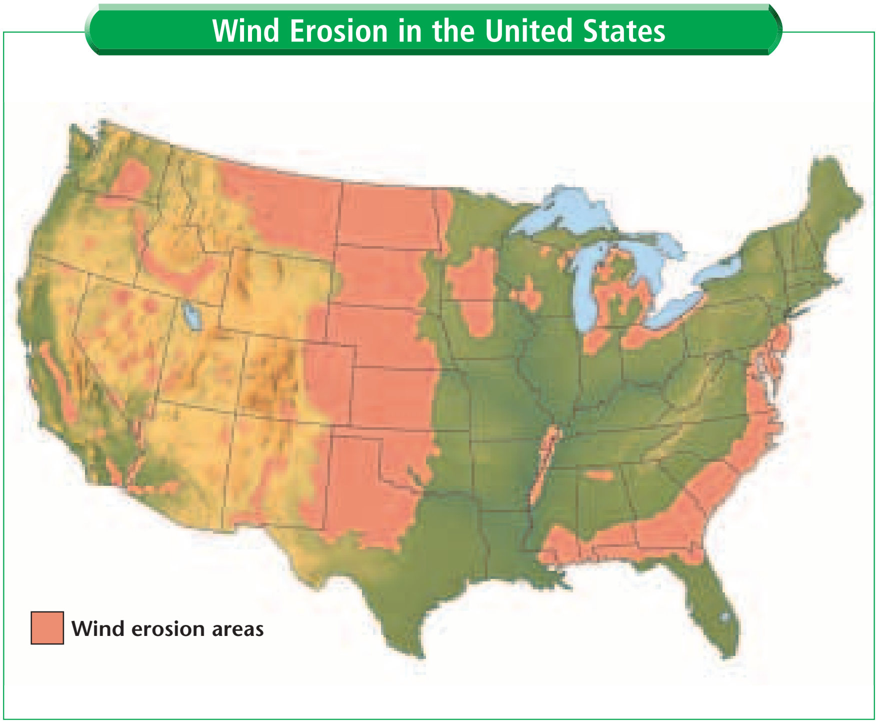
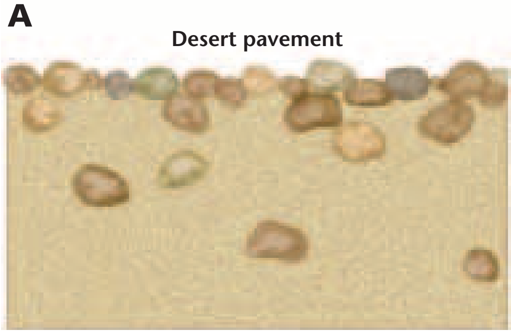


Figure 8-13 Desert pavement is the coarse sediment found on a desert floor **(A).** This desert pavement is located near the Gila River in New Mexico and Arizona **(B).**

A



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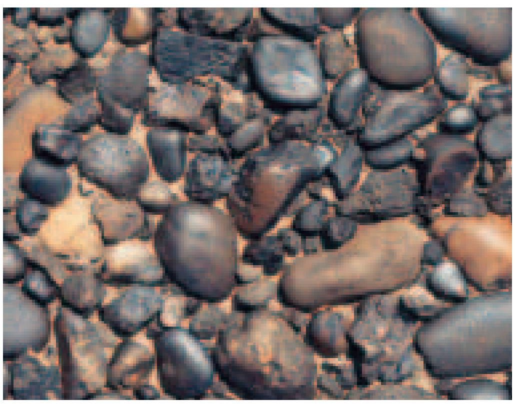


Thus, wind transport and erosion primarily occur in areas with little vegetative cover, such as deserts, semiarid areas, seashores, and some lakeshores. As shown in ***Figure 8-12,*** wind erosion is a problem in many parts of the United States. You will learn more about wind erosion in the *MiniLab* later in this section.

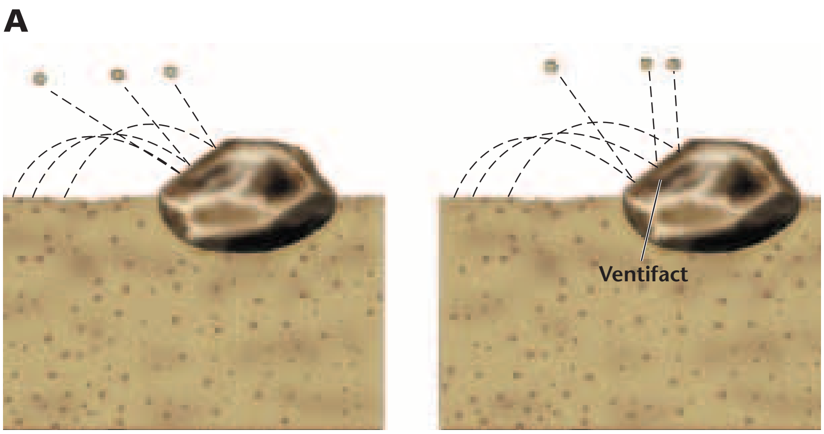
The lowering of the land surface that results from the wind's removal of surface particles is called **deflation.** The particles removed may be composed of any material. In areas of intense wind erosion, coarse gravel and pebbles are usually left behind as the finer surface material is removed by winds. The coarse surface left behind is called desert pavement, shown in ***Figures 8-13A and 8-13B.*** Deflation is a major problem in many agricultural areas of the world.

