

HS Erosion and Deposition

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CHAPTER**1****HS Erosion and Deposition****CHAPTER OUTLINE**

- 1.1 Water Erosion and Deposition
- 1.2 Wave Erosion and Deposition
- 1.3 Wind Erosion and Deposition
- 1.4 Glacial Erosion and Deposition
- 1.5 Erosion and Deposition by Gravity
- 1.6 References



This image taken by astronauts on the International Space Station is of the mouth of the largest river in Madagascar. The Betsiboka River runs into the Betsiboka Estuary seen here. Decades of logging have cleared so much forest land in Madagascar that eroded soil clogs the river. When tropical storms strike, as in this image of when tropical Cyclone Gafilo struck the island in March 2004, the rate of erosion is even greater. Viewing this scene caused the astronauts to say that Madagascar is “bleeding into the ocean.” Fortunately the government of Madagascar is working to reverse the problem by reducing erosion, encouraging reforestation, and controlling land clearing.

1.1 Water Erosion and Deposition

Lesson Objectives

- Describe how surface streams produce erosion.
- Describe the types of deposits left behind by streams.
- Describe landforms that are produced as ground water flows.

Vocabulary

- alluvial fan
- base level
- bed load
- column
- competence
- delta
- dissolved load
- floodplain
- gradient
- groundwater
- headwaters
- meander
- natural levee
- saltation
- sinkhole
- stalactite
- stalagmite
- suspended load
- travertine

Introduction

Streams – any running water from a rivulet to a raging river – complete the hydrologic cycle by returning precipitation that falls on land to the oceans (**Figure 1.1**). Some of this water moves over the surface and some moves through the ground as **groundwater**. Flowing water does the work of both erosion and deposition.

Erosion and Deposition by Streams

Erosion by Streams

Flowing streams pick up and transport weathered materials by eroding sediments from their banks. Streams also carry ions and ionic compounds that dissolve easily in the water. Sediments are carried as:

- **Dissolved load:** Dissolved load is composed of ions in solution. These ions are usually carried in the water all the way to the ocean.

**FIGURE 1.1**

As streams flow towards the ocean, they carry weathered materials.

- **Suspended load:** Sediments carried as solids as the stream flows are suspended load. The size of particles that can be carried is determined by the stream's velocity ([Figure 1.2](#)). Faster streams can carry larger particles. Streams that carry larger particles have greater **competence**. Streams with a steep **gradient** (slope) have a faster velocity and greater competence.
- **Bed load:** Particles that are too large to be carried as suspended load are bumped and pushed along the stream bed as bed load. Bed load sediments do not move continuously. This intermittent movement is called **saltation**. Streams with high velocities and steep gradients do a great deal of down cutting into the stream bed, which is primarily accomplished by movement of particles that make up the bed load.
- A video of bedload transport is found here: <http://faculty.ggs.uwyo.edu/heller/SedMovs/Sed%20Movie%20file/s/bdld.mov>

Stages of Streams

As a stream flows from higher elevations, like in the mountains, towards lower elevations, like the ocean, the work of the stream changes. At a stream's **headwaters**, often high in the mountains, gradients are steep ([Figure 1.3](#)). The stream moves fast and does lots of work eroding the stream bed.

**FIGURE 1.2**

Rivers carry sand, silt and clay as suspended load. During flood stage, the suspended load greatly increases as stream velocity increases.

**FIGURE 1.3**

This stream begins as meltwater from a glacier.

As a stream moves into lower areas, the gradient is not as steep. Now the stream does more work eroding the edges of its banks. Many streams develop curves in their channels called **meanders** (Figure 1.4).

As the river moves onto flatter ground, the stream erodes the outer edges of its banks to carve a **floodplain**, which is a flat level area surrounding the stream channel (Figure 1.5).

Base level is where a stream meets a large body of standing water, usually the ocean, but sometimes a lake or pond. Streams work to down cut in their stream beds until they reach base level. The higher the elevation, the farther the stream is from where it will reach base level and the more cutting it has to do.

Stream Deposition

As a stream gets closer to base level, its gradient lowers and it deposits more material than it erodes. On flatter ground, streams deposit material on the inside of meanders. Placer mineral deposits, described in the Earth's Minerals chapter, are often deposited there. A stream's floodplain is much broader and shallower than the stream's

**FIGURE 1.4**

(a) At a meander, a stream actively erodes its outer banks and deposits material along the inside curves. This causes these meanders to migrate laterally over time. (b) This stream has deposited larger materials such as gravel and pebbles along the inside curve of a meander. (c) This image is a topographic map. The San Juan River eroded the land surface as the Colorado Plateau uplifted. The river

**FIGURE 1.5**

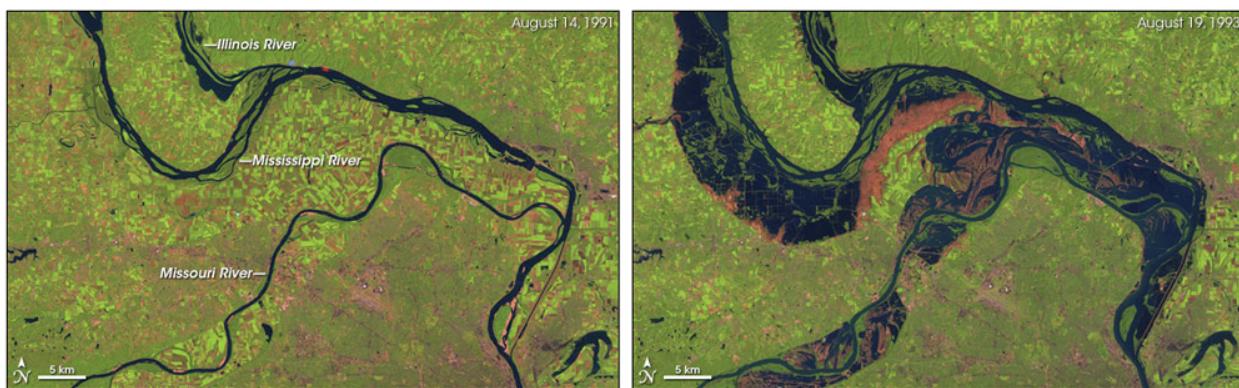
The Vistula River in Poland flows onto its floodplain.

channel. When a stream flows onto its floodplain, its velocity slows and it deposits much of its load. These sediments are rich in nutrients and make excellent farmland (**Figure 1.6**).

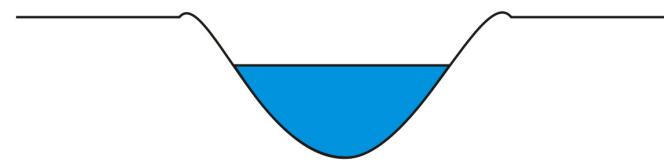
A stream at flood stage carries lots of sediments. When its gradient decreases, the stream overflows its banks and broadens its channel. The decrease in gradient causes the stream to deposit its sediments, the largest first. These large sediments build a higher area around the edges of the stream channel, creating **natural levees** (**Figure 1.7**).

