MODULE 1: The Earth

- Origin, Age and Internal structure of the Earth; Materials of Earth; Earth as a closed system. Geomorphology - Weathering of rocks and its engineering considerations; Geological work of wind and running water.

EARTH SYSTEMS—THE HYDROLOGIC CYCLE

The interrelationship of the hydrosphere, geosphere, biosphere, and atmosphere is easy to visualize through the **hydrologic cycle,** the movement and interchange of water between the sea, air, and land (figure 16.1).

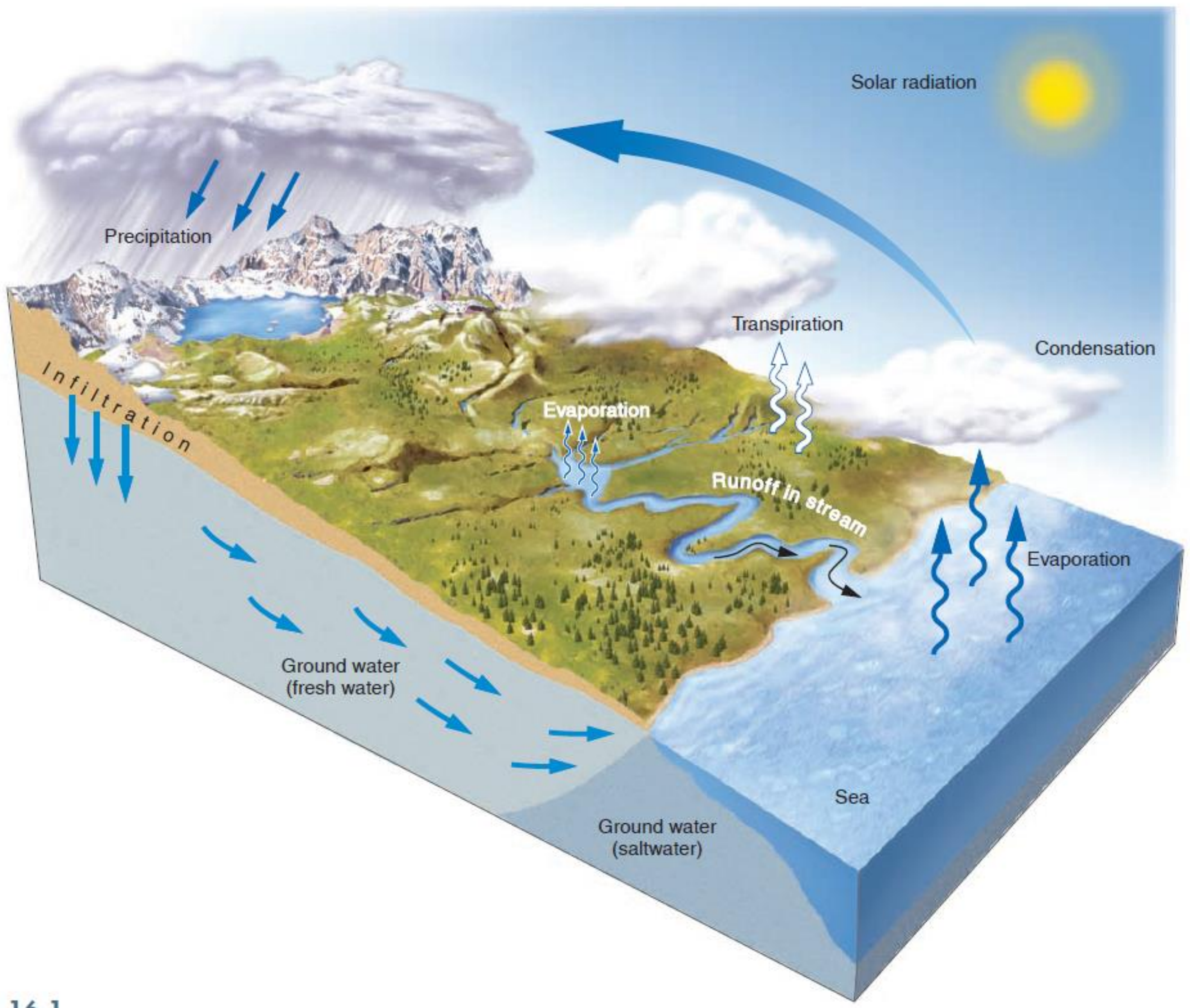


FIGURE 16.1

The hydrologic cycle. Water vapor evaporates from the land and sea, condenses to form clouds, and falls as precipitation (rain and snow). Water falling on land runs off over the surface as streams or infiltrates into the ground to become ground water. It returns to the atmosphere again by evaporation and transpiration (the loss of water to the air by plants). Visit *http://observe.nasa.gov/nasa/earth/hydrocycle/hydro1.html*

Running Water

The precipitation that falls on land either enters the soil (infiltration) or remains at the surface, moving downslope as runoff.

Runoff initially flows in broad, thin sheets across hillslopes by a process called sheet flow. This thin, unconfined flow eventually develops threads of current that form tiny channels called rills. Rills meet to form gullies, which join to form brooks, creeks, or streams—then, when they reach an undefined size, they are called rivers.

Although the terms river and stream are often used interchangeably, geologists define stream as water that flows in a channel, regardless of size. River, on the other hand, is a general term for streams that carry substantial amounts of water and have numerous tributaries.

