Mass Wasting: The Work of Gravity

CHAPTER

15

This debris flow at La Conchita, California, in January 2005, was triggered by extraordinary rains. Read a case study in Box 15.1. (Photo by David McNew/ Getty Images)

Earth's surface is never perfectly flat, but instead consists of slopes of many different varieties. Some are steep and precipitous; others are moderate or gentle. Some are long and gradual; others are short and abrupt. Slopes can be mantled with soil and covered by vegetation or consist of barren rock and rubble. Taken together, slopes are the most common elements in our physical landscape. Although most slopes may appear to be stable and unchanging, the force of gravity causes material to move downslope. At one extreme, the movement may be gradual and practically imperceptible. At the other extreme, it may consist of a roaring debris flow or a thundering rock avalanche. Landslides are a worldwide natural hazard. When these hazardous processes lead to loss of life and property, they become natural disasters.

Landslides as Natural Disasters

Even in areas with steep slopes, catastrophic landslides are relatively rare occurrences. As a result people living in susceptible areas often do not appreciate the risk of living where they do. However, media reports remind us that such events occur with some regularity around the world (Figure 15.1). The three examples described here occurred during a span of just four months.

On October 8, 2005, a magnitude 7.6 earthquake struck the Kashmir region between India and Pakistan. Compounding the tragic effects caused directly by the severe ground shaking were hundreds of landslides triggered by the quake and its many aftershocks. Rockfalls and debris slides thundered down steep mountain slopes and were focused into narrow valleys where many people made their homes. The landslides also blocked roads and trails, delaying attempts to reach those in need.

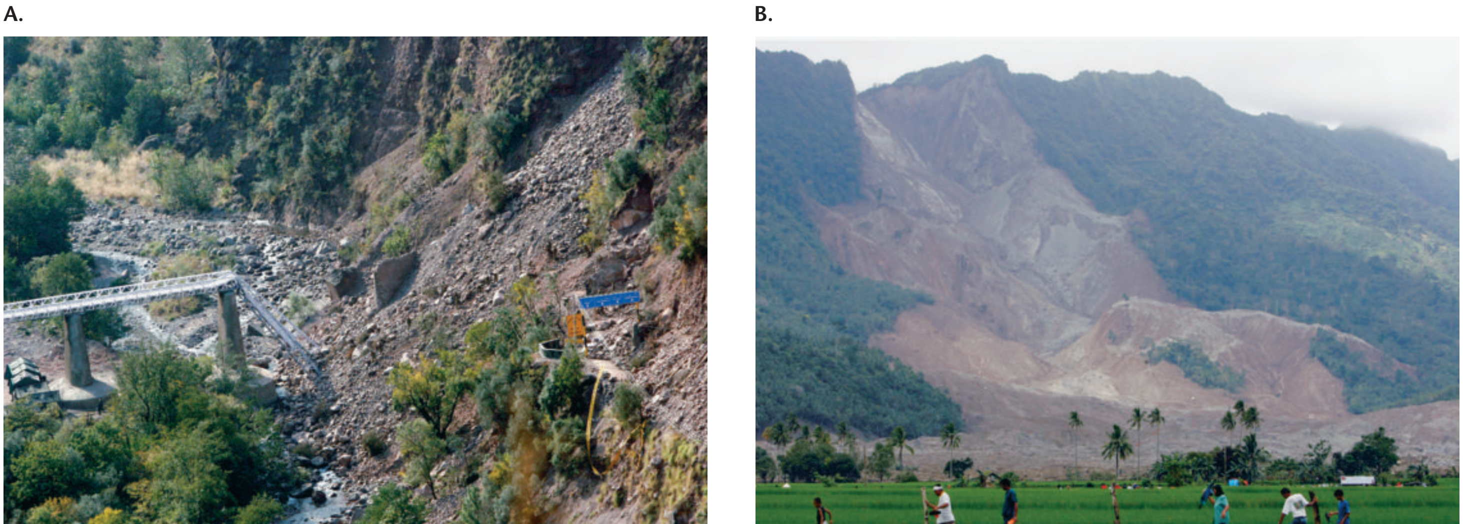
Just three days earlier, on October 5, 2005, torrential rains from Hurricane Stan triggered mudflows in Guatemala. A slurry of mud 1 kilometer wide and up to 12 meters (40 feet) deep buried the village of Panabaj. Death toll estimates for the area approached 1400 people. Flows such as this can travel at speeds of 50 kilometers (30 miles) per hour down rugged mountain slopes.

On February 17, 2006, only a few months after the tragedy in Central America, a lethal mudflow triggered by extraordinary rains buried a small town on the Philippine island of Leyte. A mass of mud engulfed this remote coastal area to depths as great as 10 meters (30 feet). Although an accurate count of fatalities was difficult, as many as 1800 people perished. This region is prone to such events due in part to the fact that deforestation has denuded the nearby mountain slopes. In the pages that follow you will take a closer look at rapid mass-wasting events in an attempt to better understand their causes and effects.

Mass Wasting and Landform Development

Landslides are spectacular examples of a basic geologic process called mass wasting. **Mass wasting** refers to the downslope movement of rock, regolith, and soil under the

FIGURE 15.1 **A.** On October 8, 2005, a major earthquake in Kashmir triggered hundreds of landslides including the one shown here. (AP Photo/Burhan Ozblici) **B.** In February 2006, heavy rains triggered this mudflow that buried a small town on the Philippine island of Leyte. (AP Photo/Pat Roque)



direct influence of gravity. It is distinct from the erosional processes that are examined in subsequent chapters because mass wasting does not require a transporting medium such as water, wind, or glacial ice.

The Role of Mass Wasting

In the evolution of most landforms, mass wasting is the step that follows weathering. By itself, weathering does not produce significant landforms. Rather, landforms develop as products of weathering are removed from the places where they originate. Once weathering weakens and breaks rock apart, mass wasting transfers the debris downslope, where a stream, acting as a conveyor belt, usually carries it away. Although there may be many intermediate stops along the way, the sediment is eventually transported to its ultimate destination: the sea.

The combined effects of mass wasting and running water produce stream valleys, which are the most common and conspicuous of Earth's landforms. If streams alone were responsible for creating the valleys in which they flow, the valleys would be very narrow features. However, the fact that most river valleys are much wider than they are deep is a strong indication of the significance of mass-wasting processes in supplying material to streams. This is illustrated by the Grand Canyon (Figure 15.2). The walls of the canyon extend far from the Colorado River, owing to the transfer of weathered debris downslope to the river and its tributaries by mass-wasting processes. In this manner, streams and mass wasting combine to modify and sculpt the surface. Of course, glaciers, groundwater, waves, and wind are also important agents in shaping landforms and developing landscapes.

Students Sometimes Ask . . .

It seems as though you have used the term "landslide" to refer to several different things—from mudflows to rock avalanches. What exactly is the definition of "landslide"?

Although many people, including geologists, frequently use the word *landslide,* the term has no specific definition in geology. Rather, it is a popular nontechnical term used to describe any or all relatively rapid forms of mass wasting.

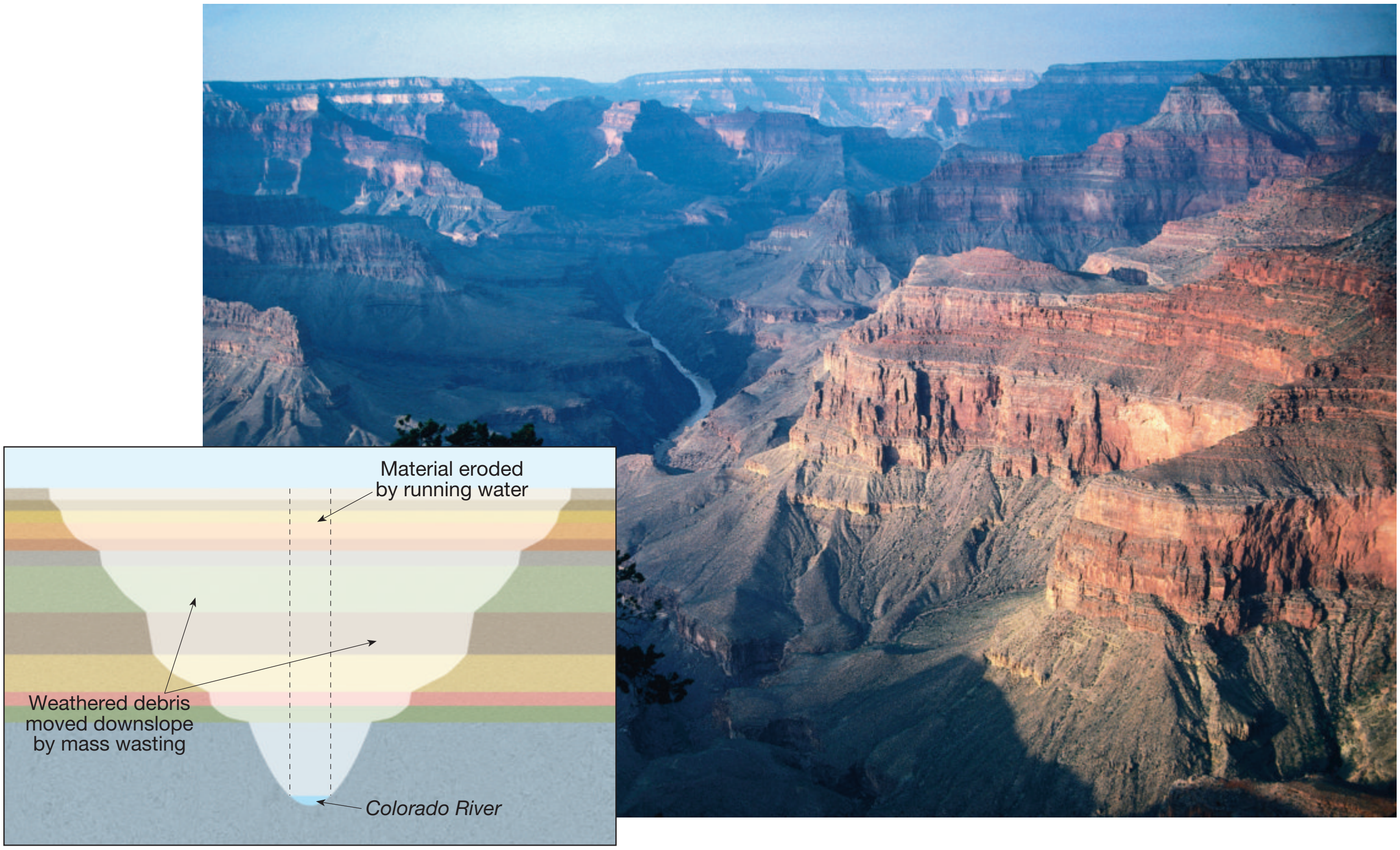


FIGURE 15.2 The walls of the Grand Canyon extend far from the channel of the Colorado River. This results primarily from the transfer of weathered debris downslope to the river and its tributaries by mass wasting processes. (Photo by Tom and Susan Bean, Inc.)