When a river enters standing water, its velocity slows to a stop. The stream moves back and forth across the region and drops its sediments in a wide triangular-shaped deposit called a **delta** (**Figure 1.8**).

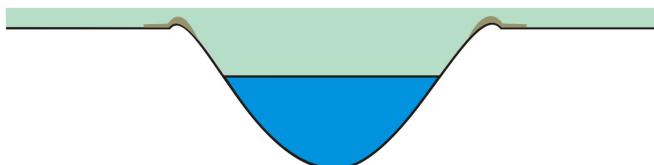
If a stream falls down a steep slope onto a broad flat valley, an **alluvial fan** develops (**Figure 1.9**). Alluvial fans generally form in arid regions.

**FIGURE 1.6**

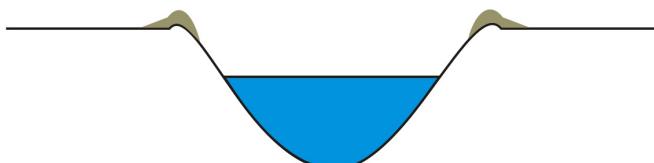
The Mississippi floodplain is heavily farmed. Flooding can wipe out farms and towns, but the stream also deposits nutrient-rich sediments that enrich the floodplain.



A stream within its banks



A stream at flood stage deposits large particles along its banks



After many floods, natural levees have been built up along stream banks

FIGURE 1.7

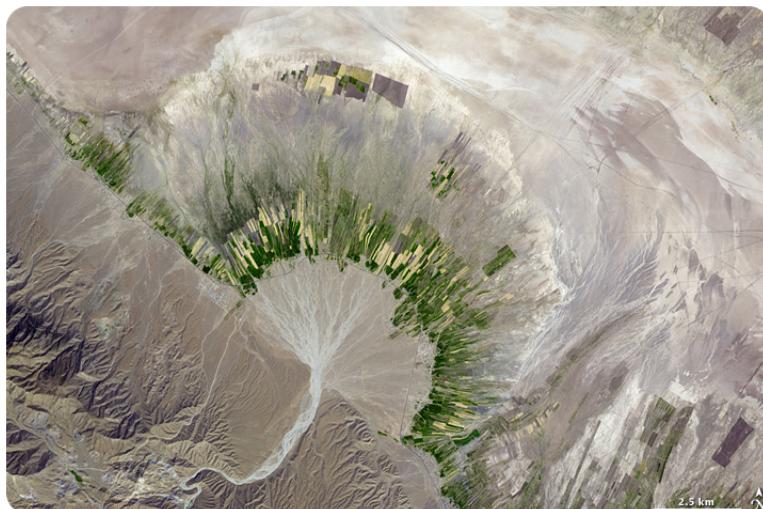
After many floods, a stream builds natural levees along its banks.

Ground Water Erosion and Deposition

Rainwater absorbs carbon dioxide (CO_2) as it falls. The CO_2 combines with water to form carbonic acid. The slightly acidic water sinks into the ground and moves through pore spaces in soil and cracks and fractures in rock.

**FIGURE 1.8**

(a) The Nile River delta has a classic triangular shape, like the capital Greek letter delta. (b) Sediment in the Yellow River delta. The main stream channel splits into many smaller distributaries.

**FIGURE 1.9**

An alluvial fan in Iran. The mountains are in the lower right corner of the photograph.

The flow of water underground is **ground water**.

Ground water is a strong erosional force, as it works to dissolve away solid rock (Figure 1.10). Carbonic acid is especially good at dissolving the rock limestone.

**FIGURE 1.10**

When water sinks into the ground, it becomes ground water.

Cave Formation

Working slowly over many years, ground water travels along small cracks. The water dissolves and carries away the solid rock gradually enlarging the cracks. Eventually a cave may form ([Figure 1.11](#)).

**FIGURE 1.11**

Caverns many football fields long and as high as many meters tall form where ground water erodes away rock.

Ground water carries the dissolved minerals in solution. The minerals may then be deposited, for example, as **stalagmites** or **stalactites** (Figure 1.12).

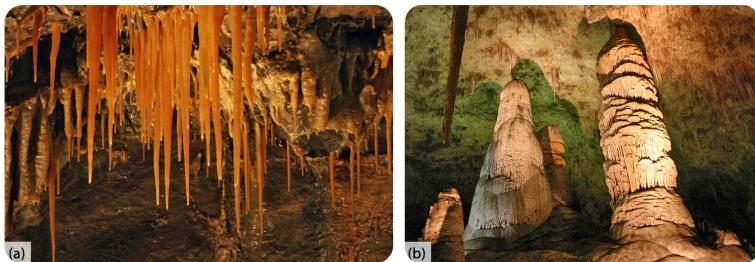


FIGURE 1.12

(a) Stalactites form as calcium carbonate drips from the ceiling of a cave, forming beautiful icicle-like formations. The word stalactite has a c and it forms from the ceiling. (b) Stalagmites form as calcium carbonate drips from the ceiling to the floor of a cave and then grow upwards. The g in stalagmite means it forms on the ground.

If a stalactite and stalagmite join together, they form a **column**. One of the wonders of visiting a cave is to witness the beauty of these amazing and strangely captivating structures. Caves also produce a beautiful rock, formed from calcium carbonate, **travertine**. Ground water saturated with calcium carbonate precipitates as the mineral calcite or aragonite. Mineral springs that produce travertine can be hot, warm or even cold (Figure 1.13).



FIGURE 1.13

Travertine is a beautiful form of limestone.

You can explore a fantastic cave, Kartchner Caverns, in Arizona, by watching this video: <http://video.nationalgeographic.com/video/player/science/earth-sci/exploring-kartchner-sci.html>

If the roof of a cave collapses, a **sinkhole** could form. Some sinkholes are large enough to swallow up a home or several homes in a neighborhood (Figure 1.14).

Lesson Summary

- Streams erode the land as they move from higher elevations to the sea.
- Eroded materials can be carried in a river as dissolved load, suspended load, or bed load.

**FIGURE 1.14**

This sinkhole formed in Florida.

- A river erodes deeply when it is far from its base level, the place where it enters standing water.
- Streams form bends, called meanders. Broad, flat areas are known as floodplains.
- A delta or an alluvial fan might form where the stream drops its sediment load.
- Caves form underground as ground water gradually dissolves away rock.

Review Questions

1. Define the three kinds of load that make up the particles a stream carries.
2. What is a stream's gradient? What effect does it have on the work of a stream?
3. How do streams erode their beds?
4. How does a stream produce a wide, flat floodplain?
5. What type of gradient would a river have when it is actively eroding its stream bed?
6. When would a river form an alluvial fan and when will it form a delta? Describe the characteristics of each type of deposit.
7. What are two formations that form inside caves?
8. What erosional feature formed by ground water could swallow up your house?

Points to Consider

- Would a stream at high elevations erode more than a stream at lower elevations?
- How would Earth's surface look without streams?
- Would a flash flood along a normally dry river valley be a dangerous event?
- Do you think caves could form in your neighborhood?