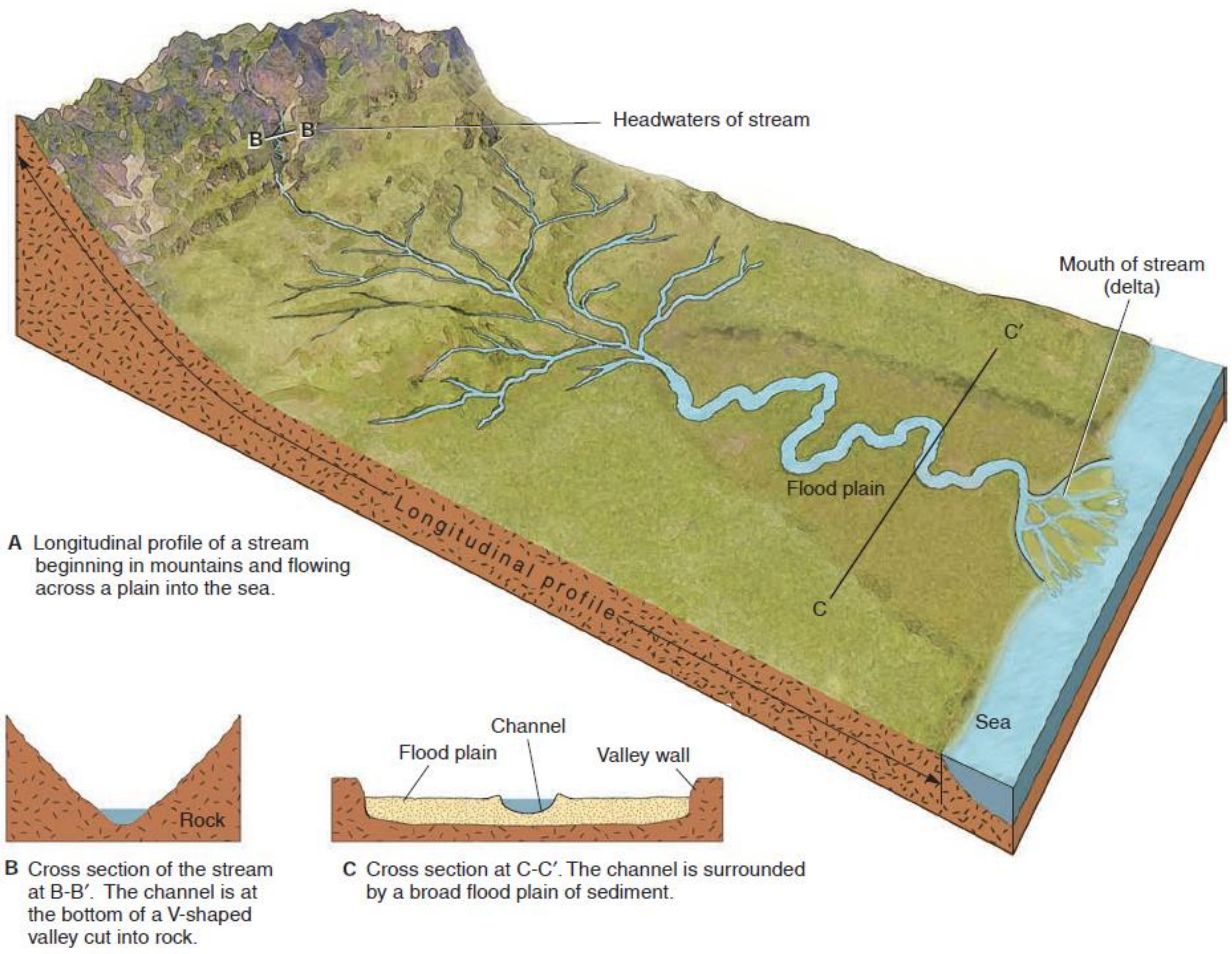
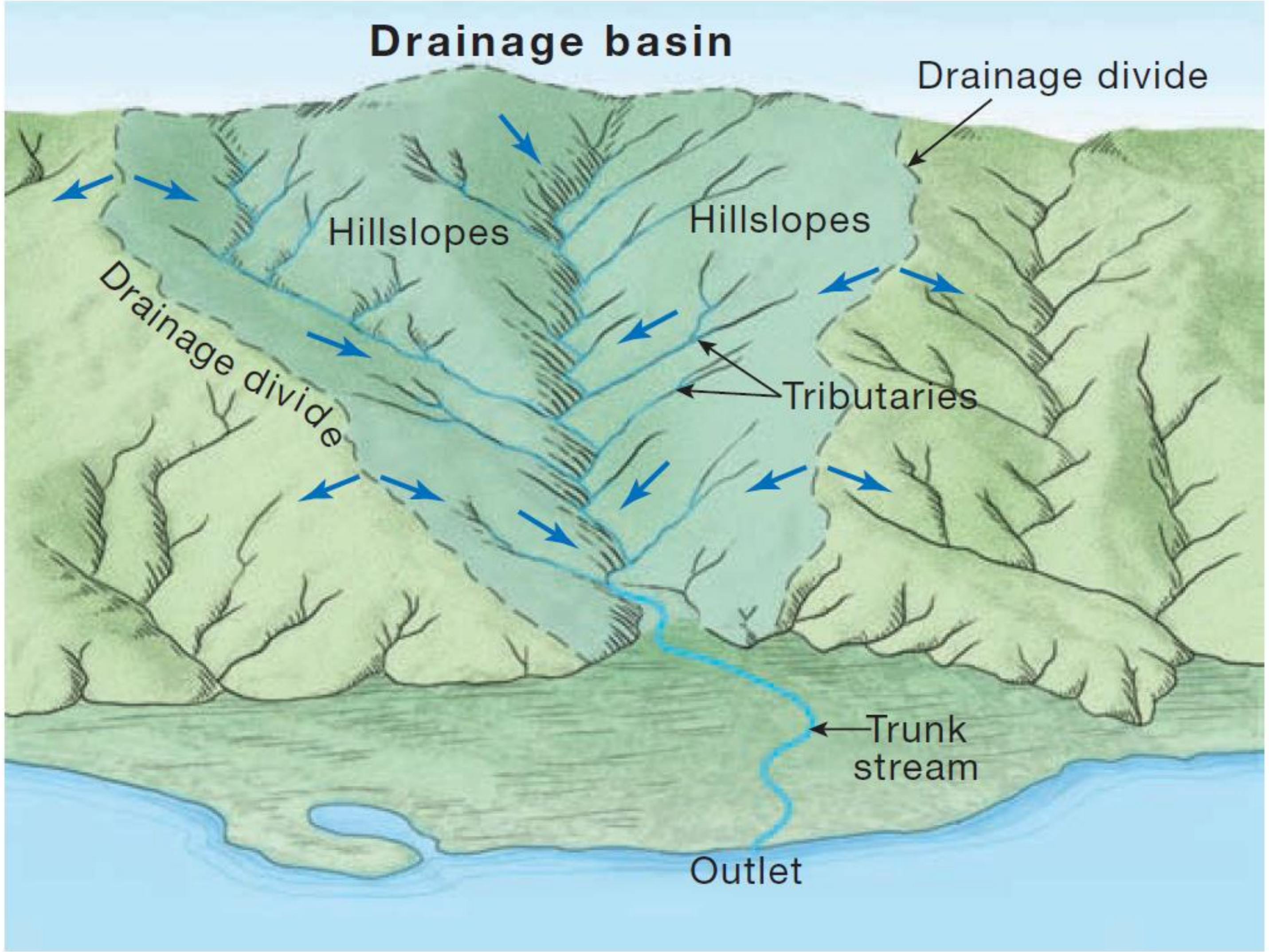