Slopes Change through Time

It is clear that if mass wasting is to occur, there must be slopes that rock, soil, and regolith can move down. It is Earth's mountain building and volcanic processes that produce these slopes through sporadic changes in the elevations of landmasses and the ocean floor. If dynamic internal processes did not continually produce regions having higher elevations, the system that moves debris to lower elevations would gradually slow and eventually cease.

Most rapid and spectacular mass-wasting events occur in areas of rugged, geologically young mountains. Newly formed mountains are rapidly eroded by rivers and glaciers into regions characterized by steep and unstable slopes. It is in such settings that massive destructive landslides, such as the Yungay disaster, occur. As mountain building subsides, mass wasting and erosional processes lower the land. Through time, steep and rugged mountain slopes give way to gentler, more subdued terrain. Thus, as a landscape ages, massive and rapid mass-wasting processes give way to smaller, less dramatic downslope movements.

Controls and Triggers of Mass Wasting

Mass Wasting
▸ Controls and Triggers of Mass Wasting

Gravity is the controlling force of mass wasting, but several factors play an important role in overcoming inertia and creating downslope movements. Long before a landslide occurs, various processes work to weaken slope material, gradually making it more and more susceptible to the pull of gravity. During this span, the slope remains stable but gets closer and closer to being unstable. Eventually, the strength of the slope is weakened to the point that something causes it to cross the threshold from stability to instability. Such an event that initiates downslope movement is called a *trigger.* Remember that the trigger is not the sole cause of the mass-wasting event but just the last of many causes. Among the common factors that trigger mass-wasting processes are saturation of material with water, oversteepening of slopes, removal of anchoring vegetation, and ground vibrations from earthquakes.

The Role of Water

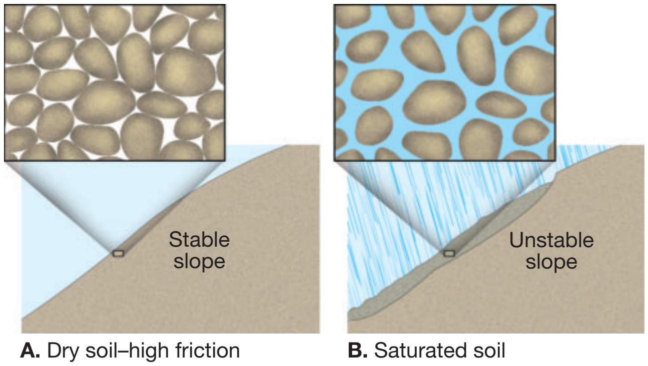
Mass wasting is sometimes triggered when heavy rains or periods of snowmelt saturate surface materials. This was the case in October 1998 when torrential downpours associated with Hurricane Mitch triggered devastating mudflows in Central America (Figure 15.3). Box 15.1 presents a case study of another event that occurred at La Conchita, California, in January 2005.

When the pores in sediment become filled with water, the cohesion among particles is destroyed, allowing them to slide past one another with relative ease. For example, when sand is slightly moist, it sticks together quite well. However, if enough water is added to fill the openings between the grains, the sand will ooze out in all directions (Figure 15.4). Thus, saturation reduces the internal resistance of materials, which are then easily set in motion by the force of gravity. When clay is wetted, it becomes very slick— another example of the "lubricating" effect of water. Water also adds considerable weight to a mass of material. The added weight in itself may be enough to cause the material to slide or flow downslope.

Oversteepened Slopes

Oversteepening of slopes is another trigger of many mass movements. There are many situations in nature where oversteepening takes place. A stream undercutting a valley wall and waves pounding against the base of a cliff are but two familiar examples. Furthermore, through their activities, people often create oversteepened and unstable slopes that become prime sites for mass wasting.

FIGURE 15.3 Heavy rains from Hurricane Mitch in the fall of 1998 triggered devastating mudflows in Central America. Water plays an important role in many mass-wasting processes. (Associated Press Photo)



A. Dry soil–high friction **B.** Saturated soil

FIGURE 15.4 The effect of water on mass wasting can be great. **A.** When little or no water is present, friction among the closely packed soil particles on the slope holds them in place. **B.** When the soil is saturated, the grains are forced apart and friction is reduced, allowing the soil to move downslope.

FIGURE 15.5 The angle of repose for this granular material is about 30°. (Photo by G. Leavens/Photo Researchers)

Unconsolidated, granular particles (sand-size or coarser) assume a stable slope called the **angle of repose** (*reposen* = to be at rest).This is the steepest angle at which material remains stable (Figure 15.5). Depending on the size and shape of the particles, the angle varies from 25 to 40 degrees. The larger, more angular particles maintain the steepest slopes. If the angle is increased, the rock debris will adjust by moving downslope.

Oversteepening is not just important because it triggers movements of unconsolidated granular materials. Oversteepening also produces unstable slopes and mass movements in cohesive soils, regolith, and bedrock. The response will not be immediate, as with loose, granular material, but sooner or later, one or more mass-wasting processes will eliminate the oversteepening and restore stability to the slope.

Removal of Vegetation

Plants protect against erosion and contribute to the stability of slopes because their root systems bind soil and regolith together. In addition, plants shield the soil surface from the erosional effects of raindrop impact (see Figure 6.23, p. 185). Where plants are lacking, mass wasting is enhanced, especially if slopes are steep and water is plentiful. When anchoring vegetation is removed by forest fires or by people (for timber, farming, or development), surface materials frequently move downslope.

An unusual example illustrating the anchoring effect of plants occurred several decades ago on steep slopes near Menton, France. Farmers replaced olive trees, which have deep roots, with a more profitable but shallow-rooted crop: carnations. When the less stable slope failed, the landslide took 11 lives.

In July 1994 a severe wildfire swept Storm King Mountain west of Glenwood Springs, Colorado, denuding the slopes of vegetation. Two months later heavy rains resulted in numerous debris flows, one of which blocked Interstate 70 and threatened to dam the Colorado River. A 5-kilometer (3-mile) length of the highway was inundated with tons of rock, mud, and burned trees. The closure of Interstate 70 imposed costly delays on this major highway. Following extensive wildfires that occurred in the summer of 2000, similar types of mass wasting threaten highways and other development near fire-ravaged hillsides throughout the West (Figure 15.6).

In addition to eliminating plants that anchor the soil, fire can promote mass wasting in other ways. Following a wildfire, the upper part of the soil may become dry and loose. As a result, even in dry weather, the soil tends to move down steep slopes. Moreover, fire can also “bake” the ground, creating a water-repellant layer at a shallow depth. This nearly impermeable barrier prevents or slows the infiltration of water, resulting in increased surface runoff during rains. The consequence can be dangerous torrents of viscous mud and rock debris.

Earthquakes as Triggers

Conditions that favor mass wasting may exist in an area for a long time without movement occurring. An additional factor is sometimes necessary to trigger the movement. Among the more important and dramatic triggers are earthquakes. An earthquake and its aftershocks can dislodge enormous volumes of rock and unconsolidated material. The event in the Kashmir region described near the beginning of the chapter is one tragic example.

Landslides Triggered by the Northridge Earthquake In January 1994 an earthquake struck the Los Angeles region of southern California. Named for its epicenter in the town of Northridge, the 6.7-magnitude event produced estimated losses of $20 billion. Some of these losses were the result of more than 11,000 landslides in an area of about 10,000 square kilometers (3900 square miles) that were set in

FIGURE 15.6 During summer, wildfires are common occurrences in many parts of the West. Millions of acres are burned each year. The loss of anchoring vegetation sets the stage for accelerated mass wasting. (Photo by Raymond Gehman)

BOX 15.1 ▸ PEOPLE AND THE ENVIRONMENT

Landslide Hazards at La Conchita, California*

Southern California lies astride a major plate boundary defined by the San Andreas Fault and numerous other related faults that are spread across the region. It is a dynamic environment characterized by rugged mountains and steep-walled canyons. Unfortunately this scenic landscape presents serious geologic hazards. Just as tectonic forces are steadily pushing the landscape upward, gravity is relentlessly pulling it downward. When gravity prevails, landslides occur.

As you might expect, some of the region's landslides are triggered by earthquakes. Many others, however, are related to periods of prolonged and intense rainfall. A tragic example of the latter situation occurred on January 10, 2005, when a massive debris flow (popularly called a *mudslide*) swept through La Conchita, California, a small town located about 80 kilometers (50 miles) northwest of Los Angeles (Figure 15.A).

FIGURE 15.A View of the La Conchita debris flow taken four days after the January 2005 event. The light-colored exposed rock in the upper part of the photo is the main scarp of a slide that occurred 10 years earlier in 1995. The January 2005 event (arrow) was a remobilization of a portion of the 1995 landslide. (Photo by Randall Jibson/U.S. Geological Survey)

Although the rapid torrent of mud took many of the town's inhabitants by surprise, such an event should not have been unexpected. Let's briefly examine the factors that contributed to the deadly debris flow at La Conchita.

The town is situated on a narrow coastal strip about 250 meters (800 feet) wide between the shoreline and a steep 180-meter (600-foot) bluff (Figure 15.B). The bluff consists of poorly sorted marine sediments and weakly cemented layers of shale, siltstone, and sandstone.

The deadly 2005 debris flow involved little or no newly failed material, but rather consisted of the remobilization of a portion of a large landslide that destroyed several homes in 1995. In fact, historical accounts dating back to 1865 indicate that landslides in the immediate area have been a regular occurrence. Further, geologic evidence shows that landsliding of a variety of types and scales has probably been occurring at La Conchita for thousands of years.