1.2 Wave Erosion and Deposition

Lesson Objectives

- Describe how the action of waves produces different shoreline features.
- Discuss how areas of quiet water produce deposits of sand and sediment.
- Discuss some of the structures humans build to help defend against wave erosion.

Vocabulary

- arch
- barrier island
- beach
- breakwater
- groin
- refraction
- sea stack
- sea wall
- spit
- wave-cut cliff
- wave-cut platform

Introduction

Waves are important for building up and breaking down shorelines. Waves transport sand onto and off of beaches. They transport sand along beaches. Waves carve structures at the shore.

Wave Action and Erosion

All waves are energy traveling through some type of material, such as water (**Figure 1.15**). Ocean waves form from wind blowing over the water.



FIGURE 1.15

Ocean waves are energy traveling through water.

The largest waves form when the wind is very strong, blows steadily for a long time, and blows over a long distance. The wind could be strong, but if it gusts for just a short time, large waves won't form. Wave energy does the work of erosion at the shore. Waves approach the shore at some angle so the inshore part of the wave reaches shallow water

sooner than the part that is further out. The shallow part of the wave 'feels' the bottom first. This slows down the inshore part of the wave and makes the wave 'bend.' This bending is called **refraction**.

Wave refraction either concentrates wave energy or disperses it. In quiet water areas, such as bays, wave energy is dispersed, so sand is deposited. Areas that stick out into the water are eroded by the strong wave energy that concentrates its power on the **wave-cut cliff** (Figure 1.16).



FIGURE 1.16

The wave erodes the bottom of the cliff, eventually causing the cliff to collapse.

Other features of wave erosion are pictured and named in Figure 1.17. A **wave-cut platform** is the level area formed by wave erosion as the waves undercut a cliff. An **arch** is produced when waves erode through a cliff. When a sea arch collapses, the isolated towers of rocks that remain are known as **sea stacks**.



FIGURE 1.17

(a) The high ground is a large wave-cut platform formed from years of wave erosion. (b) A cliff eroded from two sides produces an arch. (c) The top of an arch erodes away, leaving behind a tall sea stack.

Wave Deposition

Rivers carry sediments from the land to the sea. If wave action is high, a delta will not form. Waves will spread the sediments along the coastline to create a **beach** (Figure 1.18). Waves also erode sediments from cliffs and shorelines and transport them onto beaches.

Beaches can be made of mineral grains, like quartz, rock fragments, and also pieces of shell or coral (Figure 1.19). Waves continually move sand along the shore. Waves also move sand from the beaches on shore to bars of sand

**FIGURE 1.18**

Sand deposits in quiet areas along a shoreline to form a beach.

**FIGURE 1.19**

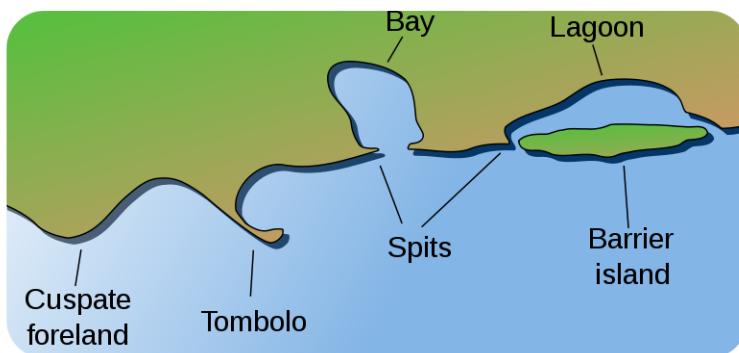
Quartz, rock fragments, and shell make up the sand along a beach.

offshore as the seasons change. In the summer, waves have lower energy so they bring sand up onto the beach. In the winter, higher energy waves bring the sand back offshore.

Some of the features formed by wave-deposited sand are in [Figure 1.20](#). These features include barrier islands and spits. A **spit** is sand connected to land and extending into the water. A spit may hook to form a tombolo.

Shores that are relatively flat and gently sloping may be lined with long narrow **barrier islands** ([Figure 1.21](#)). Most barrier islands are a few kilometers wide and tens of kilometers long.

In its natural state, a barrier island acts as the first line of defense against storms such as hurricanes. When barrier islands are urbanized ([Figure 1.21](#)), hurricanes damage houses and businesses rather than vegetated sandy areas in which sand can move. A large hurricane brings massive problems to the urbanized area.

**FIGURE 1.20**

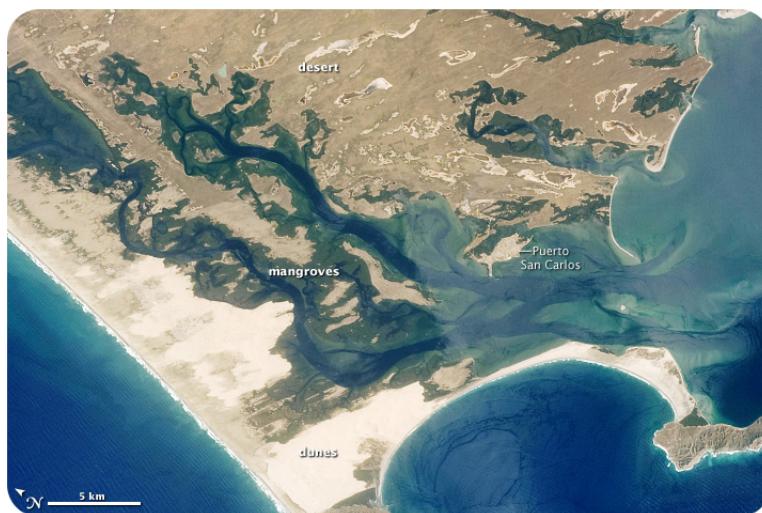
Examples of features formed by wave-deposited sand.

**FIGURE 1.21**

(a) Barrier islands off of Alabama. A lagoon lies on the inland side. (b) Barrier islands, such as Padre Island off the coast of Texas, are made entirely of sand. (c) Barrier islands are some of the most urbanized areas of our coastlines, such as Miami Beach.

Protecting Shorelines

Intact shore areas protect inland areas from storms that come off the ocean (Figure 1.22).

**FIGURE 1.22**

Dunes and mangroves along Baja California protect the villages that are found inland.

Where the natural landscape is altered or the amount of development make damage from a storm too costly to consider, people use several types of structures to attempt to slow down wave erosion. A few are pictured below (Figure 1.23). A **groin** is a long narrow pile of rocks built perpendicular to the shoreline to keep sand at that beach.

A **breakwater** is a structure built in the water parallel to the shore in order to protect the shore from strong incoming waves. A **seawall** is also parallel to the shore, but it is built onshore.



FIGURE 1.23

(a) Groins trap sand on the up-current side so then people down current build groins to trap sand too. (b) Breakwaters are visible in this satellite image parallel to the shoreline. (c) Seawalls are similar to breakwaters except built onshore. Extremely large storm waves may destroy the sea wall, leaving the area unprotected.

People do not always want to choose safe building practices, and instead choose to build a beach house right on the beach. Protecting development from wave erosion is difficult and expensive.