FIGURE 16.2

Longitudinal profile and cross sections of a typical stream.

Drainage Basins

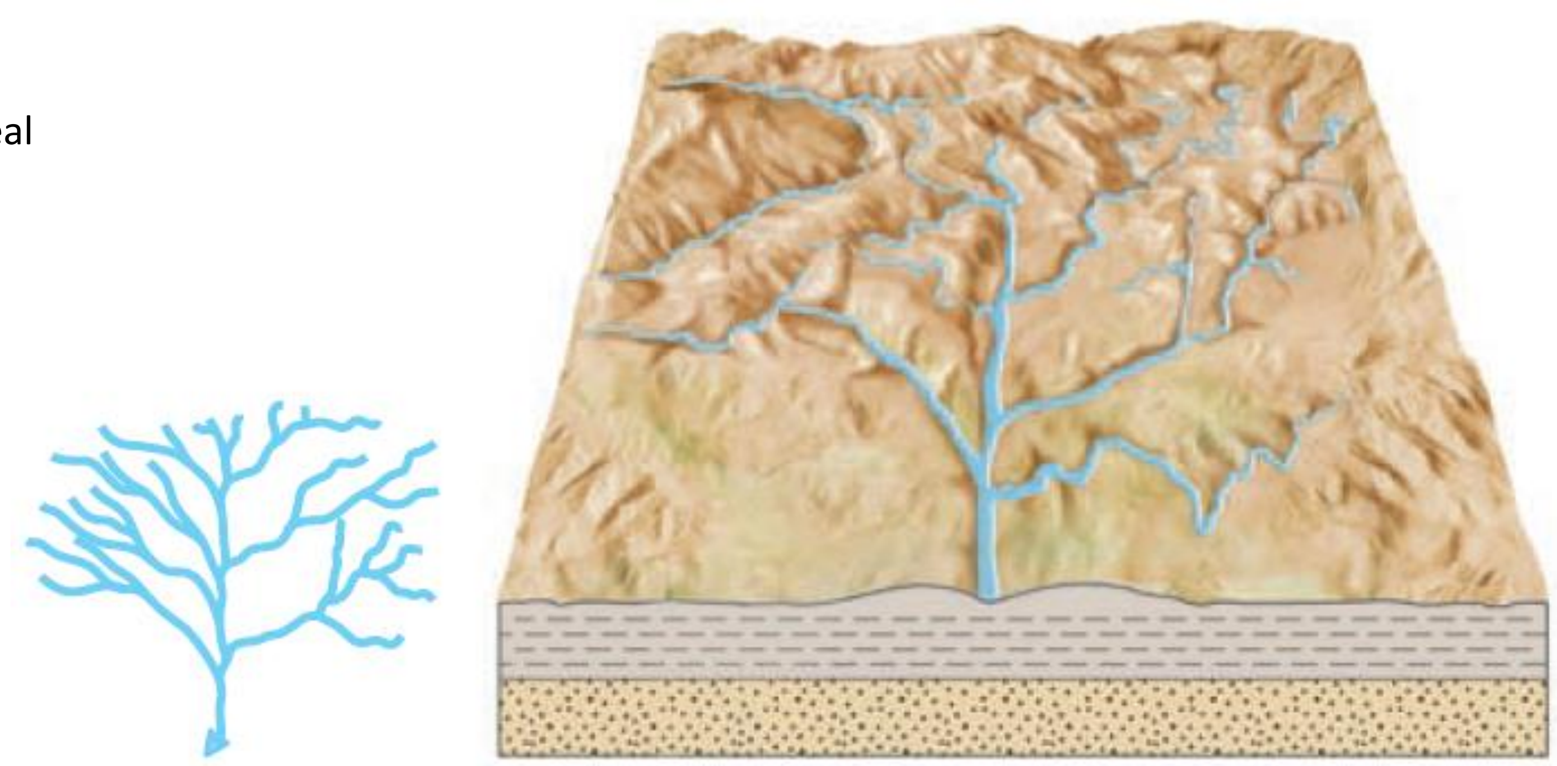
Every stream drains an area of land called a drainage basin (FIGURE 9.4). Each drainage basin is bounded by an imaginary line called a divide, something that is clearly visible as a sharp ridge in some mountainous areas but can be rather difficult to discern in more subdued topographies. The outlet, where the stream exits the drainage basin, is at a lower elevation than the rest of the basin.