The most significant contributing factor to the tragic 2005 debris flow was prolonged and intense rain. The event occurred at the end of a span that produced near record amounts of rainfall in Southern California. Wintertime rainfall at nearby Ventura totaled 49.3 centimeters (19.4 inches) as compared to an average value of just 12.2 centimeters (4.8 inches). As Figure 15.C indicates, much of that total fell during the two weeks immediately preceding the debris flow.

This was not the first destructive landslide to strike La Conchita, nor is it likely to

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*Based in part on material prepared by the U.S. Geological Survey.

motion by the quake (Figure 15.7). Most were shallow rock falls and slides, but some were much larger and filled canyon bottoms with jumbles of soil, rock, and plant debris. The debris in canyon bottoms created a secondary threat because it can mobilize during rainstorms, producing debris flows. Such flows are common and often disastrous in southern California.

The mass-wasting processes triggered by the Northridge earthquake destroyed dozens of homes and caused extensive damage to roads, pipelines, and well machinery in oil fields. In some places more than 75 percent of slope areas were denuded by landslides, making them vulnerable to subsequent mass wasting triggered by heavy rains.

Liquefaction Intense ground shaking during earthquakes can cause water-saturated surface materials to lose their strength and behave as fluidlike masses that flow. This process, called *liquefaction,* was a major cause of property damage in Anchorage, Alaska, during the massive 1964 Good Friday earthquake described in Chapter 11.

FIGURE 15.B The larger image is a view down the length of the 2005 La Conchita debris flow. It also depicts the setting of the small town between the ocean and a steep cliff. The arrow on the larger photo is pointing to the house shown on the inset. The flow was quite viscous and moved houses in its path rather than flowing around them. As you can see, the left side of the house was detached and moved. (Photo by Randall Jibson/U.S. Geological Survey)

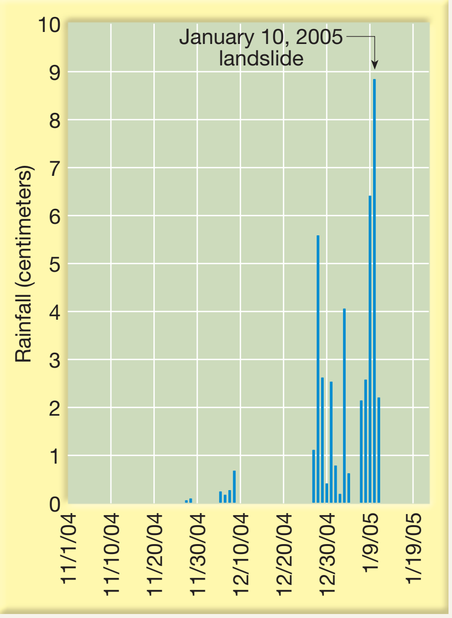

FIGURE 15.C Daily rainfall at the nearby town of Ventura during the weeks leading up to the January 2005 La Conchita event. Each line on the bar graph shows rain for a particular day. The 2005 debris flow occurred at the culmination of the heaviest rainfall of the season. About 80 percent of the season's exceptional total fell in this short span. (After National Weather Service)

be the last. The town's geologic setting and history of rapid mass-wasting events clearly support this notion. When the amount and intensity of rainfall is sufficient, debris flows are to be expected. The concluding paragraph from a U.S. Geological Survey report puts it this way:

> The La Conchita area has experienced, and will likely continue to experience, a rather bewildering variety of landslide hazards. Different landslide scenarios are more or less likely to occur as a result of different specific rainfall conditions, and no part of the community can be considered safe from landslides. Unfortunately, we currently lack the understanding to accurately forecast what might happen in each possible rainfall scenario. Prudence would certainly dictate, however, that we anticipate renewed landslide activity during or after future periods of prolonged and/or intense rainfall. Future earthquakes, of course, also could trigger landsliding in the area.*

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*Jibsen, Randall W. "Landslide Hazards at La Conchita, California," *U.S. Geological Survey Open-File Report 2005-1067*, p. 11.

Landslides without Triggers?

Do rapid mass-wasting events always require some sort of trigger such as heavy rains or an earthquake? The answer is no; such events sometimes occur without being triggered. For example, on the afternoon of May 9, 1999, a landslide killed 10 hikers and injured many others at Sacred Falls State Park near Hauula on the north shore of Oahu, Hawaii. The tragic event occurred when a mass of rock from a canyon wall plunged 150 meters (500 feet) down a nearly vertical slope to the valley floor. Because of safety concerns, the park was closed so that landslide specialists from the U.S. Geological Survey could investigate the site. Their study concluded that the landslide occurred *without triggering* from any discernible external conditions.

Many rapid mass-wasting events occur without a discernible trigger. Slope materials gradually weaken over time under the influence of long-term weathering, infiltration of water, and other physical processes. Eventually, if the strength falls below what is necessary to maintain slope stability, a landslide will occur. The timing of such events is

FIGURE 15.7 Various forms of mass wasting can be triggered by earthquakes. This home in Pacific Palisades, California, was destroyed by a landslide triggered by the January 1994 Northridge earthquake. In some cases, damages from earthquake-induced mass wasting are greater than damages caused directly by an earthquake's ground vibrations. (Photo by Chromo Sohm/Corbis/The Stock Market)

Students Sometimes Ask . . .

How many deaths result from landslides each year?

The U.S. Geological Survey estimates that between 25 and 50 people are killed by landslides annually in the United States. The worldwide death toll, of course, is much higher.

random, and thus accurate prediction is impossible (see Box 15.2).

Classification of Mass-Wasting Processes

There is a broad array of different processes that geologists call mass wasting. Generally, the different types are classified based on the type of material involved, the kind of motion displayed, and the velocity of the movement.

Type of Material

The classification of mass-wasting processes on the basis of the material involved in the movement depends upon whether the descending mass began as unconsolidated material or as bedrock. If soil and regolith dominate, terms such as debris, mud, or earth are used in the description. In contrast, when a mass of bedrock breaks loose and moves downslope, the term rock may be part of the description.

Type of Motion

In addition to characterizing the type of material involved in a mass-wasting event, the way in which the material moves may also be important. Generally, the kind of motion is described as either a fall, a slide, or a flow.

Fall When the movement involves the freefall of detached individual pieces of any size, it is termed a **fall.** Fall is a common form of movement on slopes that are so steep that loose material cannot remain on the surface. The rock may fall directly to the base of the slope or move in a series of leaps and bounds over other rocks along the way. Rockfalls are the primary way in which *talus slopes* are built and maintained (Figure 15.8). Many falls result when freeze and thaw cycles and/or the action of plant roots loosen rock to the point that gravity takes over. Although signs along bedrock cuts on highways warn of falling rock, few of us have actually witnessed such an event. However, as the image in Figure 15.9 illustrates, they do indeed occur.

When large masses of rock plunge from great heights they hit the ground with enormous force and often trigger additional mass-wasting events. One deadly example occurred in Peru. In May 1970, an earthquake caused a huge mass of rock and ice to break free from the precipitous north face of Nevados Huascaran, the loftiest peak in the Peruvian Andes. The material plunged nearly a kilometer and pulverized on impact. The rock avalanche that followed rushed down the mountainside made fluid by trapped air and ice. Along the way it ripped loose millions of tons of additional debris that ultimately and tragically buried more than 20,000 people in the towns of Yungay and Ranrahirca.

A different effect triggered by a rockfall occurred in Yosemite National Park less than 6 months before the event pictured in Figure 15.9. On July 10, 1996, two large rock masses broke loose from steep cliffs and fell about 500 meters (1640 feet) to the floor of Yosemite Valley. The impacts were great enough to be recorded at seismic stations 200 kilometers (125

FIGURE 15.8 Talus is a slope built of angular rock fragments. Mechanical weathering, especially frost wedging, loosens the pieces of bedrock, which then fall to the base of the cliff. With time, a series of steep, cone-shaped accumulations build up at the base of the vertical slope. These talus cones are in Banff National Park, Alberta, Canada. (Photo by Marli Miller)

BOX 15.2 ▸ PEOPLE AND THE ENVIRONMENT

The Vaiont Dam Disaster

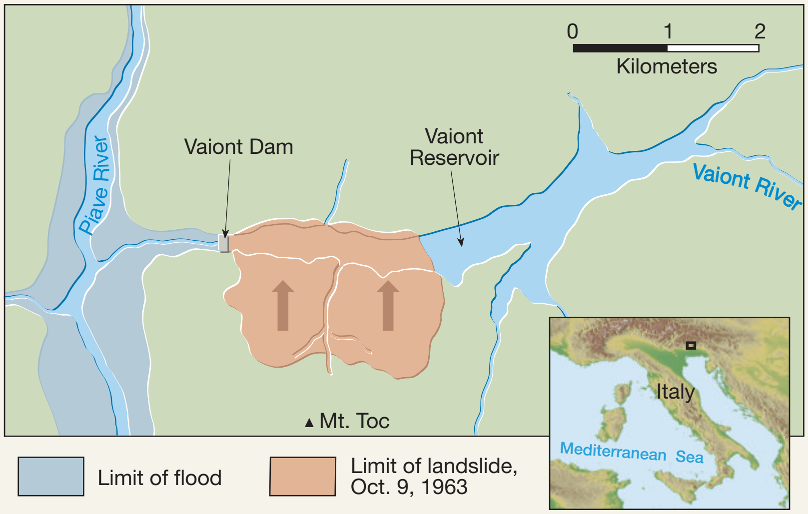

FIGURE 15.D Sketch map of the Vaiont River area showing the limits of the landslide, the portion of the reservoir that was filled with debris, and the extent of flooding downstream. (After G. A. Kiersch, "Vaiont Reservoir Disaster," *Civil Engineering* 34 (1964): 32–39.)

Most often landslides are triggered by a natural event, such as heavy rains or an earthquake. However, sometimes the rapid downslope movement of surface material is caused by the actions of people. Such is the case with the example discussed in this box. Unfortunately it had disastrous consequences.

In 1960 a large dam, almost 265 meters (870 feet) tall, was built across Vaiont Canyon in the Italian Alps. It was engineered without good geological input, and the result was a disaster only three years later.

The bedrock in Vaiont Canyon slanted steeply downward toward the lake impounded behind the dam. The bedrock was weak, highly fractured limestone strata with beds of clay and numerous solution cavities. As the reservoir filled behind the completed dam, rocks became saturated and the clays became swollen and more plastic. The rising water reduced the internal friction that had kept the rock in place.