Protection does not always work. The northeastern coast of Japan was protected by anti-tsunami seawalls. Yet waves from the 2011 tsunami that resulted from the Tohoku earthquake washed over the top of some seawalls and caused others to collapse. Japan is now planning to build even higher seawalls to prepare for any future (and inevitable) tsunami.

Lesson Summary

- Waves in the ocean are what we see as energy travels through the water.
- Wave energy produces erosional formations such as cliffs, wave cut platforms, sea arches, and sea stacks.
- When waves reach the shore, they can form deposits such as beaches, spits, and barrier islands.
- Groins, jetties, breakwaters, and seawalls are structures that protect the shore from breaking waves.

Review Questions

1. Name three structures that people build to try to prevent wave erosion. How well do they work?
2. Name three natural landforms that are produced by wave erosion.
3. What are the names of the parts of a waveform?
4. Describe the process that produces wave refraction.
5. If you were to visit a beach surrounded by coral reefs, what would the beach be made of?

Points to Consider

- What situations would increase the rate of erosion by waves?
- If barrier islands are nature's first line of defense against ocean storms, why do people build on them?
- Could a seawall ever increase the amount of damage done by waves?

1.3 Wind Erosion and Deposition

Lesson Objectives

- Describe the ways particles are carried by wind.
- Discuss several ways that wind erosion changes land surfaces.
- Describe how sand dunes form.
- Describe the type of deposits formed by windborne silts and clays.

Vocabulary

- deflation
- desert pavement
- desert varnish
- loess
- sand dune
- slip face
- ventifacts

Introduction

The power of wind to erode depends on particle size, wind strength, and whether the particles are able to be picked up. Wind is a more important erosional force in arid than humid regions.

Transport of Particles by Wind

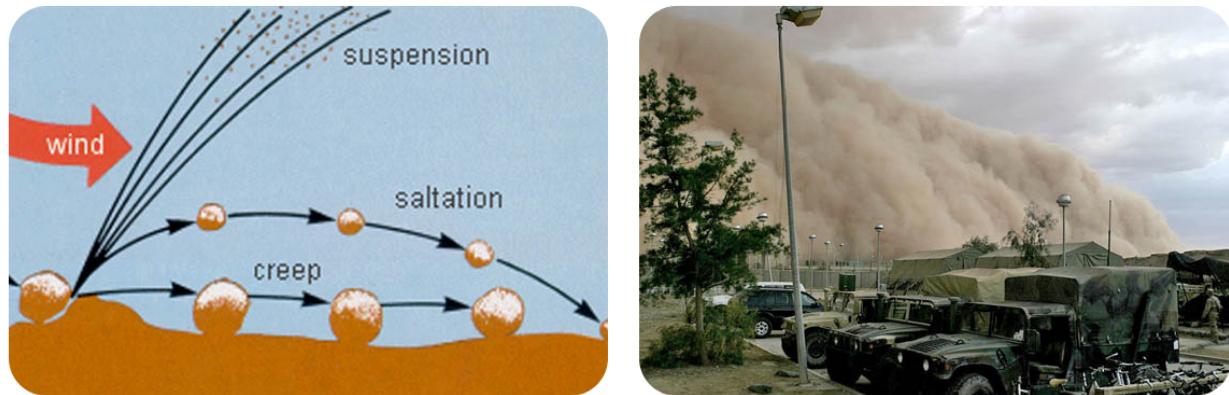
Wind transports small particles, such as silt and clay, over great distances, even halfway across a continent or an entire ocean basin. Particles may be suspended for days. Wind more easily picks up particles on ground that has been disturbed, such as a construction site or a sand dune. Just like flowing water, wind transports particles as both bed load and suspended load. For wind, bed load is made of sand-sized particles, many of which move by saltation ([Figure 1.24](#)). The suspended load is very small particles of silt and clay.

Wind Erosion

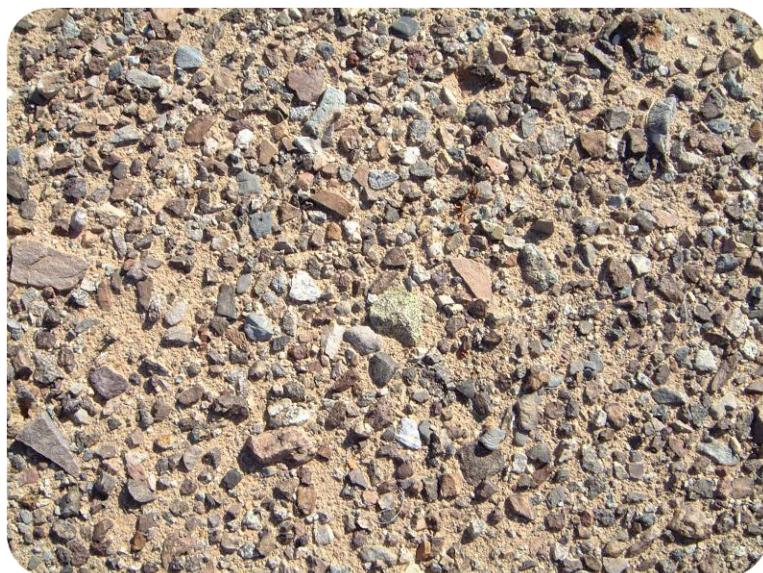
Wind is a stronger erosional force in arid regions than it is in humid regions because winds are stronger. In humid areas, water and vegetation bind the soil so it is harder to pick up. In arid regions, small particles are selectively picked up and transported. As they are removed, the ground surface gets lower and rockier, causing **deflation**. What is left is **desert pavement** ([Figure 1.25](#)), a surface covered by gravel sized particles that are not easily moved by wind.

Particles moved by wind do the work of abrasion. As a grain strikes another grain or surface it erodes that surface. Abrasion by wind may polish natural or human-made surfaces, such as buildings. Stones that have become polished and faceted due to abrasion by sand particles are called **ventifacts** ([Figure 1.26](#)).

Exposed rocks in desert areas often develop a dark brown to black coating called **desert varnish**. Wind transports clay-sized particles that chemically react with other substances at high temperatures. The coating is formed of iron

**FIGURE 1.24**

(a) Wind transport is by suspension, saltation, and creep (bed load). (b) In a sandstorm, sand is usually within a meter of the ground. A dust storm's smaller particles can travel higher. A dust storm as it approaches Al Asad, Iraq.

**FIGURE 1.25**

This desert pavement formed in the Mojave Desert as a result of deflation.

and manganese oxides ([Figure 1.27](#)).

Wind Deposition

Deserts and seashores sometimes have **sand dunes** ([Figure 1.28](#)). Beach dunes have different compositions depending on their location. Beach dunes are usually quartz because in humid areas other minerals weather into clays. In the tropics, sand dunes may be composed of calcium carbonate, which is common. In deserts, sand dunes may be composed of a variety of minerals. There is little weathering and so less stable minerals are left behind.

**FIGURE 1.26**

As wind blows from different direction, polished flat surfaces create a ventifact.

**FIGURE 1.27**

Ancient people carved these petroglyphs into desert varnish near Canyonlands National Park in Utah.