DRAINAGE PATTERNS

A drainage pattern can, in many cases, reveal the nature and structure of the rocks underneath it.

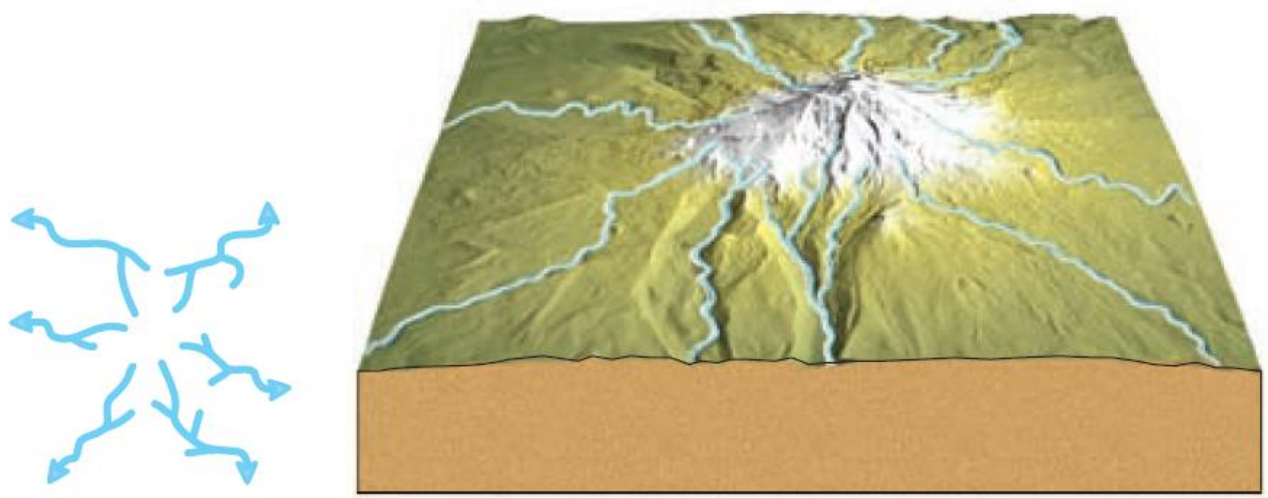
If the pattern resembles branches of a tree or nerve dendrites, it is called **dendritic.** Dendritic drainage patterns develop on uniformly erodible rock or regolith and are the most common type of pattern.



A Dendritic

DRAINAGE PATTERNS

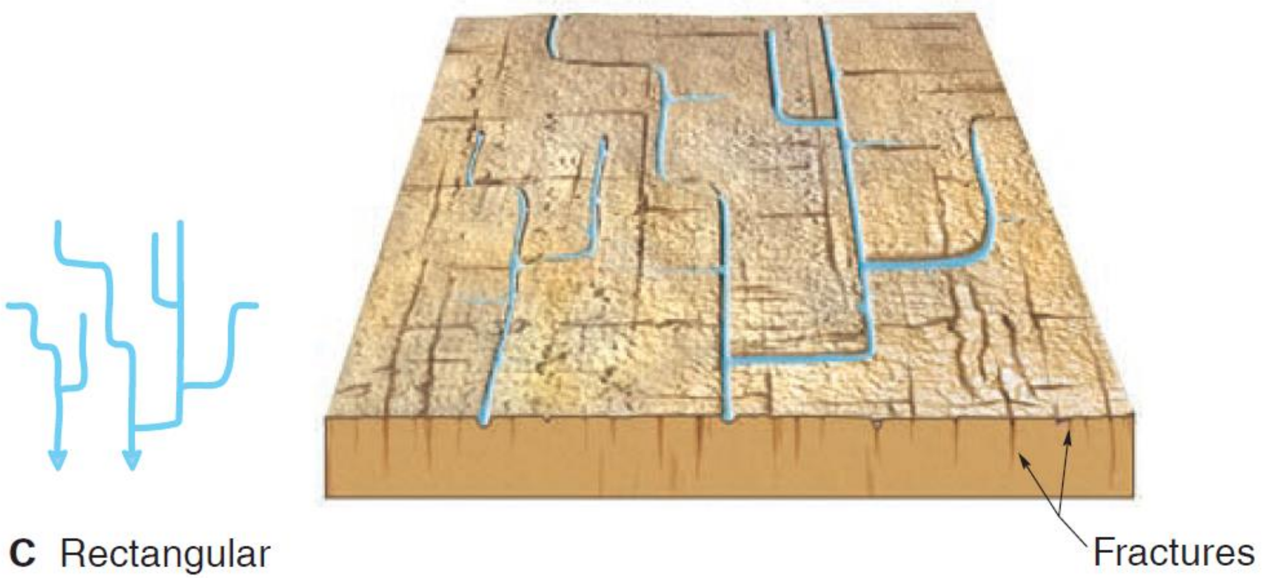
A **radial pattern,** in which streams diverge outward like spokes of a wheel, forms on high conical mountains, such as composite volcanoes and domes