Measurements made shortly after the reservoir was filled hinted at the problem, because they indicated that a portion of the mountain was slowly creeping downhill at the rate of 1 centimeter per week. In September 1963 the rate increased to 1 centimeter per day, then 10–20 centimeters per day, and eventually as much as 80 centimeters on the day of the disaster.

Finally, the mountainside let loose. In just an instant, 240 million cubic meters of rock and rubble slid down the mountainside and filled nearly 2 kilometers of the gorge to heights of 150 meters above the reservoir level (Figure 15.D). This pushed the water completely over the dam in a wave more than 90 meters high. More than 1.5 kilometers downstream, the wall of water was still 70 meters high, destroying everything in its path.

The entire event lasted less than seven minutes, yet it claimed an estimated 2600 lives. Although this is known as the worst dam disaster in history, the Vaiont Dam itself remained intact. And while the catastrophe was triggered by human interference with the Vaiont River, the slide eventually would have occurred on its own; however, the effects would not have been nearly as tragic.

FIGURE 15.9 In January 1997, this rockfall blocked Highway 140 near the Arch Rock entrance to Yosemite National Park, California. (Photo by Roger J. Wyan/AP/Wide World Photos)

Students Sometimes Ask . . .

How difficult is it to walk up a talus slope?

Very. It might be more accurately described as a scramble because of its steepness. Ascending a talus slope of coarser material involves climbing from boulder to boulder. A talus slope composed of finer material is more difficult to climb because you can cause the material to slide as you ascend. Often, this tiring activity results in sliding about one-half step backward for each step you take.

miles) from the site. When the dislodged rock masses struck the ground, they generated atmospheric pressure waves that were comparable in velocity to a tornado or hurricane. The force of the airblasts uprooted and snapped more than a thousand trees, including some that were 40 meters tall.

Slide Many mass-wasting processes are described as **slides.** The term refers to mass movements in which there is a distinct zone of weakness separating the slide material from the more stable underlying material. Two basic types of slides are recognized. *Rotational slides* are those in which the surface of rupture is a concave-upward curve that resembles the shape of a spoon and the descending material exhibits a downward and outward rotation. By contrast, a *translational slide* is one in which a mass of material moves along a relatively flat surface such as a joint, fault, or bedding plane. Such slides exhibit little rotation or backward tilting.

Flow The third type of movement common to mass-wasting processes is termed **flow.** Flow occurs when material moves downslope as a viscous fluid. Most flows are saturated with water and typically move as lobes or tongues.

Rate of Movement

Some of the events that have been described so far in this chapter involved very rapid rates of movement. For example, it is estimated that the debris that rushed down the slopes of Peru's Nevados Huascaran moved at speeds in excess of 200 kilometers (125 miles) per hour. This most rapid type of mass movement is termed a **rock avalanche** (*avaler* = to descend). Many researchers believe that rock avalanches, such as the one that produced the scene in Figure 15.10, must literally "float on air" as they move downslope. That is, high velocities result when air becomes trapped and compressed beneath the falling mass of debris, allowing it to move as a buoyant, flexible sheet across the surface.

Most mass movements, however, do not move with the speed of a rock avalanche. In fact, a great deal of mass wasting is imperceptibly slow. One process that we will examine later, termed *creep,* results in particle movements that are usually measured in millimeters or centimeters per year. Thus, as you can see, rates of movement can be spectacularly sudden or exceptionally gradual. Although various types of mass wasting are often classified as either rapid or slow, such a distinction is highly subjective because a wide range of rates exists between the two extremes. Even the velocity of a single process at a particular site can vary considerably.

Slump

Mass Wasting
▸ Types of Mass Wasting

Slump refers to the downward sliding of a mass of rock or unconsolidated material moving as a unit along a curved surface (Figure 15.11). Usually the slumped material does

Students Sometimes Ask . . .

Are snow avalanches considered a type of mass wasting?

Sure. Sometimes these thundering downslope movements of snow and ice move large quantities of rock, soil, and trees. Of course, snow avalanches are very dangerous, especially to skiers on high mountain slopes and to buildings and roads at the bottom of slopes in avalanche-prone regions.

About 10,000 snow avalanches occur each year in the mountainous western United States. In an average year they claim between 15 and 25 lives in the United States and Canada. They are a growing problem as more people become involved in winter sports and recreation.

FIGURE 15.10 This 4-kilometer-long tongue of rubble was deposited atop Alaska's Sherman Glacier by a rock avalanche. The event was triggered by a tremendous earthquake in March 1964. (Photo by Austin Post, U.S. Geological Survey)

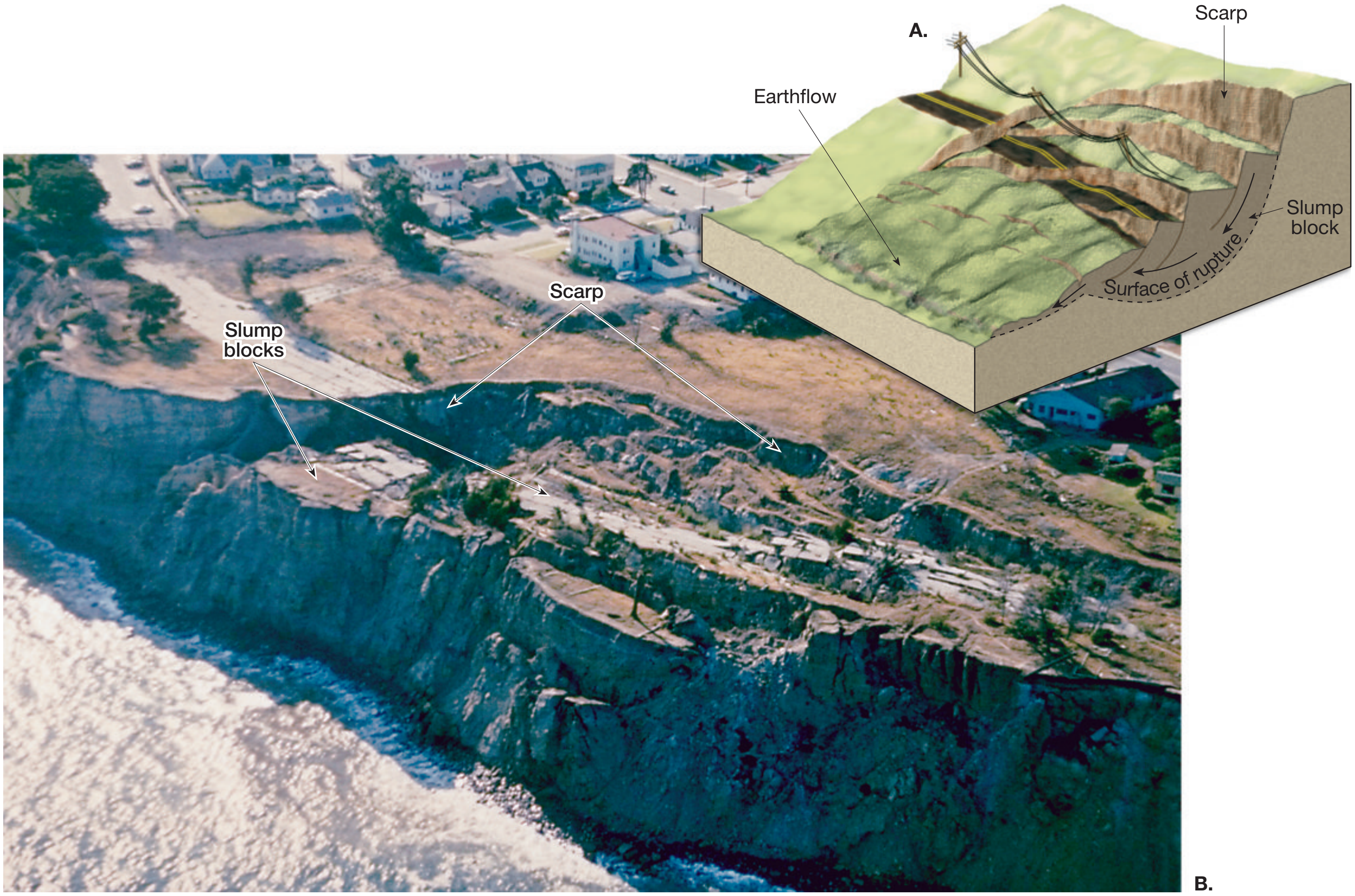

FIGURE 15.11 **A.** Slump occurs when material slips downslope en masse along a curved surface of rupture. It is an example of a rotational slide. Earthflows frequently form at the base of the slump. **B.** Slump at Point Fermin, California. Slump is often triggered when slopes become oversteepened by erosional processes such as wave action. (Photo by John S. Shelton)

not travel spectacularly fast nor very far. This is a common form of mass wasting, especially in thick accumulations of cohesive materials such as clay. The ruptured surface is characteristically spoon-shaped and concave upward or outward. As the movement occurs, a crescent-shaped scarp is created at the head, and the block's upper surface is sometimes tilted backward. Although slump may involve a single mass, it often consists of multiple blocks. Sometimes water collects between the base of the scarp and the top of the tilted block. As this water percolates downward along the surface of rupture, it may promote further instability and additional movement.

Slump commonly occurs because a slope has been oversteepened. The material on the upper portion of a slope is held in place by the material at the bottom of the slope. As this anchoring material at the base is removed, the material above is made unstable and reacts to the pull of gravity. One relatively common example is a valley wall that becomes oversteepened by a meandering river. The photo in Figure 15.11 provides another example in which a coastal cliff has been undercut by wave action at its base. Slumping may also occur when a slope is overloaded, causing internal stress on the material below. This type of slump often occurs where weak, clay-rich material underlies layers of stronger, more resistant rock such as sandstone. The seepage of water through the upper layers reduces the strength of the clay below, resulting in slope failure.