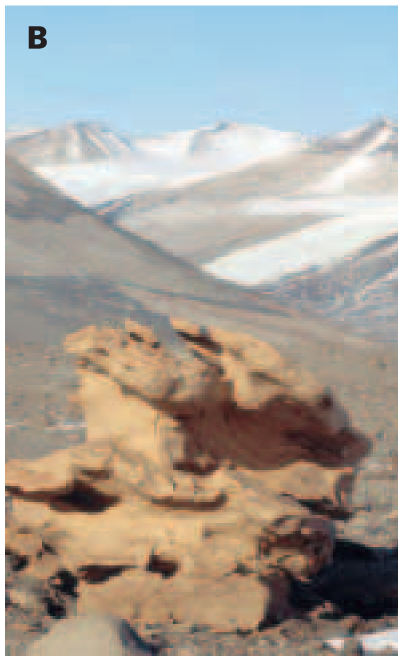
During the 1930s, portions of the Great Plains region, which stretches from Montana to Texas, experienced severe drought. The area was already suffering from the effects of poor agricultural practices, in which huge areas of natural vegetation were removed to clear the land for farming. Strong winds readily picked up the dry surface particles, which lacked any protective vegetation. Such severe dust storms resulted that daytime skies were often darkened and the region became known as the Dust Bowl. Today, the Great Plains are characterized by thousands of shallow depressions known as deflation blowouts. They are the result of the removal of surface sediment by wind erosion during the 1930s. The depressions range in size from a few meters to hundreds of meters in diameter.

Another process of erosion, called **abrasion,** occurs when particles such as sand rub against the surface of rocks or other materials. Abrasion occurs as part of the erosional activities of winds, streams, and glaciers. In wind abrasion, wind picks up materials such as sand particles and blows them against rocks and other objects. Because sand is often made of quartz, a very hard mineral, wind abrasion can be a very effective agent of erosion; windblown sand particles eventually wear away rocks, as shown in ***Figure 8-14.*** Structures such as telephone poles also may be worn away or undermined by wind abrasion, and paint and glass on homes and vehicles may be damaged by windblown sand. Materials that are exposed to wind abrasion show unique characteristics. For example, windblown sand causes rocks to become pitted and grooved. With continued abrasion, rocks become polished on the windward side and develop smooth surfaces with sharp edges, as shown in ***Figure 8-15A.*** In areas of shifting winds, abrasion patterns correspond to wind shifts, and different sides of rocks become polished and smooth. Rocks shaped by wind-blown sediments, such as those shown in ***Figure 8-15B,*** are called **ventifacts.**

Figure 8-14 The forces of abrasion carved this conglomerate rock called the Baja Mushroom, located at Puerto Ballandra, near La Paz, Baja, Mexico.

Figure 8-15 Rocks that are exposed to windblown sand become pitted and grooved **(A).** These ventifacts are located in Bull Pass, Antarctica **(B).**





MiniLab

Where does wind erosion occur?

Interpret a wind erosion map to find out what parts of the United States are subject to wind erosion.

Procedure

Refer to the wind erosion map shown in *Figure 8-12* to answer the following questions.

Analyze and Conclude

1. Which areas of the United States experience wind erosion?
2. Where is the largest area of wind erosion? The second largest?
3. What coastal areas are subject to wind erosion?

Figure 8-16 The wind is lifting sand particles from the top of this sand dune in the Namibia Desert in Namibia, a country located on the west coast of Africa.

Wind Deposition

Wind deposition occurs in areas where there are changes in wind velocity. As wind velocity decreases, some of the wind-blown sand and other materials can no longer stay airborne, and they drop out of the air stream to form a deposit on the ground.

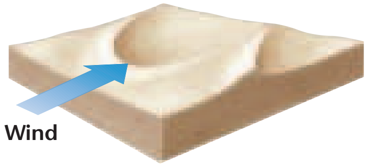
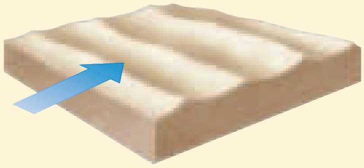
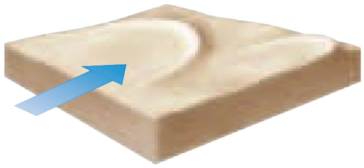
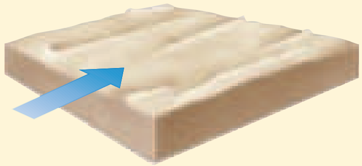
Formation of Dunes In wind-blown environments, sand particles tend to accumulate where an object, such as a rock, landform, or piece of vegetation, blocks the particles' forward movement. Sand continues to be deposited as winds blow in one general direction. Over time, the pile of wind-blown sand develops into a **dune,** as shown in ***Figure 8-16.*** The conditions under which a dune forms determine its particular shape. These conditions include the availability of sand, wind velocity, wind direction, and the amount of vegetation present. All dunes have a characteristic profile. The gentler slope of a dune is located on the side from which the wind blows, the windward side. The steeper slope is on the side protected from the wind, called the leeward side.

The velocity of the wind above the ground surface determines the height of a dune. The heights of dunes are usually in the range of 12 to 25 m. The maximum height is variable, but the world's tallest dunes, in Saudi Arabia, measure more than 100 m in height.

Although quartz sand is the most common component of dunes, any dry, granular material can be formed into a dune, as long as winds continue to blow in a consistent direction and at a speed great enough to transport particles. Gypsum dunes are found at the White Sands National Monument in New Mexico, for example, and there are calcite dunes in Bermuda and areas in the Caribbean.

CONTENTS

Table 8-1 Types of Sand Dunes

Type	Shape	Size	Area of formation
Barchan		Maximum size: 30 m high, 300 m point to point.	The most common dunes. Generally form in areas of constant wind direction. Migrate 8–15 m per year.
Transverse		Maximum height: 25 m.	Form in areas with strong winds and abundant sand.
Parabolic		Maximum height: 30 m.	Form in areas with moderate winds and some vegetation. Include extremely curved types called hairpin dunes. Common on seacoasts.
Longitudinal		Maximum height: 90 m. Can be 100 km long. Average dimensions are 8 m in height and 60 m in length.	Form in areas with high, somewhat variable winds and little sand.