Dune sands are usually very uniform in size and shape. Particles are sand-sized, because larger particles are too heavy for the wind to transport by suspension. Particles are rounded, since rounded grains roll more easily than angular grains.

For sand dunes to form there must be an abundant supply of sand and steady winds. A strong wind slows down, often over some type of obstacle, such as a rock or some vegetation and drops its sand. As the wind moves up and over the obstacle, it increases in speed. It carries the sand grains up the gently sloping, upwind side of the dune by saltation. As the wind passes over the dune, its speed decreases. Sand cascades down the crest, forming the **slip face** of the dune. The slip face is steep because it is at the angle of repose for dry sand, about 34° (**Figure 1.29**).

Wind deposits dune sands layer by layer. If the wind changes directions, cross beds form. Cross beds are named for the way each layer is formed at an angle to the ground (**Figure 1.30**).

The types of sand dune that forms depends on the amount of sand available, the character and direction of the wind, and the type of ground the sand is moving over. Some dune types are shown below.

- An animation of the formation of the dunes at Great Sand Dunes National Park is seen on this website: <http://www.nps.gov/grsa/naturescience/sanddunes.htm>.

**FIGURE 1.28**

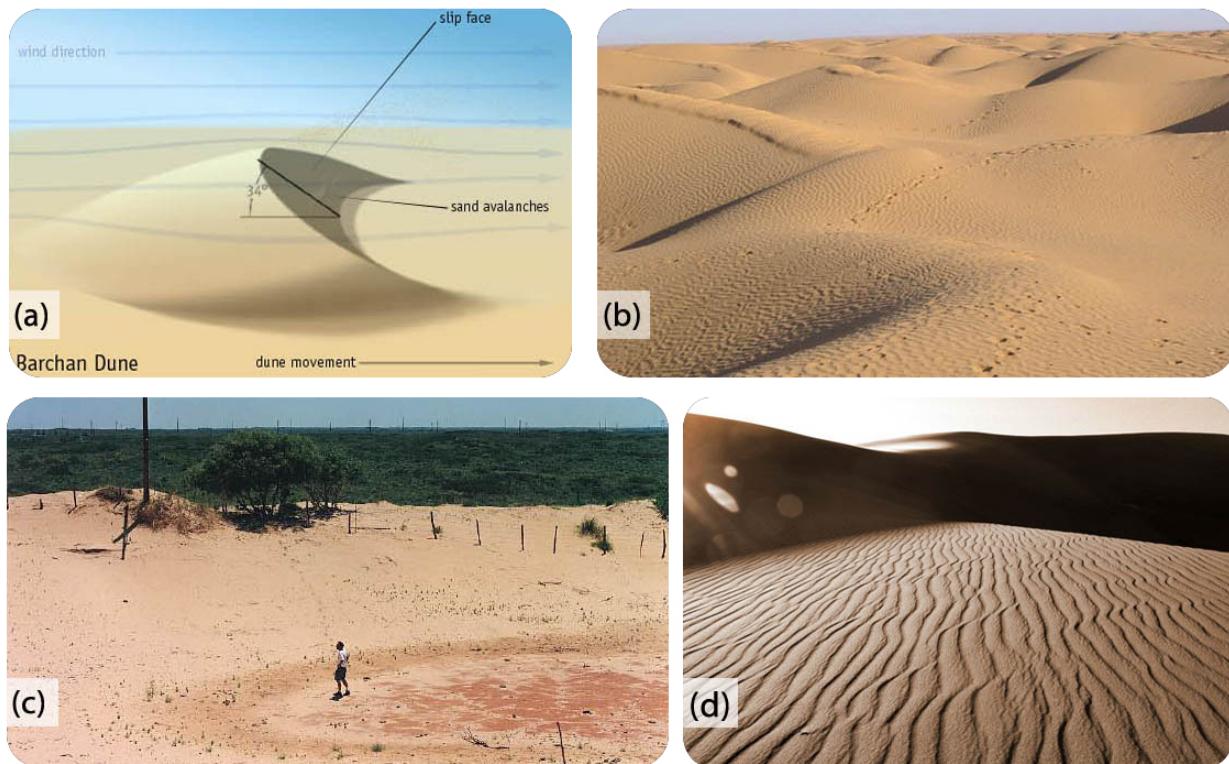
This sand dune in Morocco shows secondary sand ripples along its slip face.

**FIGURE 1.29**

Sand dunes slope gently in the upwind direction. Downwind, a steeper slip face forms.

**FIGURE 1.30**

The cross-bedded sandstones in Es-Salante Canyons, Utah, are ancient sand dunes.

**FIGURE 1.31**

(a) Crescent shaped barchan dunes need adequate amount of sand, winds consistent in one direction and hard ground. The crescent shape curves in the direction the wind blows. Barchan dunes blend together into large scale sand ripples called transverse dunes seen in the image of the dunes in Morocco, above. (b) Star-shaped dunes have several ridges of sand radiating from a central point. (c) Parabolic dunes form a U-shape that curves into the wind direction. Some type of vegetation at least partly covers the sand. (d) Linear dunes form long straight lines parallel to the wind direction. They form in areas with low sand and winds coming together from different directions.

Loess

Windblown silt and clay deposited layer on layer over a large area are **loess**, which comes from the German word *loose* ([Figure 1.32](#)). Loess deposits form downwind of glacial outwash or desert, where fine particles are available. Loess deposits make very fertile soils in many regions of the world.

Fine-grained mud in the deep ocean is formed from silts and clays brought from the land by wind. The particles are deposited on the sea surface, then slowly settle to the deep ocean floor, forming brown, greenish, or reddish clays. Volcanic ash may also settle on the seafloor.

Lesson Summary

- Wind can carry small particles such as sand, silt, and clay.
- Wind erosion abrades surfaces and makes desert pavement, ventifacts, and desert varnish.
- Sand dunes are common wind deposits that come in different shapes, depending on winds and sand availability.

**FIGURE 1.32**

Loess deposits form nearly vertical cliffs, without grains sliding down the face.

- Loess is a very fine grained, wind-borne deposit that can be important to soil formation.

Review Questions

1. Discuss suspended load and bed load transport by wind.
2. Describe how desert pavement forms.
3. Discuss the factors necessary for sand dunes to form.
4. Name four types of sand dunes that form in desert areas.
5. Name one type of wind deposition.
6. Why is wind erosion more important in arid regions than humid areas?

Points to Consider

- Would hurricane-force winds along a coastline produce wind related erosion?
- What would be needed to convert a desert area back to a productive region for farming?
- Do you think wind could sculpt exposed rocks? Explain how this might happen.

1.4 Glacial Erosion and Deposition

Lesson Objectives

- Discuss the different erosional features formed by alpine glaciers.
- Describe the processes by which glaciers change the underlying rocks.
- Discuss the particles deposited by glaciers as they advance and recede.
- Describe the landforms created by glacial deposits.