Rockslide

Mass Wasting
▸ **Types of Mass Wasting**

Rockslides occur when blocks of bedrock break loose and slide down a slope (Figure 15.12). If the material involved is largely unconsolidated, the term **debris slide** is used instead. Such events are among the fastest and most destructive mass movements. Usually rockslides take place in a geologic setting where the rock strata are inclined, or where joints and fractures exist parallel to the slope. When such a rock unit is undercut at the base of the slope, it loses support and the rock eventually gives way. Sometimes the rockslide is triggered when rain or melting snow lubricates the

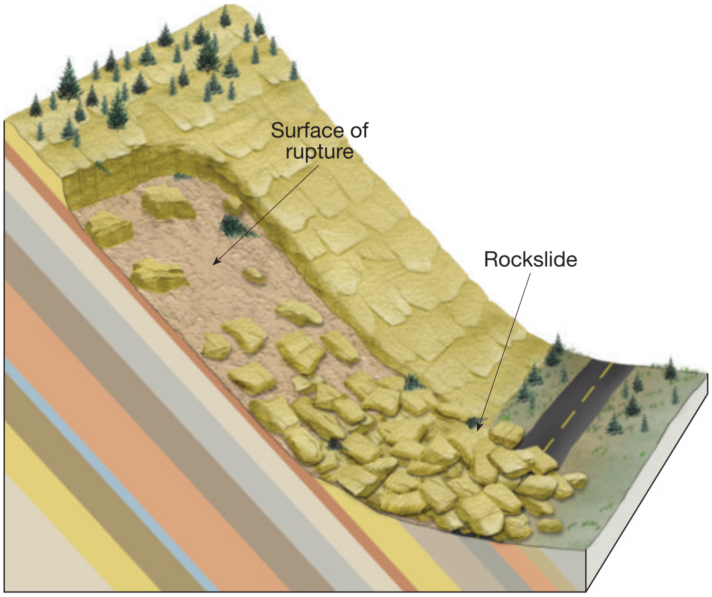

FIGURE 15.12 Rockslides and debris slides are rapid movements that are classified as translational slides in which the material moves along a relatively flat surface with little or no rotation or backward tilting.

underlying surface to the point that friction is no longer sufficient to hold the rock unit in place. As a result, rockslides tend to be more common during the spring, when heavy rains and melting snow are most prevalent.

As was mentioned earlier, earthquakes can trigger rockslides and other mass movements. There are many well-known examples. The 1811 earthquake at New Madrid, Missouri, caused slides in an area of more than 13,000 square kilometers (5000 square miles) along the Mississippi River valley. On August 17, 1959, a severe earthquake west of Yellowstone National Park triggered a massive slide in the canyon of the Madison River in southwestern Montana. In a matter of moments an estimated 27 million cubic meters of rock, soil, and trees slid into the canyon. The debris dammed the river and buried a campground and highway. More than 20 unsuspecting campers perished.

Not far from the site of the Madison Canyon slide, the legendary Gros Ventre rockslide occurred 34 years earlier. The Gros Ventre River flows west from the northernmost part of the Wind River Range in northwestern Wyoming, through Grand Teton National Park, and eventually empties into the Snake River. On June 23, 1925, a massive rockslide took place in its valley, just east of the small town of Kelly. In the span of just a few minutes a great mass of sandstone, shale, and soil crashed down the south side of the valley, carrying with it a dense pine forest. The volume of debris, estimated at 38 million cubic meters (50 million cubic yards), created a 70-meter-high dam on the Gros Ventre River. Because the river was completely blocked, a lake was formed. It filled so quickly that a house that had been 18 meters (60 feet) above the river was floated off its foundation 18 hours after the slide. In 1927 the lake overflowed the dam, partially draining the lake and resulting in a devastating flood downstream.

Why did the Gros Ventre rockslide take place? Figure 15.13 shows a diagrammatic cross-sectional view of the geology of the valley. You will notice that (1) the sedimentary strata in this area dip (tilt) 15–21 degrees; (2) underlying the bed of sandstone is a relatively thin layer of clay; and (3) at the bottom of the valley the river had cut through much of the sandstone layer. During the spring of 1925, water from heavy rains and melting snow seeped through the sandstone, saturating the clay below. Because much of the sandstone layer had been cut through by the Gros Ventre River, the layer had virtually no support at the bottom of the slope. Eventually the sandstone could no longer hold its position on the wetted clay, and gravity pulled the mass down the side of the valley. The circumstances at this location were such that the event was inevitable.

Debris Flow

GEODe EARTH
Mass Wasting
▸ **Types of Mass Wasting**

Debris flow is a relatively rapid type of mass wasting that involves a flow of soil and regolith containing a large amount of water. Debris flows, which are also called **mudflows,** are most characteristic of semiarid mountainous regions and are also common on the slopes of some volcanoes. Because of their fluid properties, debris flows frequently follow canyons and stream channels. In populated areas, debris flows can pose a significant hazard to life and property (Figure 15.14).

Debris Flows in Semiarid Regions

When a cloudburst or rapidly melting mountain snows create a sudden flood in a semiarid region, large quantities of soil and regolith are washed into nearby stream channels because there is usually little vegetation to anchor the surface material. The end product is a flowing tongue of well-mixed mud, soil, rock, and water. Its consistency may range from that of wet concrete to a soupy mixture not much thicker than muddy water. The rate of flow therefore depends not only on the slope but also on the water content. When dense, debris flows are capable of carrying or pushing large boulders, trees, and even houses with relative ease.

Debris flows pose a serious hazard to development in relatively dry mountainous areas such as southern California. The construction of homes on canyon hillsides and the removal of native vegetation by brush fires and other means have increased the frequency of these destructive events. Moreover, when a debris flow reaches the end of a steep, narrow canyon, it spreads out, covering the area beyond the mouth of the canyon with a mixture of wet debris. This material contributes to the buildup of fanlike deposits at canyon mouths. The fans are relatively easy to build on, often have nice views, and are close to the mountains; in

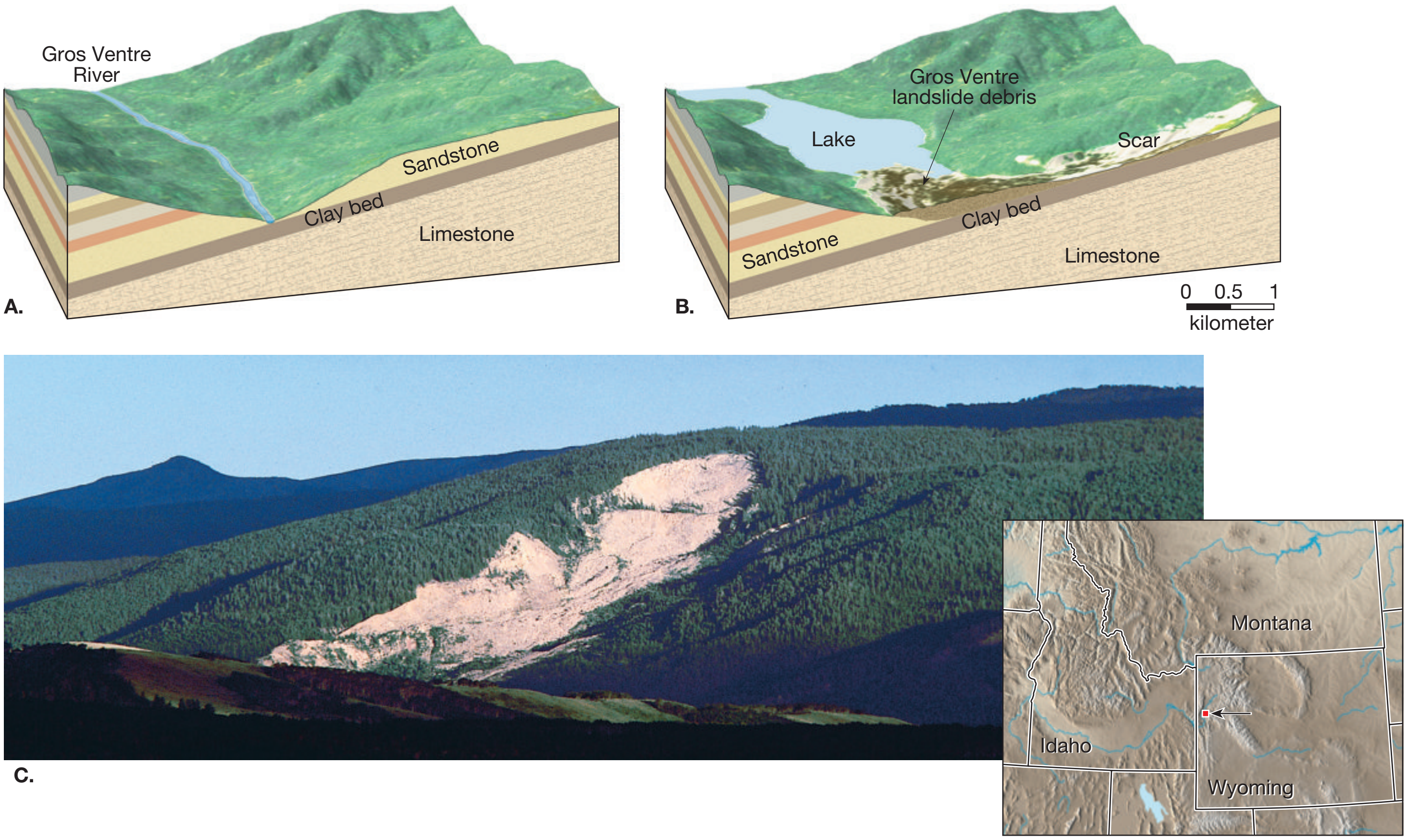

FIGURE 15.13 Parts A and B show a before-and-after cross-sectional view of the Gros Ventre rockslide. The slide occurred when the tilted and undercut sandstone bed could no longer maintain its position atop the saturated bed of clay. As the photo in part C illustrates, even though the Gros Ventre rockslide occurred in 1925, the scar left on the side of Sheep Mountain is still a prominent feature. (Parts A and B after W. C. Alden, “Landslide and Flood at Gros Ventre, Wyoming,” Transactions (AIME) 76 (1928): 348: part C photo by Stephen Trimble.)

fact, like the nearby canyons, many have become preferred sites for development. Because debris flows occur only sporadically, the public is often unaware of the potential hazard of such sites (see Box 15.3).