Types of Dunes Dunes are classified according to their shapes, as shown in ***Table 8-1.*** Barchan dunes are solitary, crescent-shaped dunes that form in flat areas where there is little sand or vegetation. Transverse dunes are formed where there is plenty of sand, little or no vegetation, and strong, steady, prevailing winds. Transverse dunes form in a series of long ridges that are perpendicular to the direction of the wind. In humid areas, U-shaped dunes, called parabolic dunes, form between clumps of plants. Where there is limited sand available, strong prevailing winds shape longitudinal dunes, which are parallel to the wind direction.

On offshore islands and on lakeshores, dunes are formed by winds blowing off the water toward the shore. Coastal dunes protect against beach and coastal erosion by reducing the direct action of wind on beach sand. They also act as buffers against the action of waves and provide shelter for vegetation. Once dune vegetation is established, it helps to anchor coastal dunes.

Figure 8-17 This sign was posted to make people aware that dunes are being restored in Okaloosa County, Florida.

Human activities, such as building in coastal-dune areas and removing dune vegetation, have disrupted dune growth and damaged dunes in many coastal areas of the United States. The destruction of dunes has led to increased beach erosion and nearshore flooding in these locations. Dune restoration areas, as shown in ***Figure 8-17,*** seek to restore and protect dunes in coastal areas.

As shown in ***Figure 8-18,*** dune migration is caused when prevailing winds continue to move sand from the windward side of a dune to its leeward side, thereby causing the dune to move slowly over time. As long as winds continue to blow, dunes continue to migrate and cover anything in their paths. Migrating dunes can block highways and cover farmland. Large dunes can even bury houses and other structures.

Earth Science Online

Topic: Wind Erosion
To find out more about wind erosion, visit the Earth Science Web Site at earthgeu.com

Activity: Research a dune restoration project. Write a newspaper article describing the project.

Loess Wind can carry fine, lightweight particles such as silt and clay in great quantities and for long distances. Many parts of Earth's surface are covered by thick layers of windblown silt, which are thought to have accumulated as a result of thousands of years of

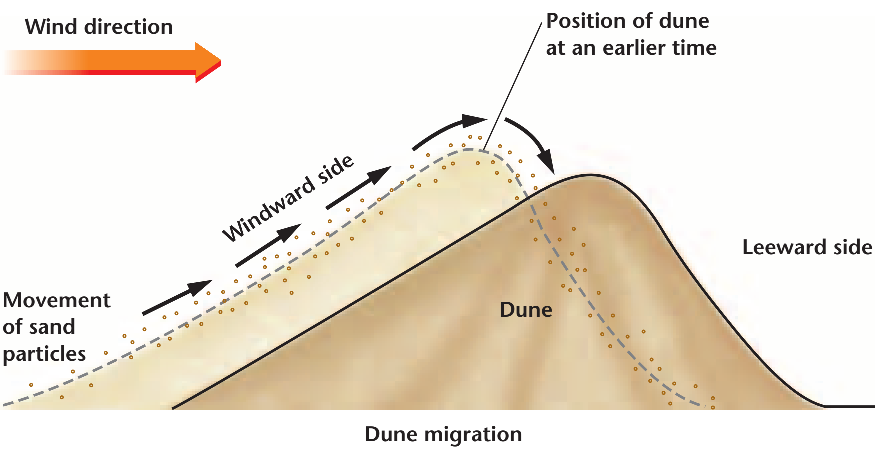


Figure 8-18 As dunes migrate, sand is moved from the windward side to the leeward side over a period of time.

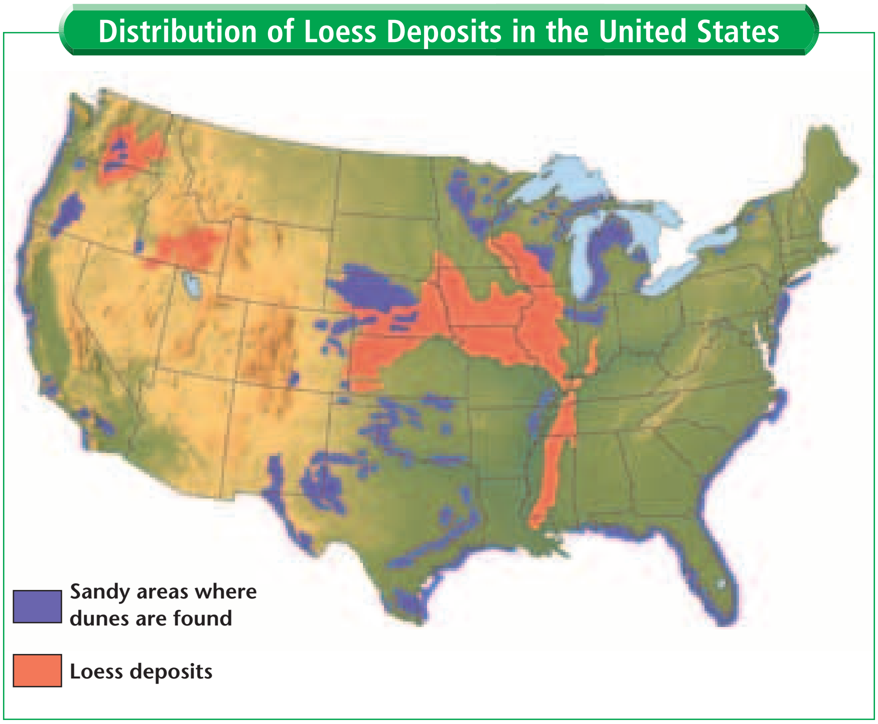


Figure 8-19 This map shows the distribution of loess soil in the United States. ***Where is the largest deposit of loess soil?***

dust storms. The source of these silt deposits may have been the fine sediments that were exposed when glaciers melted after the last ice age, more than 10 000 years ago. These thick, wind-blown silt deposits are known as **loess.** As shown in ***Figure 8-19,*** loess deposits are located in Illinois, Iowa, Missouri, South Dakota, Nebraska, Kansas, and Idaho. Where precipitation is adequate, loess soils are some of the most fertile soils on Earth because they contain abundant minerals and nutrients.