Vocabulary

- alpine (valley) glacier
- continental glacier
- end moraine
- glacial erratic
- glacial striations
- glacial till
- glaciers
- ground moraine
- hanging valley
- lateral moraine
- medial moraine
- moraine
- plucking
- terminal moraine
- varve

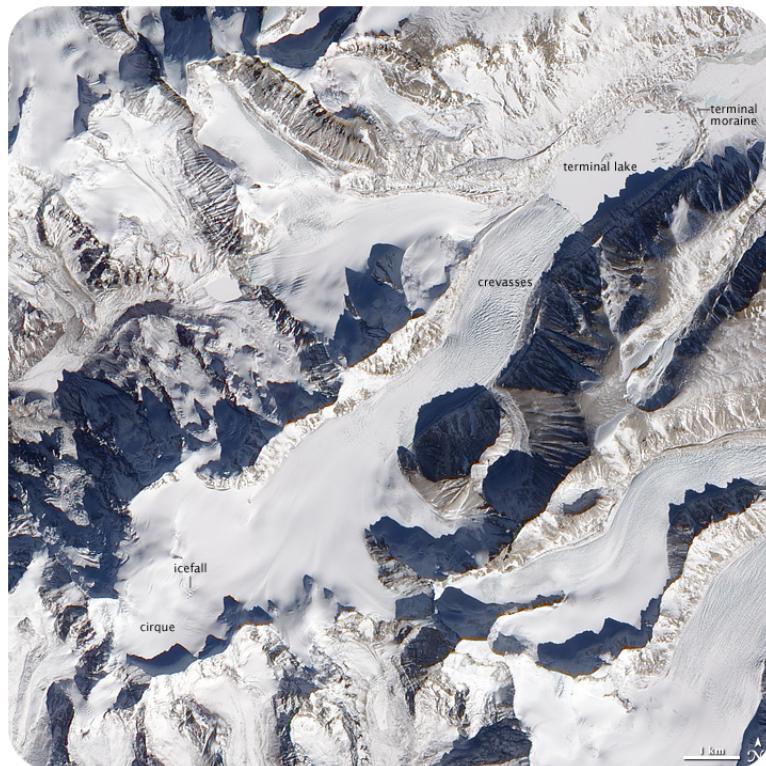
Introduction

Glaciers cover about 10% of the land surface near Earth's poles and they are also found in high mountains. During the Ice Ages, glaciers covered as much as 30% of Earth. Around 600 to 800 million years ago, geologists think that almost all of the Earth was covered in snow and ice. Scientists use the evidence of erosion and deposition left by glaciers to do a kind of detective work to figure out where the ice once was.

Formation and Movement of Glaciers

Glaciers are solid ice that move extremely slowly along the land surface ([Figure 1.33](#)). Glacial ice erodes and shapes the underlying rocks. Glaciers also deposit sediments in characteristic landforms. The two types of glaciers are:

- **Continental glaciers** are large ice sheets that cover relatively flat ground. These glaciers flow outward from where the greatest amount of snow and ice accumulate.
- **Alpine or valley glaciers** flow downhill through mountains along existing valleys.

**FIGURE 1.33**

A satellite image of glaciers in the Himalaya with some features labeled.

Glacial Erosion

Glaciers erode the underlying rock by abrasion and **plucking**. Glacial meltwater seeps into cracks of the underlying rock, the water freezes and pushes pieces of rock outward. The rock is then plucked out and carried away by the flowing ice of the moving glacier (**Figure 1.34**). With the weight of the ice over them, these rocks can scratch deeply into the underlying bedrock making long, parallel grooves in the bedrock, called **glacial striations**.

**FIGURE 1.34**

Glacial striations point the direction a glacier has gone.

Mountain glaciers leave behind unique erosional features. When a glacier cuts through a 'V' shaped river valley, the glacier pucks rocks from the sides and bottom. This widens the valley and steepens the walls, making a 'U' shaped

valley (**Figure 1.35**).



FIGURE 1.35

A U shaped valley in Glacier National Park.

Smaller tributary glaciers, like tributary streams, flow into the main glacier in their own shallower 'U' shaped valleys. A **hanging valley** forms where the main glacier cuts off a tributary glacier and creates a cliff. Streams plunge over the cliff to create waterfalls (**Figure 1.36**).

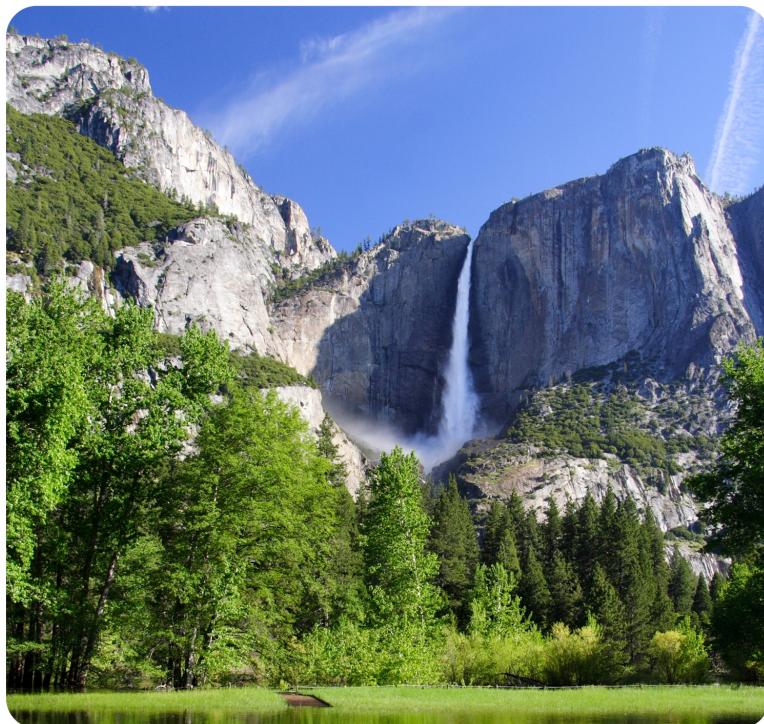


FIGURE 1.36

Yosemite Valley is known for waterfalls that plunge from hanging valleys.

Up high on a mountain, where a glacier originates, rocks are pulled away from valley walls. Some of the resulting erosional features are shown: (**Figure 1.37**), and (**Figure 1.38**).

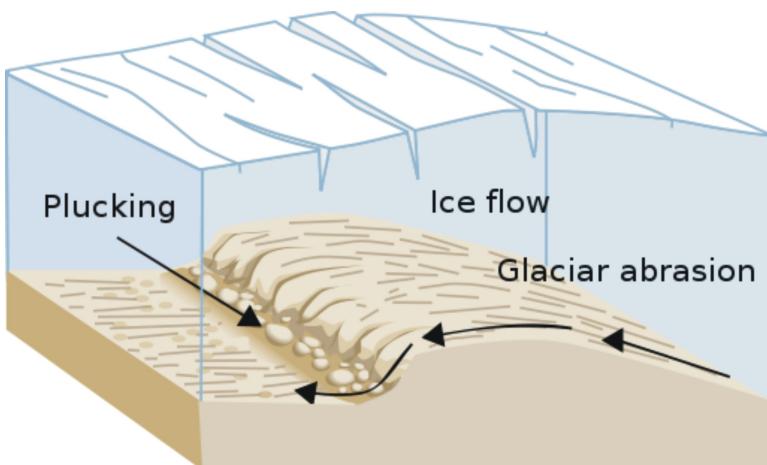
Depositional Features of Glaciers

As glaciers flow, mechanical weathering loosens rock on the valley walls, which falls as debris on the glacier. Glaciers can carry rock of any size, from giant boulders to silt (**Figure 1.39**). These rocks can be carried for many kilometers for many years. These rocks with a different rock type or origin from the surrounding bedrock are **glacial erratics**. Melting glaciers deposit all the big and small bits of rocky material they are carrying in a pile. These unsorted deposits of rock are called **glacial till**.