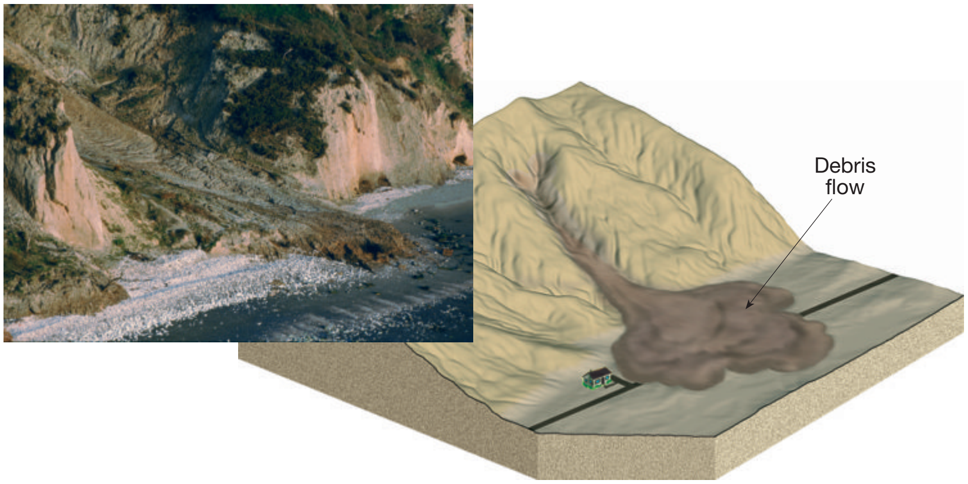

FIGURE 15.14 Debris flow is a moving tongue of well-mixed mud, soil, rock, and water. Its consistency may range from that of wet concrete to a soupy mixture not much thicker than muddy water. (Photo by Tony Waltham)

Lahars

Debris flows composed mostly of volcanic materials on the flanks of volcanoes are called **lahars.** The word originated in Indonesia, a volcanic region that has experienced many of these often destructive events. Historically, lahars have been one of the deadliest volcano hazards. They can occur either during an eruption or when a volcano is quiet. They take place when highly unstable layers of ash and debris become saturated with water and flow down steep volcanic slopes, generally following existing stream channels. Heavy rainfalls often trigger these flows. Others are initiated when large volumes of ice and snow are melted by heat flowing to the surface from within the volcano or by the hot gases and near-molten debris emitted during a violent eruption.

When Mount St. Helens erupted in May 1980, several lahars were created. The flows and accompanying floods raced down the valleys of the north and south forks of the Toutle River at speeds that were often in excess of 30 kilometers (20 miles) per hour. Fortunately, the affected area was not densely settled. Nevertheless, more than 200 homes were destroyed or severely damaged (Figure 15.15). Most bridges met a similar fate. According to the U.S. Geological Survey:

> Even after traveling many tens of miles from the volcano and mixing with cold waters, the mudflows maintained temperatures in the range of about 84° to 91° C; they undoubtedly had higher temperatures closer to the eruption source. . . . Locally the mudflows surged up the valley walls as much as 360 feet and over hills as high as 250 feet. From the evidence left by the "bathtub-ring" mudlines, the larger mudflows at their peak averaged from 33 to 66 feet deep.*

Eventually the lahars in the Toutle River drainage area carried more than 50 million cubic meters of material to the lower Cowlitz and Columbia rivers. The deposits temporarily reduced the water-carrying capacity of the Cowlitz River by 85 percent, and the depth of the Columbia River navigational channel was decreased from 12 meters to less than 4 meters.

In November 1985, lahars were produced during the eruption of Nevado del Ruiz, a 5300-meter (17,400-foot) volcano in the Andes Mountains of Colombia. The eruption melted much of the snow and ice that capped the uppermost 600 meters (2000 feet) of the peak, producing torrents of hot viscous mud, ash, and debris. The lahars moved outward from the volcano, following the valleys of three rain-swollen rivers that radiate from the peak. The flow that moved down the valley of the Lagunilla River was the most destructive. It devastated the town of Armero, 48 kilometers (30 miles) from the mountain. Most of the more than 25,000 deaths caused by the event occurred in this once thriving agricultural community.

FIGURE 15.15 A house damaged by a lahar along the Toutle River, west-northwest of Mount St. Helens. The end section of the house was torn free and lodged against trees. (Photo by D. R. Crandell, U.S. Geological Survey)

Death and property damage due to the lahars also occurred in 13 other villages within the 180-square-kilometer (70-square-mile) disaster area. Although a great deal of pyroclastic material was explosively ejected from Nevado del Ruiz, it was the lahars triggered by this eruption that made this such a devastating natural disaster. In fact, it was the worst volcanic disaster since 28,000 people died following the 1902 eruption of Mount Pelée on the Caribbean island of Martinique.**

Earthflow

Mass Wasting
▸ **Types of Mass Wasting**

We have seen that debris flows are frequently confined to channels in semiarid regions. In contrast, **earthflows** most often form on hillsides in humid areas during times of heavy precipitation or snowmelt. When water saturates the soil and regolith on a hillside, the material may break away, leaving a scar on the slope and forming a tongue- or teardrop-shaped mass that flows downslope (Figure 15.16).

The materials most commonly involved are rich in clay and silt and contain only small proportions of sand and coarser particles. Earthflows range in size from bodies a few meters long, a few meters wide, and less than a meter deep to masses more than 1 kilometer long, several hundred meters wide, and more than 10 meters deep. Because earthflows are quite viscous, they generally move at slower rates than the more fluid debris flows described in the preceding section. They are characterized by a slow and persistent movement and may remain active for periods ranging from days to years. Depending on the steepness of the slope and the material's consistency, measured velocities range from less than a millimeter a day up to several meters a day. Over the time span that earthflows are active, movement is typically faster during wet periods than during drier times. In addition to occurring as isolated hillside phenomena, earthflows commonly take place in association with large slumps. In this situation, they may be seen as tonguelike flows at the base of the slump block (see Figure 15.11, p. 411).

Slow Movements

Mass Wasting
▸ **Types of Mass Wasting**

Movements such as rockslides, rock avalanches, and lahars are certainly the most spectacular and catastrophic forms of mass wasting. As these events have been known to kill

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*Robert I. Tilling, *Eruptions of Mount St. Helens: Past, Present, and Future.* Washington, DC: U.S. Government Printing Office, 1987.

**A discussion of the Mount Pelée eruption can be found in Chapter 5.

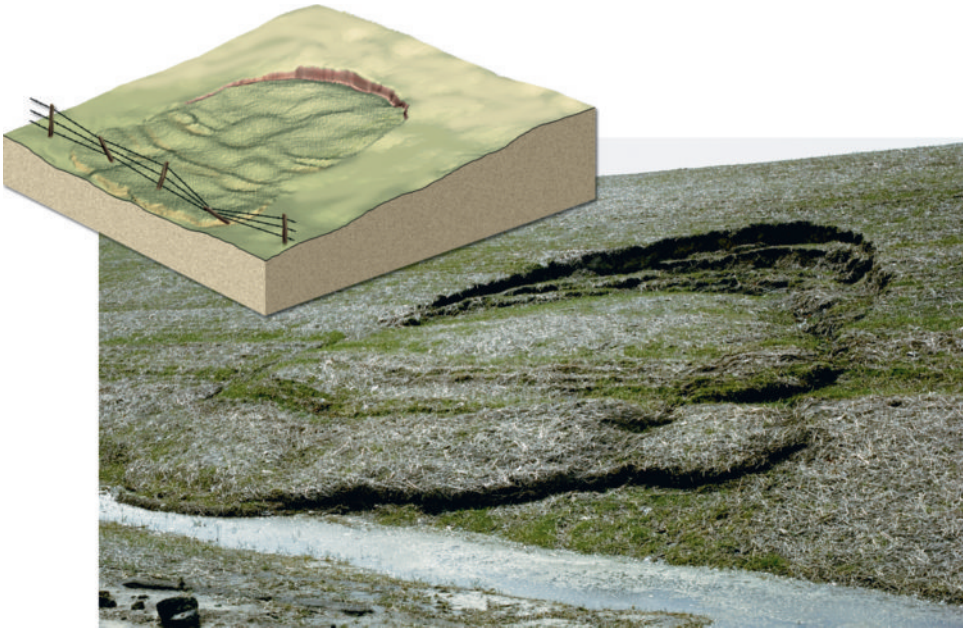

FIGURE 15.16 This small, tongue-shaped earthflow occurred on a newly formed slope along a recently constructed highway. It formed in clay-rich material following a period of heavy rain. Notice the small slump at the head of the earthflow. (Photo by E. J. Tarbuck)

thousands, they deserve intensive study so that through more effective prediction, timely warnings, and better controls can help save lives. However, because of their large size and spectacular nature, they give us a false impression of their importance as a mass-wasting process. Indeed, sudden movements are responsible for moving less material than the slower and far more subtle action of creep. Whereas rapid types of mass wasting are characteristic of mountains and steep hillsides, creep takes place on both steep and gentle slopes and is thus much more widespread.

Creep

Creep is a type of mass wasting that involves the gradual downhill movement of soil and regolith. One factor that contributes to creep is the alternate expansion and contraction of surface material caused by freezing and thawing or wetting and drying. As shown in Figure 15.17, freezing or wetting lifts particles at right angles to the slope, and thawing or drying allows the particles to fall back to a slightly lower level. Each cycle therefore moves the material a tiny distance downslope. Creep is aided by anything that disturbs the soil, such as raindrop impact and disturbance by plant roots and burrowing animals. Creep is also promoted when the ground becomes saturated with water. Following a heavy rain or snowmelt, a waterlogged soil may lose its internal cohesion, allowing gravity to pull the material downslope. Because creep is imperceptibly slow, the process cannot be observed in action. What can be observed, however, are the effects of creep. Creep causes fences and utility poles to tilt and retaining walls to be displaced (Figure 15.18).

Solifluction

When soil is saturated with water, the soggy mass may flow downslope at a rate of a few millimeters or a few centimeters per day or per year. Such a process is called **solifluction** (literally, "soil flow"). It is a type of mass wasting that is common wherever water cannot escape from the saturated surface layer by infiltrating to deeper levels. A dense clay hardpan in soil or an impermeable bedrock layer can promote solifluction.

Solifluction is also common in regions underlain by *permafrost*. Permafrost refers to the permanently frozen ground that occurs in association with Earth's harsh tundra and ice-cap climates. (There is more about permafrost in the next section.) Solifluction occurs in a zone above the permafrost called the *active layer*, which thaws to a depth of about a meter during the brief high-latitude summer and then refreezes in winter. During the summer season, water is unable to percolate into the impervious permafrost layer below. As a result, the active layer becomes saturated and slowly flows. The process can occur on slopes as gentle as 2 to 3 degrees. Where there is a well-developed mat of vegetation, a solifluction sheet may move in a series of well-defined lobes or as a series of partially overriding folds (Figure 15.19).