Section Assessment

1. What climatic conditions are most likely to produce wind erosion?
2. How does the vegetation growing in an area affect the wind's ability to modify the surface of Earth?
3. Draw a diagram showing how deflation occurs in wind erosion.
4. Why is wind abrasion such an effective agent of erosion?
5. How do dunes form?
6. **Thinking Critically** How can wind erosion directly affect human activities?

Skill Review

7. **Inferring** Describe the differences in appearance of wind-worn particles and water-worn particles. For more help, refer to the *Skill Handbook.*

SECTION 8.3 Glaciers

OBJECTIVES

- **Explain** *how glaciers form.*
- **Compare** *and* **contrast** *the conditions that produce valley glaciers and those that produce continental glaciers.*
- **Describe** *how glaciers modify the landscape.*
- **Recognize** *glacial landscape features.*

VOCABULARY

glacier
valley glacier
continental glacier
cirque
moraine
outwash plain
drumlin
esker

Glaciers formed much of the landscape that exists presently in the northern United States and elsewhere in the world. Glaciers shape the landscape by eroding, transporting, and depositing huge volumes of rocks and sediments. Today, scientists measure the movements of glaciers and changes in their sizes to track climatic changes. Air bubbles trapped deep in glacial ice can provide data about the composition of Earth's atmosphere at the time when these ancient ice layers were formed. Scientists can also study ice cores in glaciers to learn about Earth's environmental past, as shown in the *Problem-Solving Lab* in this section.

MOVING MASSES OF ICE

A large, moving mass of ice is called a **glacier.** Glaciers form near Earth's poles and in mountainous areas at high elevations. They currently cover only about 10 percent of Earth's surface, as shown in ***Figure 8-20.*** Even in the past, when glaciers were much more widespread than they are today, many areas of the world did not experience glacial activity. For example, during the last ice age, which began about 1.6 million years ago and ended over 10 000 years ago, ice probably covered only about 30 percent of Earth.

Areas of high latitude, such as Greenland and Antarctica, and areas of high elevation, such as the Alps, have cold temperatures year-round. Cold temperatures keep fallen snow from completely melting, and each year, the snow that has not melted accumulates in

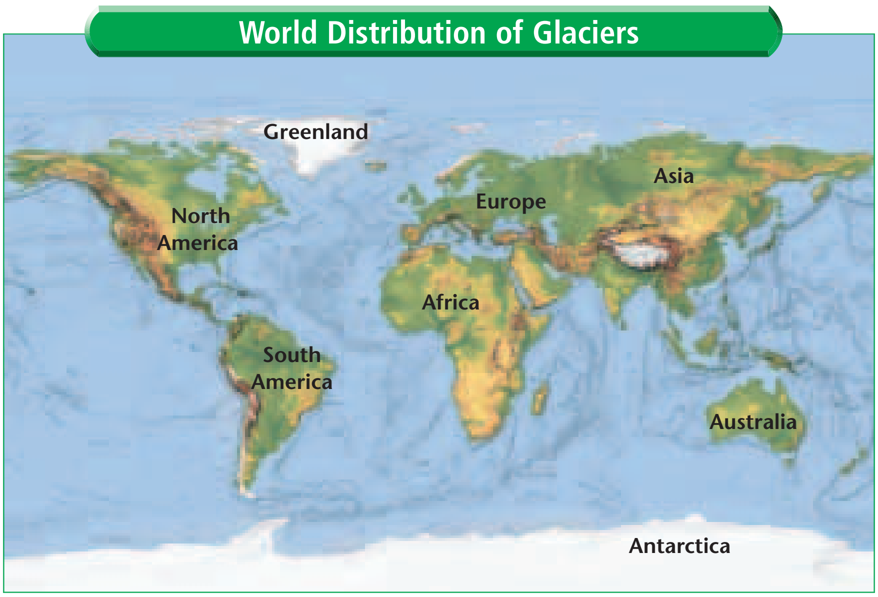


Figure 8-20 This map shows glacial distribution throughout the world. ***Locate the glacial areas in white. Are all glaciers located only in the polar regions?***

Figure 8-21 The Mendenhall Glacier is a valley glacier located in the Tongas National Forest near Juneau, Alaska.

an area called a snowfield. Thus, the total thickness of the snow layer increases as the years pass, and a glacier begins to form. The weight of the top layers of snow eventually exerts enough downward pressure to force the accumulated snow below to recrystallize into ice. This recrystallization is familiar to you if you have ever made a snowball: firmly compacting the snowball in your hands causes it to recrystallize, or partially melt to form ice. A glacier can develop in any location that provides the necessary conditions. For example, small glaciers form even in mountainous tropical areas along the equator, such as in Chile.

Valley Glaciers Glaciers can be classified as one of two types: valley glaciers or continental glaciers as shown in ***Figures 8-21*** and ***8-22.*** Glaciers that form in valleys in high, mountainous areas are called **valley glaciers.** A valley glacier is shown in ***Figure 8-21.*** The movement of a valley glacier occurs when the growing ice mass

Figure 8-22 This continental glacier is located on Antarctic Peninsula.

becomes too heavy to maintain its rigid shape and begins to flow, much like a thick liquid. For most valley glaciers, flow begins when the accumulation of snow and ice exceeds 20 m in thickness. As a valley glacier moves, deep cracks in the surface of the ice, called crevasses, can form.

The speed of a valley glacier's movement is affected by the slope of the valley floor, the temperature and thickness of the ice, and the shape of the valley walls. The sides and bottom of a valley glacier move more slowly than the middle because friction slows down the sides and bottom, where the glacier comes in contact with the ground. Movement downslope is usually very slow, less than a few millimeters per day. You will learn more about the rates of glacial movement in the *Science & Math* feature at the end of this chapter. As valley glaciers flow downslope, their powerful carving action widens V-shaped stream valleys into U-shaped glacial valleys.