B Radial

DRAINAGE PATTERNS

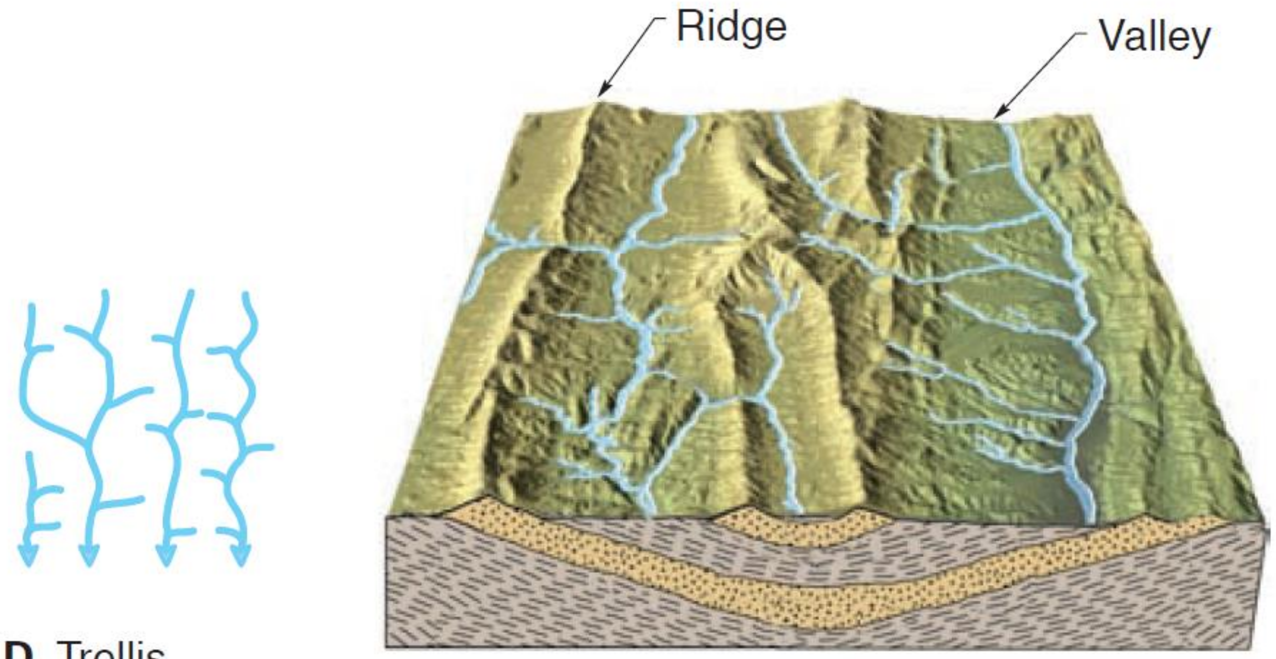
A **rectangular pattern,** in which tributaries have frequent 90° bends and tend to join other streams at right angles, develops on regularly fractured rock



C Rectangular

DRAINAGE PATTERNS

A **trellis pattern** consists of parallel main streams with short tributaries meeting them at right angles



D Trellis

River Systems

Rivers drain much of Earth's land area, with the exception of extremely arid regions and polar areas that are permanently frozen. To a large extent, the variety of rivers that exist is a reflection of the different environments in which they are found.

River systems involve not only a network of stream channels, but also the entire drainage basin.

Based on the dominant processes operating within them, river systems can be divided into three zones; *sediment production*—where erosion dominates, *sediment transport,* and *sediment deposition*.

It is important to recognize that sediment is being eroded, transported, and deposited along the entire length of a stream, regardless of which process is dominant within each zone.