Glacial till is found in different types of deposits. Linear rock deposits are called **moraines**. Geologists study moraines to figure out how far glaciers extended and how long it took them to melt away. Moraines are named by their location relative to the glacier:

**FIGURE 1.37**

(a) A bowl-shaped cirque in Glacier National Park was carved by glaciers. (b) A high altitude lake, called a tarn, forms from meltwater trapped in the cirque. (c) Several cirques from glaciers flowing in different directions from a mountain peak, leave behind a sharp sided horn, like the Matterhorn in Switzerland. (d) When glaciers move down opposite sides of a mountain, a sharp edged ridge, called an arête.

**FIGURE 1.38**

A roche mouton

**FIGURE 1.39**

A large boulder dropped by a glacier is a glacial erratic.

- **Lateral moraines** form at the edges of the glacier as material drops onto the glacier from erosion of the valley walls.
- **Medial moraines** form where the lateral moraines of two tributary glaciers join together in the middle of a larger glacier (**Figure 1.40**).

**FIGURE 1.40**

The long, dark lines on a glacier in Switzerland are medial and lateral moraines.

- Sediment from underneath the glacier becomes a **ground moraine** after the glacier melts. Ground moraine contributes to the fertile transported soils in many regions.
- **Terminal moraines** are long ridges of till left at the furthest point the glacier reached.
- **End moraines** are deposited where the glacier stopped for a long enough period to create a rocky ridge as it retreated. Long Island in New York is formed by two end moraines.

**FIGURE 1.41**

(a) An esker is a winding ridge of sand and gravel deposited under a glacier by a stream of meltwater. (b) A drumlin is an asymmetrical hill made of sediments that points in the direction the ice moved. Usually drumlins are found in groups called drumlin fields.

While glaciers dump unsorted sediments, glacial meltwater can sort and re-transport the sediments (**Figure 1.41**). As water moves through unsorted glacial till, it leaves behind the larger particles and takes away the smaller bits of sand and silt. (**Figure 1.42**).

- Try to pick out some of the glacial features seen in this Glacier National Park video: http://www.visitmt.com/national_parks/glacier/video_series/part_3.htm.

**FIGURE 1.42**

(a) A sorted deposit of sand and smaller particles is stratified drift. A broad area of stratified drift from meltwater over broad region is an outwash plain. (b) Kettle lakes form as blocks of ice in glacial till melt.

Several types of stratified deposits form in glacial regions but are not formed directly by the ice. **Varves** form where lakes are covered by ice in the winter. Dark, fine-grained clays sink to the bottom in winter but melting ice in spring brings running water that deposits lighter colored sands. Each alternating dark/light layer represents one year of deposits. If during a year, a glacier accumulates more ice than melts away, the glacier advances downhill. If a glacier melts more than it accumulates over a year, it is retreating ([Figure 1.43](#)).

**FIGURE 1.43**

Grinnell Glacier in Glacier National Park has been retreating over the past 70 years.

Lesson Summary

- The movement of ice in the form of glaciers has transformed our mountainous land surfaces with its tremendous power of erosion.
- U-shaped valleys, hanging valleys, cirques, horns, and aretes are features sculpted by ice.
- The eroded material is later deposited as large glacial erratics, in moraines, stratified drift, outwash plains, and drumlins.
- Varves are a very useful yearly deposit that forms in glacial lakes.

Review Questions

- How much of the Earth's land surface is covered by glaciers today? Where are they found?
- What are the two types of glaciers and how are they different from each other?
- What is the shape of a valley that has been eroded by rivers? How does a glacier change that shape and what does it become?

4. What two different features form as smaller side glaciers join the central main glacier?
5. How do glaciers erode the surrounding rocks?
6. Name the erosional features that are formed by glaciers high in the mountains and describe how they form.
7. Describe the different types of moraines formed by glaciers.
8. Describe the difference between glacial till and stratified drift. Give an example of how each type of deposit forms.
9. Name and describe the two asymmetrical hill shaped landforms created by glaciers.

Further Reading / Supplemental Links

- Glacial landforms illustrated: http://www.uwsp.edu/geo/faculty/lemke/alpine_glacial_glossary/glossary.html

Points to Consider

- What features would you look for to determine if glaciers had ever been present?
- If glaciers had never formed, how would soil in Midwestern North America be different?
- Can the process of erosion produce landforms that are beautiful?

1.5 Erosion and Deposition by Gravity

Lesson Objectives

- Describe the ways that material can move downhill by gravity.
- Discuss the factors that increase the likelihood of landslides.
- Describe the different types of gravity-driven movement of rock and soil.
- Describe ways to prevent and be aware of potential landslides or mudflows.

Vocabulary

- avalanche
- creep
- landslide
- mudflow
- slump
- talus slope

Introduction

Gravity shapes the Earth's surface by moving weathered material from a higher place to a lower one. This occurs in a variety of ways and at a variety of rates including sudden, dramatic events as well as slow steady movements that happen over long periods of time. The force of gravity is constant and it is changing the Earth's surface right now.

Types of Movement Caused by Gravity

Weathered material may fall away from a cliff because there is nothing to keep it in place. Rocks that fall to the base of a cliff make a **talus slope** (Figure 1.44). Sometimes as one rock falls, it hits another rock, which hits another rock, and begins a landslide.

Landslides and Avalanches

Landslides and **avalanches** are the most dramatic, sudden, and dangerous examples of earth materials moved by gravity. Landslides are sudden falls of rock, whereas avalanches are sudden falls of snow.

- A video of a snow avalanche is seen here: <http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20file%20Avalanches.mov>

When large amounts of rock suddenly break loose from a cliff or mountainside, they move quickly and with tremendous force (Figure 1.45). Air trapped under the falling rocks acts as a cushion that keeps the rock from slowing down. Landslides and avalanches can move as fast as 200 to 300 km/hour.

Landslides are exceptionally destructive. Homes may be destroyed as hillsides collapse. Landslides can even bury entire villages. Landslides may create lakes when the rocky material dams a stream. If a landslide flows into a lake or bay, they can trigger a tsunami (Figure 1.46).

**FIGURE 1.44**

Pieces of rock regularly fall to the base of cliffs to form talus slopes.

**FIGURE 1.45**

(a) Landslides are called rock slides by geologists. (b) A snow avalanche moves quickly down slope, burying everything in its path.