NATIONAL GEOGRAPHIC

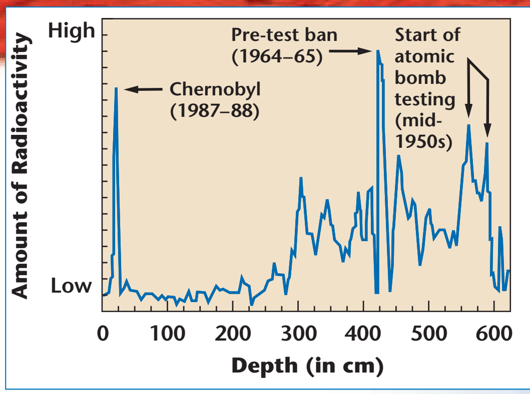
To learn more about glaciers, go to the **National Geographic Expedition** on page 874.

Continental Glaciers Glaciers that cover broad, continent-sized areas, such as the one shown in ***Figure 8-22,*** are called **continental glaciers.** They form under the same climatic conditions as valley glaciers, but they move in a different way. A continental glacier is

Problem-Solving Lab

Using Graphs

Observe how ice cores record history Scientists drill ice cores from glaciers and study them to learn about the past. Ice cores taken from the arctic region, for example, have been found to contain preserved radioactive fallout. Data collected from the study of these ice cores have been plotted on the graph. Use the graph to answer the following questions.



Analysis

1. At what depth in the ice cores was the highest amount of radioactivity found? At what depth was the lowest amount found?
2. Describe what happened to the amount of radioactivity in the ice cores between the pre-test ban and Chernobyl.
3. Infer what happened to the amount of radioactivity in the ice cores after Chernobyl.

Thinking Critically

4. What information or material other than radioactive fallout do you think ice cores might preserve within them?

thickest at its center. The weight of this thicker central region forces the rest of the glacier to flatten out in all directions. Continental glaciers, also called ice sheets, are much larger than valley glaciers. During periods in the past, when Earth experienced colder average temperatures than it does today, continental glaciers covered huge portions of Earth's surface. Today's continental glaciers cover much smaller areas, and they are confined to Greenland, northern Canada, and Antarctica.

Figure 8-23 Glacial striations are found on quartzite rocks located in Blue Mounds State Park in Minnesota.

Glacial Erosion

Of all the erosional agents, glaciers are the most powerful because of their great size, weight, and density. When a valley glacier moves, it breaks off pieces of rock through a process called plucking. Fallen rocks also accumulate along the edges of glaciers and give the sides a striped appearance. When glaciers with embedded rocks move over bedrock valley walls, they act like the grains on a piece of sandpaper, grinding out parallel scratches into the bedrock, as shown in ***Figure 8-23.*** Small scratches are called striations, and the larger ones are called grooves. Scratches and grooves provide evidence of a glacier's history and establish its direction of movement.

Glacial erosion can create certain features, as shown in ***Figure 8-24.*** In addition to carving U-shaped valleys, valley glaciers also scoop out deep depressions, called **cirques.** Where two cirques on opposite sides of a valley meet, they form a sharp, steep ridge called an arete. Where

Figure 8-24 Glacial features include hanging valleys, cirques, waterfalls, U-shaped valleys, horns, and aretes.

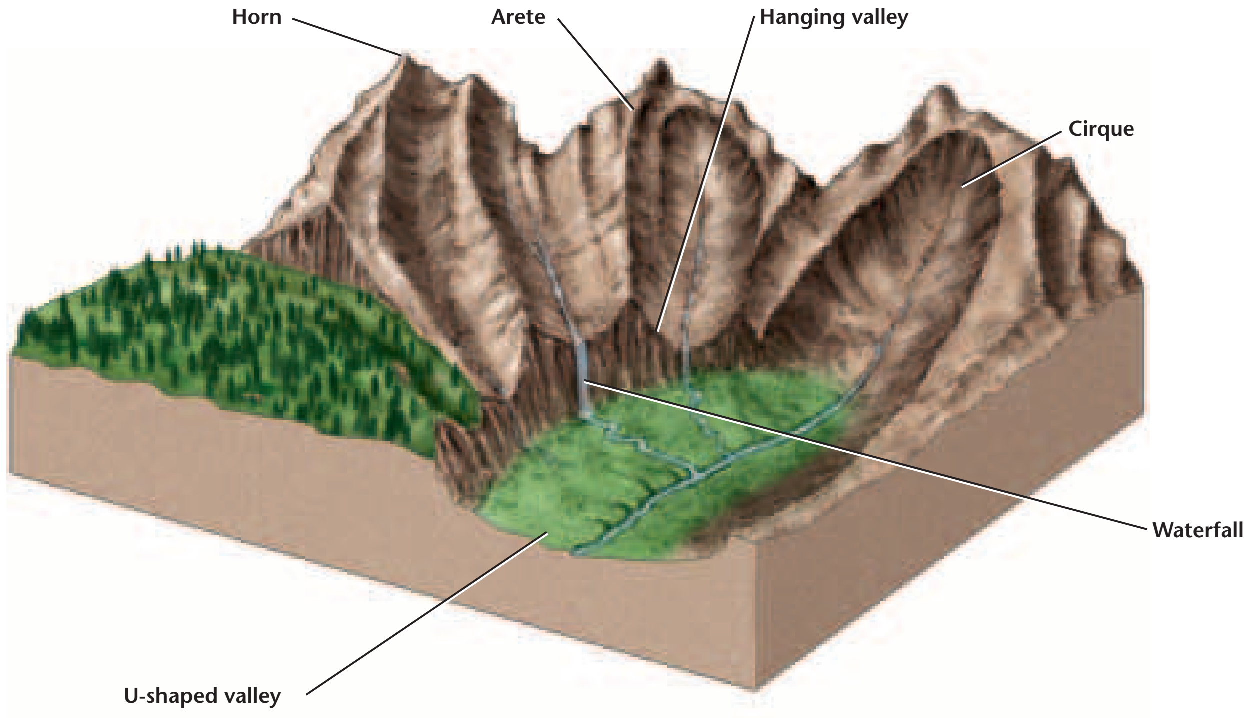


Figure 8-25 This terminal moraine was formed on Exit Glacier in Kenai Fjords National Park, in Alaska.

there are glaciers on three or more sides of a mountaintop, a steep, pyramid-shaped peak forms. This is known as a horn. The most famous example of this feature is Switzerland's Matterhorn. A tributary valley that enters a U-shaped valley from high up a mountain side is called a hanging valley.