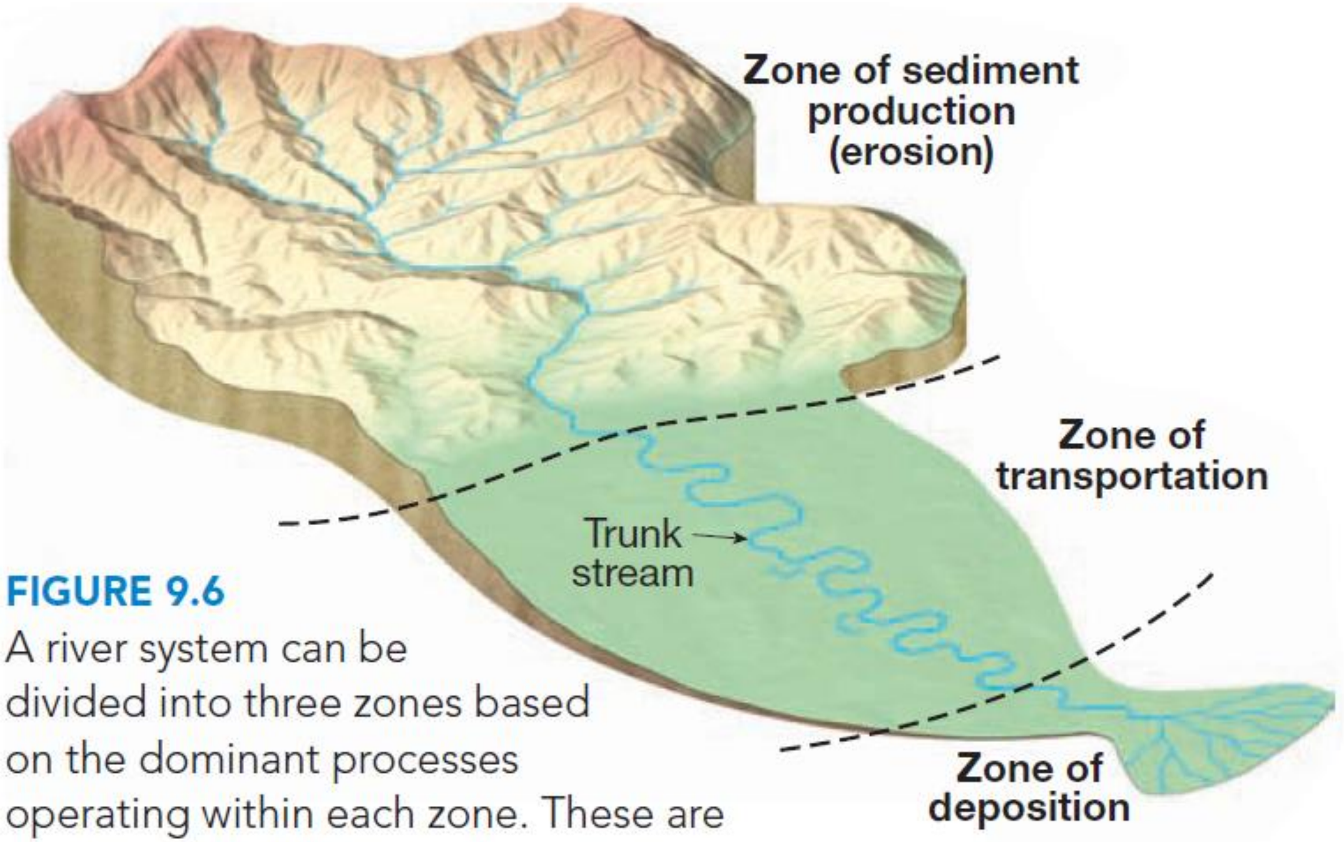


FIGURE 9.6
A river system can be divided into three zones based on the dominant processes operating within each zone. These are the zones of sediment production (erosion), sediment transport, and sediment deposition. *(Adapted from Shumm)*

FACTORS AFFECTING STREAM EROSION AND DEPOSITION

- Stream erosion and deposition are controlled primarily by a river's *velocity* and, to a lesser extent, its *discharge.*
- Velocity is largely controlled by
    - the stream *gradient,*
    - channel shape and channel roughness.

Gradient

The slope of a stream channel, expressed as the vertical drop of a stream over a specified distance, is called gradient**.**

Channel Shape and Roughness

The *shape of the channel* also controls stream velocity. Hard, resistant rock is difficult to erode, so a stream may have a relatively narrow channel in such rock. As a result, it flows rapidly. If the stream flows onto a softer rock that is easier to erode, the channel may widen, and the river will slow down because of the increased surface area dragging on the flowing water.

The roughness of the channel also controls velocity. A stream can flow rapidly over a smooth channel, but a rough, boulder-strewn channel floor creates more friction and slows the flow

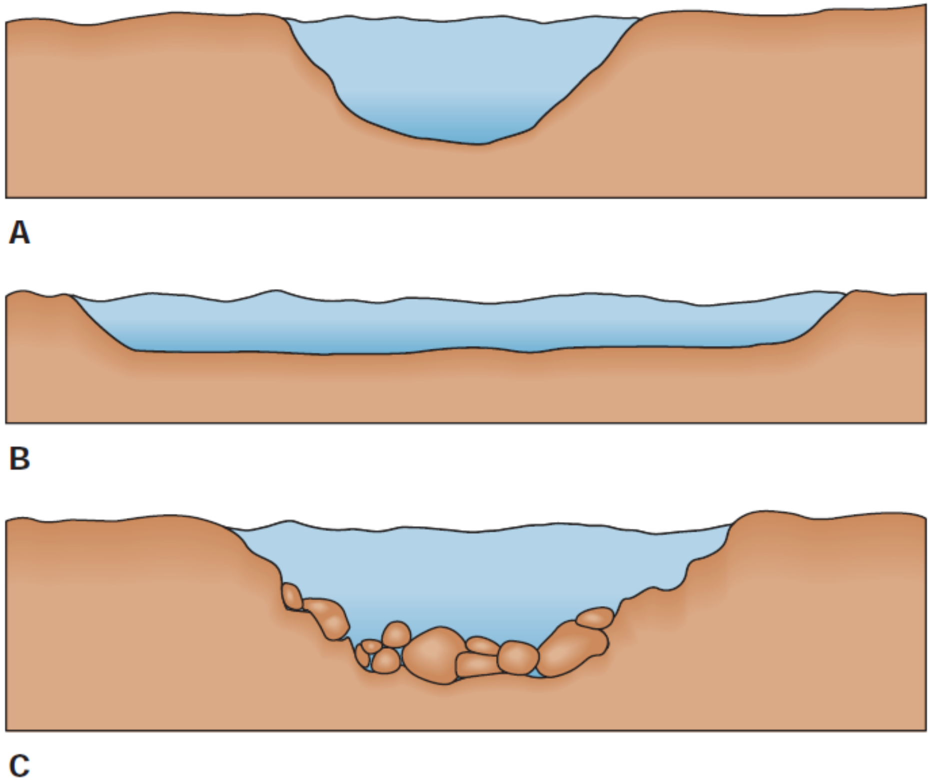


FIGURE 16.8

Channel shape and roughness influence stream velocity. (*A*) Semicircular channel allows stream to flow rapidly. (*B*) Wide, shallow channel increases friction, slowing river down. (*C*) Rough, boulder-strewn channel slows river.