The Sensitive Permafrost Landscape

Many of the mass-wasting disasters described in this chapter had sudden and disastrous impacts on people. When the activities of people cause ice contained in permanently frozen ground to melt, the impact is more gradual and less

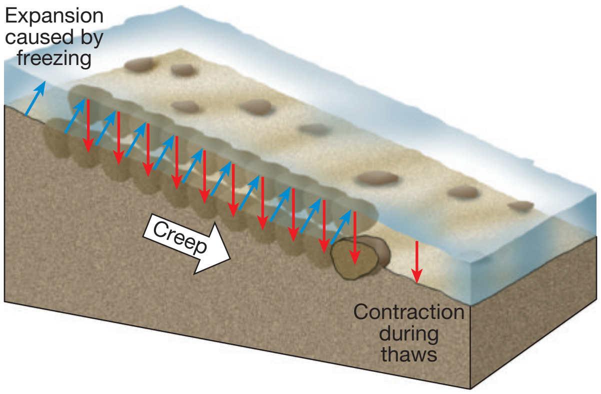

FIGURE 15.17 The repeated expansion and contraction of the surface material causes a net downslope migration of rock particles—a process called *creep.*

BOX 15.3 ▶ PEOPLE AND THE ENVIRONMENT

Debris Flows on Alluvial Fans: A Case Study from Venezuela*

FIGURE 15.E Area of Venezuela affected by disastrous debris flows and flash floods in 1999.

FIGURE 15.F Aerial view of the highly developed alluvial fan at Caraballeda, Venezuela, covered by material from a massive debris flow. (Kimberly White/REUTERS/Corbis/Bettmann)

FIGURE 15.G Debris-flow damage. Huge boulders (in excess of 300 tons) were transported by some flows. (AP/Wide World Photo)

In December 1999, heavy rains triggered thousands of landslides along the coast of Venezuela (Figure 15.E). Debris flows and flash floods caused severe property damage and the tragic loss of an estimated 19,000 lives. The sites of most of the death and destruction were *alluvial fans*. These landforms are gently sloping, cone- to fan-shaped accumulations of sediment that are commonly found where high-gradient streams leave narrow valleys in mountainous areas and abruptly meet flat terrain.**

Several hundred thousand people live in the narrow coastal zone north of Caracas, Venezuela. They occupy alluvial fans located at the base of steep mountains that rise to elevations of more than 2000 meters (6600 feet) because these sites are the only areas that are not too steep to build on (Figure 15.F). Such settings are highly vulnerable to rainfall-induced landslides.

An unusually wet period in December 1999 included rains of 20 centimeters (8 inches) on December 2 and 3, followed by an additional 91 centimeters (36 inches) between December 14 and 16. The heavy rains triggered thousands of debris flows and other types of mass wasting. Once created, these moving masses of mud and rock coalesced to form giant debris flows that moved rapidly through steep, narrow canyons before exiting onto the alluvial fans.

On virtually every alluvial fan in the area, debris flows and flash floods brought massive amounts of sediment, including boulders as large as 10 meters (33 feet) in diameter. Hundreds of houses and other structures were damaged or destroyed (Figure 15.G). Total damages approached $2 billion.

This example from Venezuela shows the potential for extreme loss of life and property damage where large numbers of people occupy alluvial fans. The possibility for similar events of comparable magnitude exists in other parts of the world.

Building communities on alluvial fans can transform natural processes into major lethal events. Kofi Annan, Secretary General of the United Nations, put it this way: "The term 'natural disaster' has become an increasingly anachronistic misnomer. In reality, human behavior transforms natural hazards into what should really be called unnatural disasters."***

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*Based on material prepared by the U.S. Geological Survey.

**For more about alluvial fans, see p. 443 in Chapter 16 and p. 523 in Chapter 19.

***Matthew C. Larsen, et al., *Natural Hazards on Alluvial Fans: The Venezuela Debris Flow and Flash Flood Disaster,* U.S. Geological Survey Fact Sheet FS 103, p. 4.

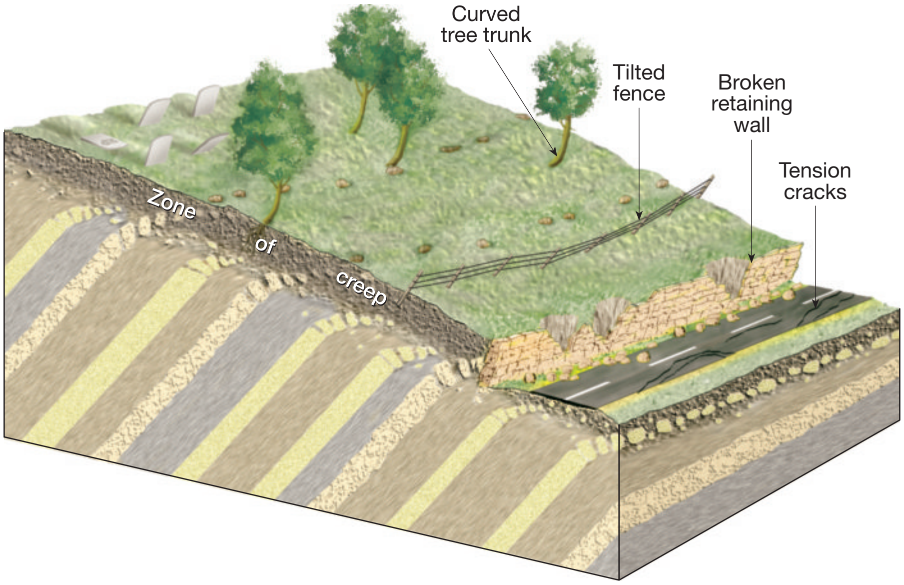


FIGURE 15.18 Although creep is an imperceptibly slow movement, its effects are often visible.

deadly. Nevertheless, because permafrost regions are sensitive and fragile landscapes, the scars resulting from poorly planned actions can remain for generations.

Permanently frozen ground, known as **permafrost,** occurs where summers are too cool to melt more than a shallow surface layer. Deeper ground remains frozen year-round. Strictly speaking, permafrost is defined only on the basis of temperature; that is, it is ground with temperatures that have remained below 0°C (32°F) continuously for two years or more. The degree to which ice is present in the ground strongly affects the behavior of the surface material. Knowing how much ice is present and where it is located is very important when it comes to constructing roads, buildings, and other projects in areas underlain by permafrost.

Permafrost is extensive in the lands surrounding the Arctic Ocean. It covers more than 80 percent of Alaska, about 50 percent of Canada, and a substantial portion of northern Siberia (Figure 15.20). Near the southern margins of the region, the permafrost consists of relatively thin, isolated masses. Farther north, the area and thickness gradually increase to the point where the permafrost is essentially continuous and its thickness may approach or even exceed 500 meters. In the discontinuous zone, land-use planning is frequently more difficult than in the continuous zone farther north because the occurrences of permafrost are patchy and difficult to predict.

When people disturb the surface, such as by removing the insulating vegetation mat or by building roads and buildings, the delicate thermal balance is disturbed, and the permafrost can thaw (Figure 15.21A). Thawing produces unstable ground that may slide, slump, subside, and undergo severe frost heaving. When a heated structure is built directly on permafrost that contains a high proportion of ice, thawing creates soggy material into which a building can sink. One solution is to place buildings and other structures on piles, like stilts. Such piles allow subfreezing air to circulate between the floor of the building and the soil and thereby keep the ground frozen.

When oil was discovered on Alaska's North Slope, many people were concerned about the building of a pipeline linking the oil fields at Prudhoe Bay to the ice-free port of Valdez 1300 kilometers to the south. There was serious concern that such a massive project might damage the sensitive permafrost environment. Many also worried about possible oil spills.

Because oil must be heated to about 60°C to flow properly, special engineering procedures had to be developed to isolate this heat from the permafrost. Methods included insulating the pipe, elevating portions of the pipeline above ground level, and even placing cooling devices in the ground to keep it frozen (Figure 15.21B). The Alaskan pipeline is clearly one of the most complex and costly projects ever built in the Arctic tundra. Detailed studies and careful engineering helped minimize adverse effects resulting from the disturbance of frozen ground.

Submarine Landslides

As you might imagine, mass-wasting processes are not confined to land. The development of high-quality instruments that perform ocean-floor imaging has allowed us to determine that submarine mass wasting is a common and widespread phenomenon. For example, studies reveal enormous submarine landslides on the flanks of the Hawaiian chain as well as along the continental shelf and slope of the U.S. mainland. In

FIGURE 15.19 Solifluction lobes northeast of Fairbanks, Alaska. Solifluction occurs in permafrost regions when the active layer thaws in summer. (Photo by James E. Patterson)

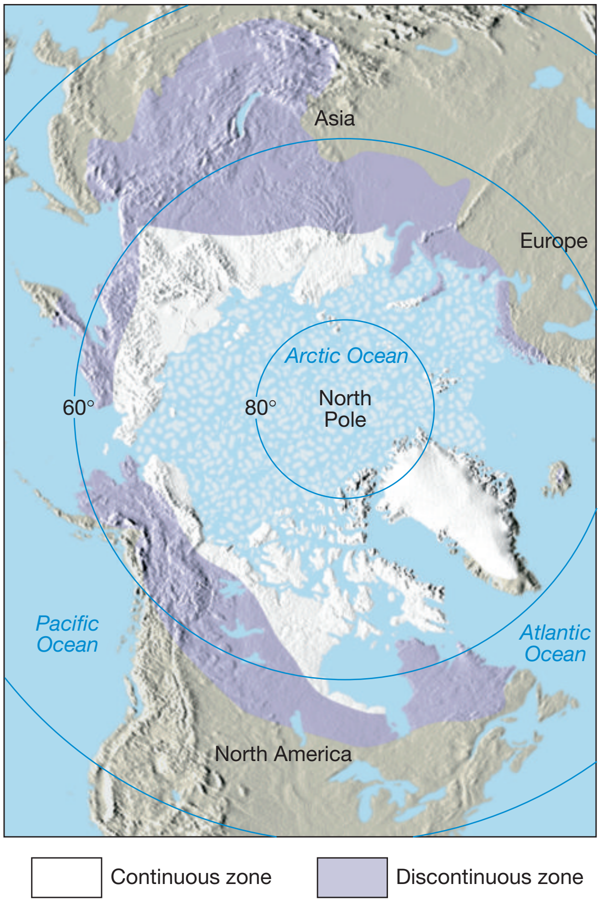


FIGURE 15.20 Distribution of permafrost in the Northern Hemisphere. More than 80 percent of Alaska and about 50 percent of Canada are underlain by permafrost. Two zones are recognized. In the continuous zone, the only ice-free areas are beneath deep lakes or rivers. In the higher-latitude portions of the discontinuous zone, there are only scattered islands of thawed ground. Moving southward, the percentage of unfrozen ground increases until all the ground is unfrozen. (After the U.S. Geological Survey)

fact, many submarine landslides, mostly in the form of slumps and debris avalanches, appear to be much larger than any similar mass-wasting events that occur on land.