GLACIAL DEPOSITION

Glacial till is the mixed debris that glaciers carry embedded in their ice and on their tops, sides, and front edges. When a glacier melts, glacial till is left behind. Ridges consisting of till deposited by glaciers are called **moraines.** Those at the foot of a large glacier are called terminal moraines, shown in ***Figure 8-25,*** and those at its sides are called lateral moraines. Where two glaciers join together, their lateral moraines combine to form a medial moraine.

Outwash When a glacier melts and begins to recede, meltwater floods the valley below. Meltwater contains gravel, sand, and fine silt formed from the grinding action of the glacier on underlying rock. When this sediment is deposited by meltwater, it is called outwash. The area at the leading edge of the glacier, where the meltwater streams flow and deposit outwash, is called an **outwash plain.**

Drumlins and Eskers Glaciers that move over older moraines form the material into elongated landforms called **drumlins.** A drumlin's steeper slope faces the direction from which the glacier came. Drumlin fields are found in Wisconsin, Massachusetts, and New York State. Long, winding ridges of layered sediments that are deposited by streams flowing under a melting glacier are called **eskers.**

Figure 8-26 This kettle lake, which was formed in glacial till, is located in Glacial Lakes State Park, Minnesota **(A).** This cirque lake is located in the western Cascade Mountains, in the state of Washington **(B).**

Glacial Lakes Sometimes, a large block of ice breaks off a glacier and is later covered by sediment. When the ice block melts, it leaves behind a depression called a kettle hole. After the ice block melts, the kettle hole fills with water from precipitation and runoff to form a kettle lake. Kettle lakes, such as the one shown in ***Figure 8-26A,*** are common in New England, New York State, and Wisconsin. As shown in ***Figure 8-26B,*** cirques also can fill with water, and they become cirque lakes. When a terminal moraine blocks off a valley, the valley fills with water to form a lake. Moraine-dammed lakes include the Great Lakes and the Finger Lakes of northern New York State which are long and narrow.

Mass movements, wind, and glaciers all contribute to the changing of Earth's surface. These processes constantly wear down landforms, and in many ways, they also impact human populations and activities.

SECTION ASSESSMENT

1. Explain how valley glaciers and continental glaciers form.
2. Draw a glacial landscape and label the glacial features.
3. How can a valley glacier modify the mountainous area where it forms? What glacial features form in mountainous areas?
4. How is a kettle lake formed?
5. **Thinking Critically** What evidence of past glaciers can be found on Earth today?

SKILL REVIEW

6. **Comparing and Contrasting** Make a data table that compares and contrasts the characteristics of valley glaciers and continental glaciers. For more help, refer to the *Skill Handbook.*

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Mapping GeoLab

Mapping a Landslide

Around midday on April 27, 1993, in a normally quiet, rural area of New York State, the landscape dramatically changed. Unexpectedly, almost 1 million m^3 of earth debris slid over 300 m down the lower slope of Bare Mountain and into Tully Valley. The debris flowed over the road and buried nearby homes. The people who lived there had no knowledge of any prior landslides occurring in the area, yet this landslide was the largest to occur in New York State in more than 75 years. What caused this large mass of earth material to move so suddenly?

Preparation

Problem

How can you use a drawing based on a topographic map to infer how the Tully Valley Landslide occurred?

Materials

metric ruler
pencil

Procedure

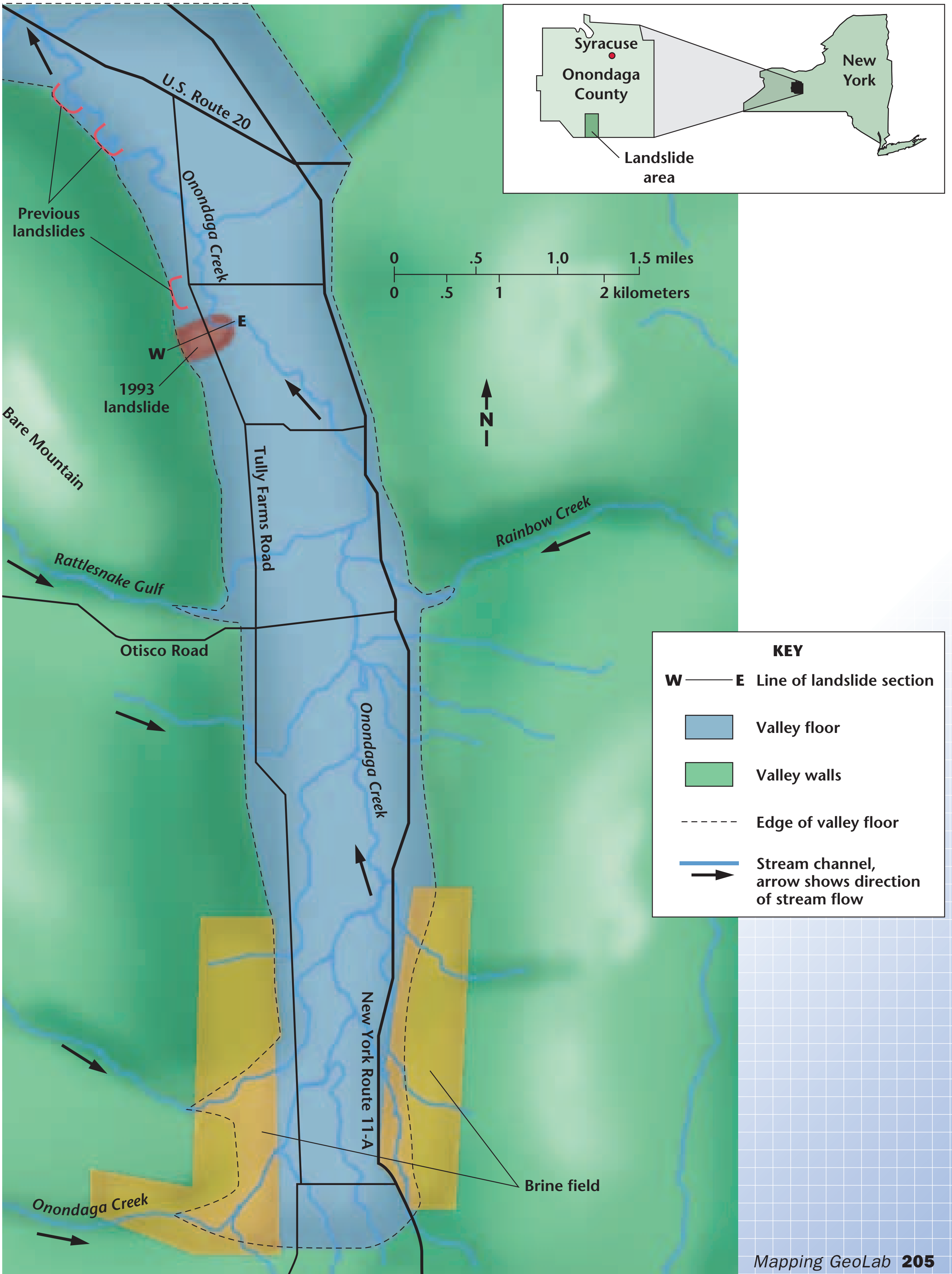
1. Use the map to answer the following questions. Be sure to check the map's scale.
2. Measure the length and width of the Tully Valley in kilometers. Double-check your results.