**FIGURE 1.46**

The 1958 landslide into Lituya Bay, Alaska, created a 524m tsunami that knocked down trees at elevations higher than the Empire State Building (light gray).

Landslides often occur on steep slopes in dry or semi-arid climates. The California coastline, with its steep cliffs and years of drought punctuated by seasons of abundant rainfall, is prone to landslides. At-risk communities have developed landslide warning systems. Around San Francisco Bay, the National Weather Service and the U.S. Geological Survey use rain gauges to monitor soil moisture. If soil becomes saturated, the weather service issues a warning. Earthquakes, which may occur on California's abundant faults, can also trigger landslides.

- Rapid downslope movement of material is seen in this video: <http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/dflows.mov>.

KQED: Landslide Detectives

Hillside properties in the San Francisco Bay Area and elsewhere may be prone to damage from landslides. Geologists are studying the warning signs and progress of local landslides to help reduce risks and give people adequate warnings of these looming threats. Learn more at:<http://science.kqed.org/quest/video/landslide-detectives/>

**MEDIA**

Click image to the left for more content.

Mudflows and Lahars

Added water creates natural hazards produced by gravity (**Figure 1.47**). On hillsides with soils rich in clay, little rain, and not much vegetation to hold the soil in place, a time of high precipitation will create a **mudflow**. Mudflows follow river channels, washing out bridges, trees, and homes that are in their path.

- A debris flow is seen in this video: <http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/Moscardo.mov>.

**FIGURE 1.47**

The white areas on green hillsides mark scars from numerous mudflows.

A lahar is mudflow that flows down a composite volcano (**Figure 1.48**). Ash mixes with snow and ice melted by the eruption to produce hot, fast-moving flows. The lahar caused by the eruption of Nevado del Ruiz in Columbia in 1985 killed more than 23,000 people.

**FIGURE 1.48**

A lahar is a mudflow that forms from volcanic ash and debris.

Slump and Creep

Less dramatic types of downslope movement move earth materials slowly down a hillside. **Slump** moves materials as a large block along a curved surface (**Figure 1.49**). Slumps often happen when a slope is undercut, with no support for the overlying materials, or when too much weight is added to an unstable slope.

Creep is the extremely gradual movement of soil downhill. Curves in tree trunks indicate creep because the base of the tree is moving downslope while the top is trying to grow straight up (**Figure 1.50**). Tilted telephone or power company poles are also signs of creep.

Contributing Factors

There are several factors that increase the chance that a landslide will occur. Some of these we can prevent and some we cannot.

**FIGURE 1.49**

Slump material moves as a whole unit, leaving behind a crescent shaped scar.

**FIGURE 1.50**

Trees with curved trunks are often signs that the hillside is slowly creeping down-hill.

Water

A little bit of water helps to hold grains of sand or soil together. For example, you can build a larger sand castle with slightly wet sand than with dry sand. However too much water causes the sand to flow quickly away. Rapid snow melt or rainfall adds extra water to the soil, which increases the weight of the slope and makes sediment grains lose contact with each other, allowing flow.

Rock Type

Layers of weak rock, such as clay, also allow more landslides. Wet clay is very slippery, which provides an easy surface for materials to slide over.

Undercutting

If people dig into the base of a slope to create a road or a homesite, the slope may become unstable and move downhill. This is particularly dangerous when the underlying rock layers slope towards the area (**Figure 1.51**).

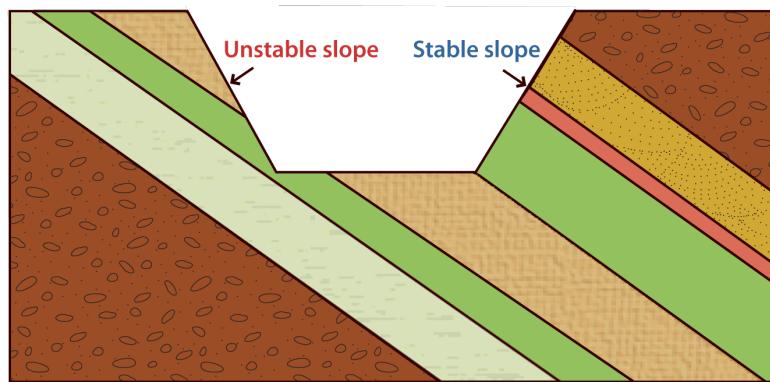


FIGURE 1.51

The slope of underlying materials must be considered when making road cuts.

- Ocean waves undercut cliffs and cause landslides on beaches as in this video: http://faculty.gg.uwyo.edu/helle/SedMovs/Sed%20Movie%20files/Cliff_retreat.mov.

When construction workers cut into slopes for homes or roads, they must stabilize the slope to help prevent a landslide (**Figure 1.52**). Trees roots or even grasses can bind soil together. It is also a good idea to provide drainage so that the slope does not become saturated with water.

Ground shaking

An earthquake, volcanic eruption, or even just a truck going by can shake unstable ground loose and cause a slide. Skiers and hikers may disturb the snow they travel over and set off an avalanche.

A very good introduction to the topic, “Landslide 101,” is a video seen on National Geographic Videos, Environment Video, Natural Disasters, Landslides, and more: <http://video.nationalgeographic.com/video/player/environment/>.

Prevention and Awareness

Landslides cause \$1 billion to \$2 billion damage in the United States each year and are responsible for traumatic and sudden loss of life and homes in many areas of the world. To be safe from landslides:

**FIGURE 1.52**

A rock wall stabilizes a slope that has been cut away to make a road.

- Be aware of your surroundings and notice changes in the natural world.
- Look for cracks or bulges in hillsides, tilting of decks or patios, or leaning poles or fences when rainfall is heavy. Sticking windows and doors can indicate ground movement as soil pushes slowly against a house and knocks windows and doors out of alignment.
- Look for landslide scars because landslides are most likely to happen where they have occurred before.
- Plant vegetation and trees on the hillside around your home to help hold soil in place.
- Help to keep a slope stable by building retaining walls. Installing good drainage in a hillside may keep the soil from getting saturated.

Lesson Summary

- Gravity moves earth materials from higher elevations to lower elevations.
- Landslides, avalanches, and mudflows are examples of dangerous erosion by gravity.
- Slump and creep move material slowly downslope.
- Plants, retaining walls, and good drainage are ways to help prevent landslides.

Review Questions

1. Describe three ways that gravity moves materials.
2. What natural events and human actions can trigger a landslide or avalanche?
3. What makes landslides and avalanches move at such great speeds?
4. Compare and contrast a mudflow and a lahar.
5. Name two ways that soil can move slowly down a slope.
6. What can people do to help prevent landslides or mudflows?

Points to Consider

- Why might someone build a home on top of land where a landslide has happened before?
 - What factors make it likely or unlikely that a landslide could happen in your area?
 - What new technologies might help people to know when a landslide will occur?
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45. . HS-ES-10-46-Landslides-avalanches.

46. . ES-1005-06.
47. . Es-1005-07.
48. . ES-1005-08.
49. . ES-1005-09.
50. . ES-1005-10.
51. . ES-1005-01.
52. . ES-1005-02.