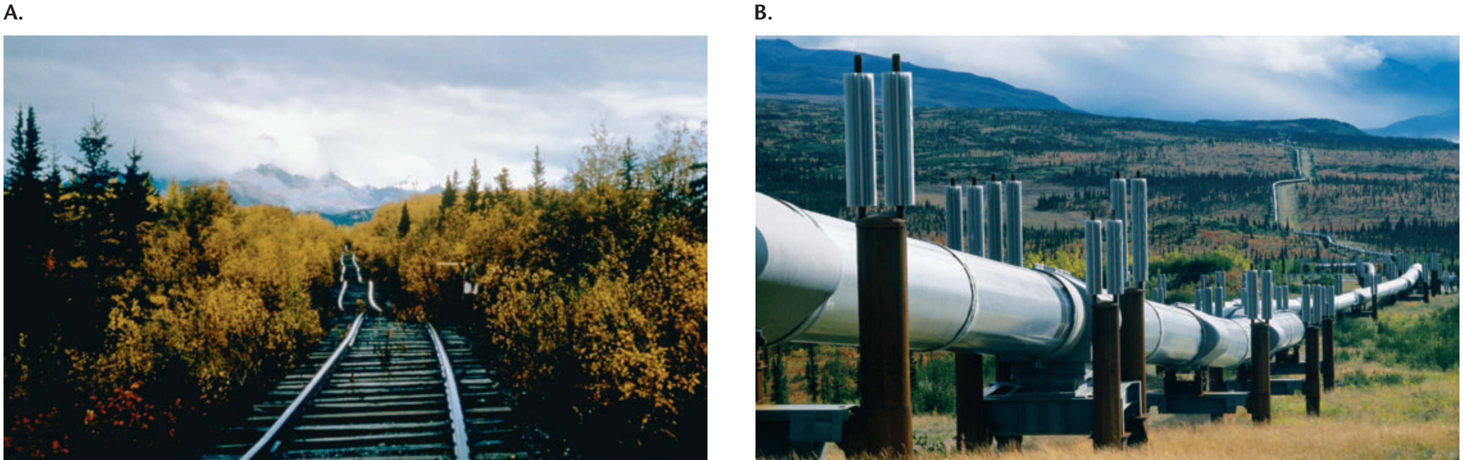
Among the most spectacular underwater landslides are those that occur on the flanks of submarine volcanoes (called *seamounts*) and volcanic islands such as Hawaii. On the submerged flanks of the Hawaiian Islands dozens of major landslides more than 20 kilometers (13 miles) long have been identified. Some have truly spectacular dimensions. One of the largest yet mapped, known as the Nuuanu debris avalanche, is on the northeastern side of Oahu. It extends for nearly 25 kilometers (15 miles) across the ocean floor, then rises up a 300-meter (nearly 1000-foot) slope at its terminus, indicating that it must have had great power and momentum. Giant blocks many kilometers across were transported by this giant landslide. It is probable that when such large and rapid events occur, they produce giant sea waves called tsunami that race across the Pacific.*

The massive submarine slides discovered on the flanks of the Hawaiian Islands are almost certainly related to the movement of magma while a volcano is active. As huge quantities of lava are added to the seaward margin of a volcano, the buildup of material eventually triggers a great landslide. In the Hawaiian chain, it appears that this process of growth and collapse is repeated at intervals of from 100,000 to 200,000 years while the volcano is active.

Along the continental margins of the U.S. mainland, large slumps and debris-flow scars mark the continental slope. These processes are triggered by the rapid buildup of unstable sediments or by such forces as storm waves and earthquakes. Submarine mass wasting is especially active near deltas, which are massive deposits of sediment at the mouths of rivers. Here, as great loads of water-saturated clay and organic-rich sediments accumulate, they become unstable and readily flow down even gentle slopes. Some of these movements have been forceful enough to damage large offshore drilling platforms.

Mass wasting appears to be an integral part of the growth of passive continental margins. Sediments supplied to the continental shelf by rivers move across the shelf to the upper continental slope. From here slumps, slides, and debris flows move sediment down to the continental rise and sometimes beyond.

FIGURE 15.21 **A.** When a rail line was built across this permafrost landscape in Alaska, the ground subsided. (Photo by Lynn A. Yehle, U.S. Geological Survey) **B.** In places in Alaska, a pipeline is suspended above ground to prevent melting of delicate permafrost. (Tom & Pat Lesson/Photo Researchers)



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*For more on these destructive waves, see the section on tsunamis in Chapter 11.

Summary

- *Mass wasting* refers to the downslope movement of rock, regolith, and soil under the direct influence of gravity. In the evolution of most landforms, mass wasting is the step that follows weathering. The combined effects of mass wasting and erosion by running water produce stream valleys.
- *Gravity is the controlling force of mass wasting.* Other factors that influence or trigger downslope movements are saturation of the material with water, oversteepening of slopes beyond the *angle of repose,* removal of vegetation, and ground shaking by earthquakes.
- The various processes included under the name of mass wasting are divided and described on the basis of (1) the type of material involved (debris, mud, earth, or rock); (2) the type of motion (fall, slide, or flow); and (3) the rate of movement (rapid or slow).
- The more rapid forms of mass wasting include *slump,* the downward sliding of a mass of rock or unconsolidated material moving as a unit along a curved surface; *rockslide,* blocks of bedrock breaking loose and sliding downslope; *debris flow,* a relatively rapid flow of soil and regolith containing a large amount of water; and *earthflow,* an unconfined flow of saturated clay-rich soil that most often occurs on a hillside in a humid area following heavy precipitation or snowmelt.
- The slowest forms of mass wasting include *creep,* the gradual downhill movement of soil and regolith; and *solifluction,* the gradual flow of a saturated surface layer that is underlain by an impermeable zone. Common sites for solifluction are regions underlain by *permafrost* (permanently frozen ground associated with tundra and ice-cap climates).
- *Permafrost,* permanently frozen ground, covers large portions of North America and Siberia. Thawing produces unstable ground that may slide, slump, subside, and undergo severe frost heaving.
- Mass wasting is not confined to land; it also occurs underwater. Many *submarine landslides,* mostly slumps and debris avalanches, are much larger than those that occur on land.

Review Questions

1. Describe how mass-wasting processes contribute to the development of stream valleys.
2. What is the controlling force of mass wasting?
3. How does water affect mass-wasting processes?
4. Describe the significance of the angle of repose.
5. How might the removal of vegetation by fire or logging promote mass wasting?
6. How are earthquakes linked to landslides?
7. How did the building of a dam contribute to the Vaiont Canyon disaster? Was the disaster avoidable? (See Box 15.2, p. 409).
8. Distinguish among fall, slide, and flow.
9. Why can rock avalanches move at such great speeds?
10. Both slump and rockslide move by sliding. In what ways do these processes differ?
11. What factors led to the massive rockslide at Gros Ventre, Wyoming?
12. Explain why building a home on an alluvial fan might not be a good idea (see Box 15.3, p. 416).
13. Compare and contrast mudflow and earthflow.
14. Describe the mass wasting that occurred at Mount St. Helens during its active period in 1980 and at Nevado del Ruiz in 1985.
15. Because creep is an imperceptibly slow process, what evidence might indicate that this phenomenon is affecting a slope?
16. What is permafrost? What portion of Earth's land surface is affected?
17. During what season does solifluction occur in permafrost regions?

Key Terms

angle of repose (p. 404)
creep (p. 415)
debris flow (p. 412)
debris slide (p. 411)
earthflow (p. 414)
fall (p. 408)
flow (p. 410)
lahar (p. 413)
mass wasting (p. 402)
mudflow (p. 412)
permafrost (p. 417)
rock avalanche (p. 410)
rockslide (p. 411)
slide (p. 410)
slump (p. 410)
solifluction (p. 415)

Web Resources

The *Earth* Website uses the resources and flexibility of the Internet to aid in your study of the topics in this chapter. Written and developed by geology instructors, this site will help improve your understanding of geology. Visit **http://www.prenhall.com/tarbuck** and click on the cover of *Earth 9e* to find:

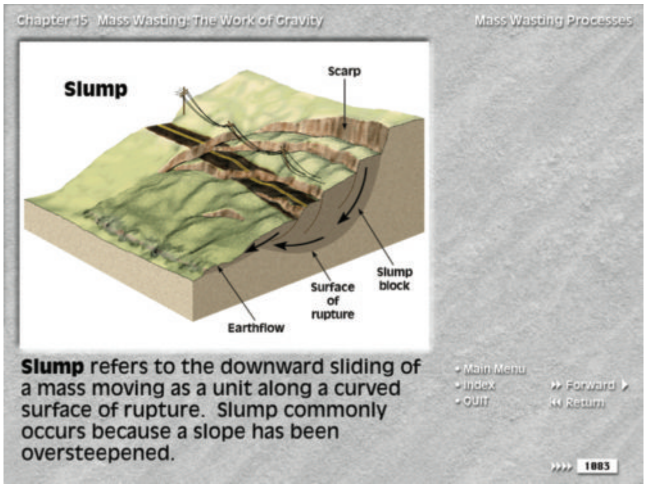
- Online review quizzes.
- Critical thinking exercises.
- Links to chapter-specific Web resources.
- Internet-wide key-term searches.

http://www.prenhall.com/tarbuck

GEODe: Earth

GEODe: Earth makes studying faster and more effective by reinforcing key concepts using animation, video, narration, interactive exercises and practice quizzes. A copy is included with every copy of *Earth.*

Mass wasting refers to the downslope movement of weathered rock and soil under the direct influence of gravity.



Slump refers to the downward sliding of a mass moving as a unit along a curved surface of rupture. Slump commonly occurs because a slope has been oversteepened.