Analyze

1. What does the shape of the valley tell you about how it formed?
2. In what direction did the landslide flow?
3. In what direction does the Onondaga Creek flow?
4. Infer from the map, which side of Tully Valley has the steepest valley walls.
5. What conditions must have been present for the landslide to occur?
6. At the time of the Tully Valley Landslide, the trees were bare. How could this have affected the conditions that caused the landslide?

Conclude & Apply

1. Why do you think the Tully Valley Landslide occurred?
2. If you planned to move into an area prone to mass movements, such as landslides, what information would you gather beforehand?



Syracuse
Onondaga County
New York
Landslide area
U.S. Route 20
Previous landslides
Onondaga Creek
E
W
1993 landslide
0 .5 1.0 1.5 miles
0 .5 1 2 kilometers
N
Bare Mountain
Tully Farms Road
Rainbow Creek
Rattlesnake Gulf
Otisco Road
Onondaga Creek
New York Route 11-A
Brine field
Onondaga Creek
KEY
W —— E Line of landslide section
Valley floor
Valley walls
Edge of valley floor
Stream channel, arrow shows direction of stream flow

Science & Math

Rates of Glacial Movement

Rates are commonly used in everyday life. An example of a rate is the number of kilometers that a car travels per hour. A rate is a ratio of measurements, where one measurement is time. The most commonly used rate is distance per unit of time, also called speed.

Scientists who want to measure how fast a glacier moves typically refer to the overall speed of the glacier's movement. However, this is only an average, because a glacier moves at many different rates. A glacier is similar to a river in that the outside edges of a glacier move more slowly than the middle as a result of friction with the banks. A cross section of a glacier from top to bottom shows how different horizontal levels of the glacier move. The top surface of a glacier may move more quickly than the bottom surface.

Making the Measurements

To measure the rate of a glacier moving at various speeds, scientists calculate the glacier's average speed. The average speed of a glacier is the sum of the different speeds within the glacier divided by the total number of measurements.

Scientists can measure the difference in speed from the top surface of a glacier to the bottom by drilling into the glacier and placing a rod through the hole. After a period of time, the rod leans in the direction of the glacier's movement. The table at right shows data obtained from a rod placed in the Worthington Glacier in Alaska after 66 days. The distance the glacier moved at different depths is given in the table. The depths were measured from the surface of the glacier.

Procedure

1. Using the rod data, calculate the speed at which the glacier moved at each depth.

Rod Data from Worthington Glacier

Depth (m)	Distance (m)	Average Speed = Distance/Time
0	13.1	0.198 m/day
20	13.1	0.198 m/day
60	12.8	0.194 m/day
100	12.2	0.185 m/day
140	11.2	0.170 m/day
180	9.57	0.145 m/day
	Average Speed of Glacier	0.182 m/day

2. After you compute the speed calculations for all depths, average them together to find the average speed of the glacier.

Challenge

1. Note that the top surface of the glacier did not move as quickly as the portion of the glacier 20 m deep. What are some possible reasons for this?
2. Graph the average speed of the glacier at each depth. Do you notice a trend? If scientists drilled another 40 m, what would the speed of the glacier's movement be at that depth?

Earth Science Online

To find out more about the rates of glacial movement, visit the Earth Science Web Site at earthgeu.com

Study Guide

Summary

SECTION 8.1

Mass Movements at Earth's Surface

Main Ideas

- Mass movement is the movement of Earth materials downslope as the result of the force of gravity. Almost all of Earth's surface undergoes mass movement.
- Mass movements may occur very slowly and become noticeable only over long periods of time. Creep is a form of slow mass movement. Rapid mass movements are noticeable.
- Variables involved in the mass movement of Earth materials include the material's weight, its resistance to sliding, and sometimes a trigger such as an earthquake. Water is important to the process of mass movement.
- Mass movements can cause great damage and loss of lives. Human activities may increase the potential for the occurrence of mass movements.