Discharge

The measure most often used to compare the size of streams is discharge—the volume of water flowing past a certain point in a given unit of time.

Discharge, usually measured in cubic meters per second, is determined by multiplying a stream's cross-sectional area by its velocity.

The discharge of a river system changes over time because of variations in the amount of precipitation received by the drainage basin. Studies show that when discharge increases, the width, depth, and flow velocity of the channel all increase predictably.

Changes Downstream

One useful way of studying a stream is to examine its longitudinal profile. Such a profile is simply a cross-sectional view of a stream from its source area (called the head or headwaters) to its mouth, the point downstream where it empties into another water body—a river, lake, or ocean.

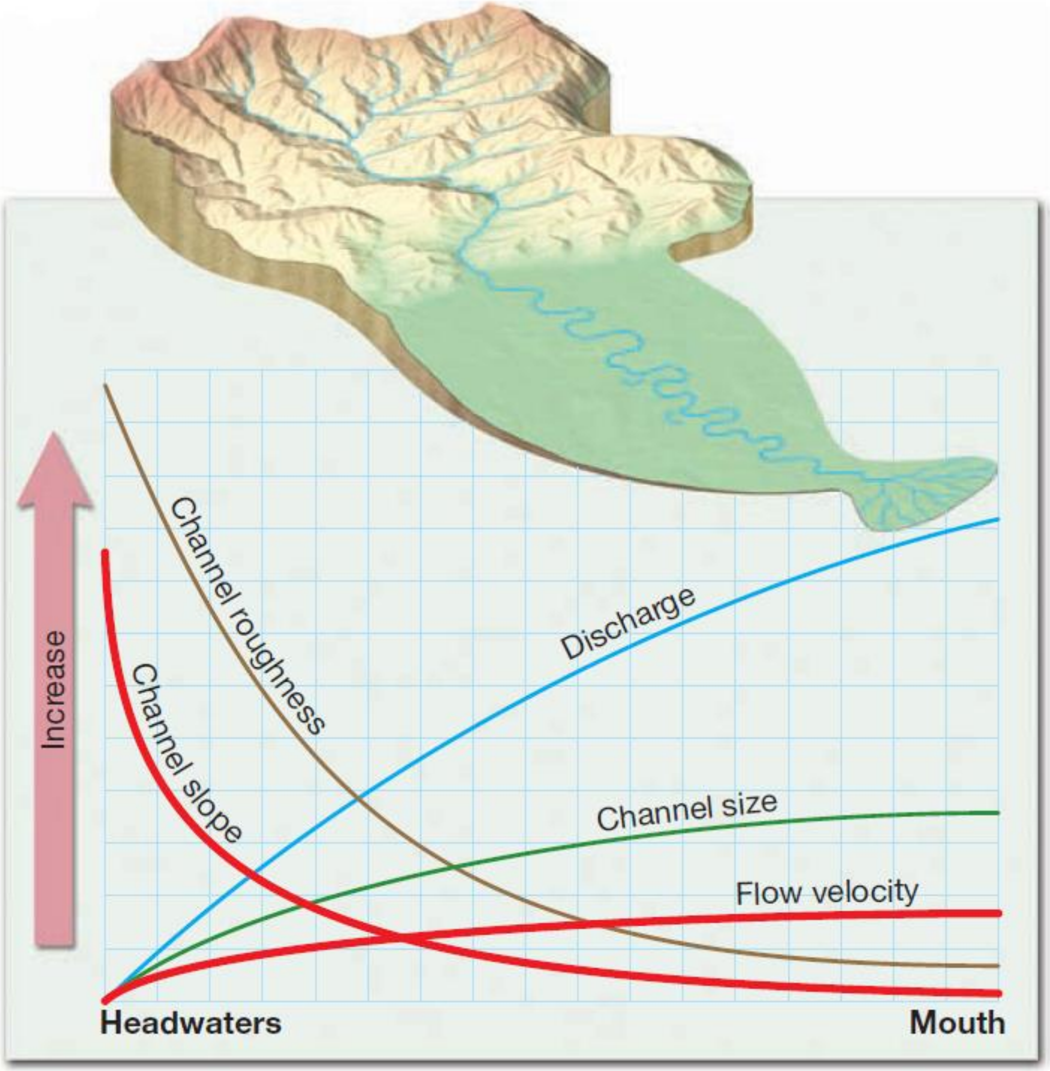


FIGURE 9.10 This graph shows how various properties of a stream channel change from its headwaters to its mouth. Although the gradient decreases toward the mouth, increases in channel size and discharge and decreases in roughness more than offset the decrease in slope. Consequently, stream flow velocity usually increases toward the mouth.

The Work of Running Water

Streams are Earth's most important erosional agents. Not only do they have the ability to downcut and widen their channels, but streams also have the capacity to transport enormous quantities of sediment delivered to them by overland flow, mass wasting, and groundwater. Eventually, much of this material is deposited to create a variety of landforms.

Stream Erosion

A stream's ability to accumulate and transport soil and weathered rock is aided by the work of raindrops, which knock sediment particles loose. When the ground is saturated, rainwater cannot infiltrate, so it flows downslope, transporting some of the material it dislodges. On barren slopes the flow of muddy water (sheet flow) often produces small channels (rills), which in time can evolve into larger gullies

Streams cut channels into bedrock through quarrying and abrasion. Quarrying involves the removal of blocks from the bed of the channel. This process is aided by fracturing and weathering that loosen the blocks sufficiently so they are moveable during times of high flow rates. Quarrying is mainly the result of the impact forces exerted by flowing water.