Vocabulary

avalanche (p. 187)
creep (p. 184)
landslide (p. 186)
mass movement (p. 181)
mudflow (p. 185)
slump (p. 187)

SECTION 8.2

Wind

Main Ideas

- Arid, semi-arid, and seashore environments are likely to experience wind erosion. Limited amounts of precipitation and protective vegetation commonly contribute to wind erosion in an area.
- Wind-carried sediments can cause abrasive action. Rocks exposed to continual wind abrasion often exhibit angular shapes with polished, smooth sides on the windward side. Features formed in wind-affected areas include deflation blowouts, dunes, and desert pavement. Dunes are classified by shape.
- The transport of Earth materials by wind can create problems for humans. Migrating dunes can block highways and cover structures.
- Loess soils deposited by wind are fertile soils because they contain minerals and nutrients.

Vocabulary

abrasion (p. 193)
deflation (p. 192)
dune (p. 194)
loess (p. 197)
ventifact (p. 193)

SECTION 8.3

Glaciers

Main Ideas

- Glaciers are large, moving masses of ice that form near Earth's poles and in mountainous areas at high elevations.
- Valley glaciers are formed in mountains, and continental glaciers are formed over broad regions of land. Valley glaciers move down mountainsides and form unique glacial features. Continental glaciers usually spread out from their centers.
- Features formed by glaciers include U-shaped valleys, hanging valleys and waterfalls in the mountains, moraines, drumlins, kettle holes along outwash plains, and several types of lakes.

Vocabulary

cirque (p. 201)
continental glacier (p. 200)
drumlin (p. 202)
esker (p. 202)
glacier (p. 198)
moraine (p. 202)
outwash plain (p. 202)
valley glacier (p. 199)

earthgeu.com/vocabulary_puzzlemaker

CHAPTER 8

Assessment

Understanding Main Ideas

1. What underlying force causes all forms of mass movement?
   a. friction
   b. gravity
   c. magnetism
   d. the Coriolis effect

2. Which of the following is an example of a slow mass movement?
   a. a mudflow
   b. a landslide
   c. creep
   d. an avalanche

3. Which of the following has the greatest erosional power?
   a. wind
   b. a landslide
   c. an avalanche
   d. a glacier

4. What is the movement of dunes called?
   a. ablation
   b. abrasion
   c. deflation
   d. migration

5. What percentage of Earth's surface is covered by glaciers?
   a. 5 percent
   b. 10 percent
   c. 15 percent
   d. 20 percent

6. Which feature is NOT formed by glaciers?
   a. moraines
   b. drumlins
   c. kettle holes
   d. dunes

7. Which state is most likely to experience wind erosion?
   a. Louisiana
   b. Kentucky
   c. Connecticut
   d. Utah

8. Which of the following has the fastest movement?
   a. solifluction
   b. creep
   c. mudflow
   d. earth flow

9. Which particles can wind move most easily?
   a. sand
   b. pebbles
   c. silt
   d. gravel

Applying Main Ideas

10. What human activity contributed to the dust storms in the Great Plains in the 1930s?
11. What mass movements are dependent on the addition of water?
12. Draw a simple diagram of the four major types of sand dunes. Then draw an arrow to show the direction of wind movement across each of the dunes.
13. Why is loess soil usually fertile?
14. How do particles eroded by wind differ from particles eroded by water?
15. What features on Earth's surface are characteristic of an outwash plain?
16. Give an example of one type of mass movement that could be caused by human activity.
17. Why do some glacial depositions have sorted sediments, while others do not?
18. How is it possible that glaciers exist at the equator?
19. How do valley glaciers form?
20. Why are some glacial lakes long and narrow, while others are round?
21. Why is wind abrasion such an effective agent of erosion?
22. What is one way to reduce the number of disasters related to mass movements?

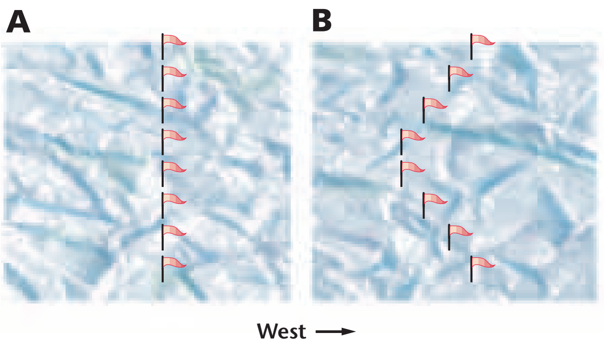
Test-Taking Tip

USE THE BUDDY SYSTEM Study in groups. A small gathering of people works well because it allows you to draw from a broader base of skills and expertise. However, keep the group small and keep on target.

Thinking Critically

Use the following information and diagram to answer questions 23 and 24.

A person studying glaciers placed flags on tall rods across a valley glacier, as shown in diagram A. When the person returned to the site the following year, the flag rods were in the positions shown in diagram B.



23. Based on the change in the positions of the flag rods, in which direction is the glacier moving?
a. north **b.** south **c.** east **d.** west

24. What can you tell about the rate of speed of different parts of the glacier?

25. **Concept Mapping** Use the following terms to construct a concept map of mass movements. For more help, refer to the *Skill Handbook.*

fast	slow	thick soil
loose materials	snow	crescent shaped
slump	creep	avalanche

Standardized Test Practice

INTERPRETING DATA Use the table below to answer questions 1-2.

Region	Characteristics
A	semi-arid; experiences intense but brief rainstorms
B	permafrost; much loose, water-logged material
C	mountainous; thick accumulations of snow
D	thick soils on semi-steep and steep slopes; occasional earthquake activity
E	arid; high cliffs and rocky shorelines

1. Which mass movement is most likely to occur in Region A?
a. mudflow **c.** slump
b. avalanche **d.** rock fall

2. Which mass movement is most likely to occur in Region B?
a. solifluction **c.** avalanche
b. mudflow **d.** slump

3. What are dunes a result of?
a. wind erosion **c.** wind deposition
b. deflation **d.** abrasion

4. Which of the following is NOT a feature of valley glaciers?
a. cirques **c.** moraines
b. loess **d.** arete

5. What is it called when wind transports materials by causing a bouncing motion of particles?
a. suspension **c.** saltation
b. deflation **d.** abrasion

earthgeu.com/standardized_test