Abrasion is the process by which the bed and banks of a bedrock channel are ceaselessly bombarded by particles carried into the flow.

Transport of Sediment by Streams

All streams, regardless of size, transport some rock material (FIGURE 9.12). Streams also sort the solid sediment they transport because finer, lighter material is carried more readily than larger, heavier particles.

Streams transport their load of sediment in three ways:

(1) in solution (dissolved load),

(2) in suspension (suspended load), and

(3) sliding or rolling along the bottom (bed load).

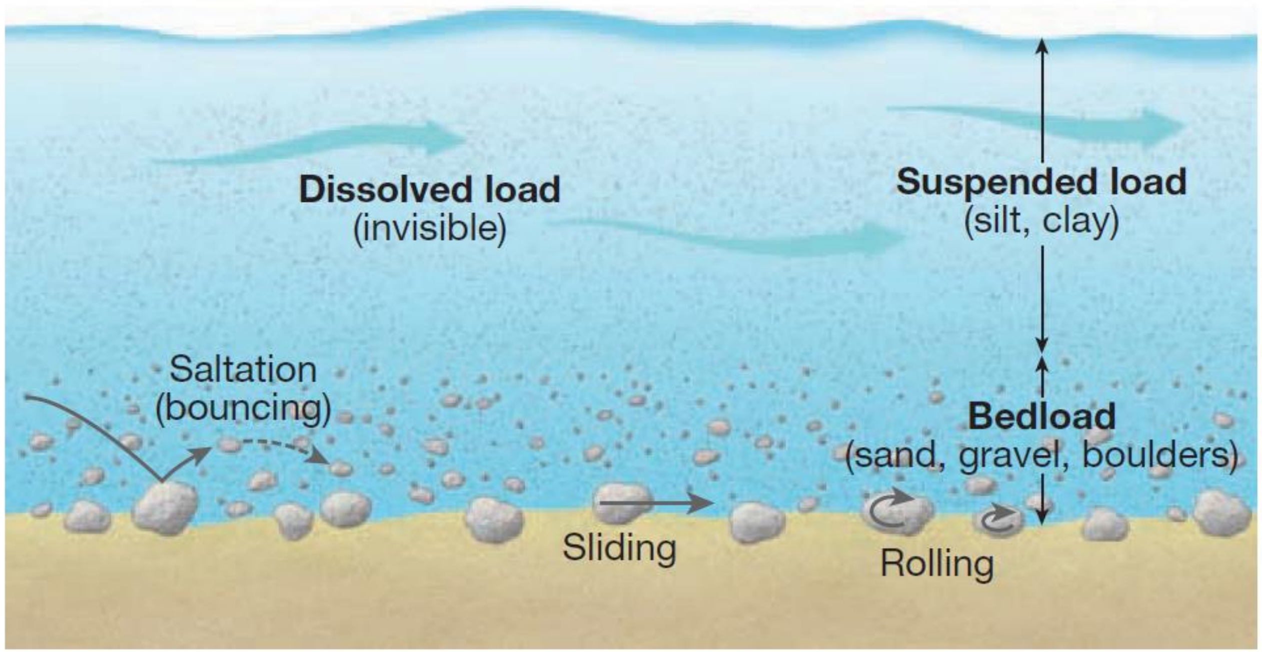


FIGURE 9.12 Streams transport their load of sediment in three ways. The dissolved and suspended loads are carried in the general flow. The bed load includes coarse sand, gravel, and boulders that move by rolling, sliding, and saltation.

Deposition of Sediment by Streams

Deposition occurs whenever a stream slows, causing a reduction in competence. As its velocity decreases, sediment begins to settle, largest particles first. Thus, stream transport provides a mechanism by which solid particles of various sizes are separated. This process, called sorting, explains why particles of similar size are deposited together.

The general term for sediment deposited by streams is alluvium. Many different depositional features are composed of alluvium. Some occur within stream channels, some occur on the valley floor adjacent to the channel, and some are found at the mouth of the stream.

Stream Channels

A basic characteristic that distinguishes streamflow from overland flow is that it is confined in a channel.

Although somewhat oversimplified, we can divide stream channels into two basic types.

Bedrock channels are those in which the streams are actively cutting into solid rock.

In contrast, when the bed and banks are composed mainly of unconsolidated sediment or alluvium, the channel is called an *alluvial channel*

Bedrock Channels

As the name suggests, bedrock channels are cut into the underlying strata and typically form in the headwaters of river systems where streams have steep slopes. The energetic flow tends to transport coarse particles that actively abrade the bedrock channel. Potholes are often visible evidence of the erosional forces at work.

Alluvial Channels

Alluvial channels form in sediment that was previously deposited in the valley. When the valley floor reaches sufficient width, material deposited by the stream can form a *floodplain* that borders the channel. Because the banks and beds of alluvial channels are composed of unconsolidated sediment (alluvium) they can undergo major changes in shape as material is continually being eroded, transported, and redeposited.

Two common types of alluvial channels are

- meandering channels and
- braided channels.

MEANDERING CHANNELS.

Streams that transport much of their load in suspension generally move in sweeping bends called meanders (FIGURE 9.14). These streams flow in relatively deep, smooth channels and primarily transport mud (silt and clay), sand, and occasionally fine gravel. Meandering channels evolve over time as individual bends migrate across the floodplain. Most of the erosion is focused at the outside of the meander, where velocity and turbulence are greatest. In time, the outside bank is undermined, especially during periods of high water. Because the outside of a meander is a zone of active erosion, it is often referred to as the cut bank (Figure 9.14).

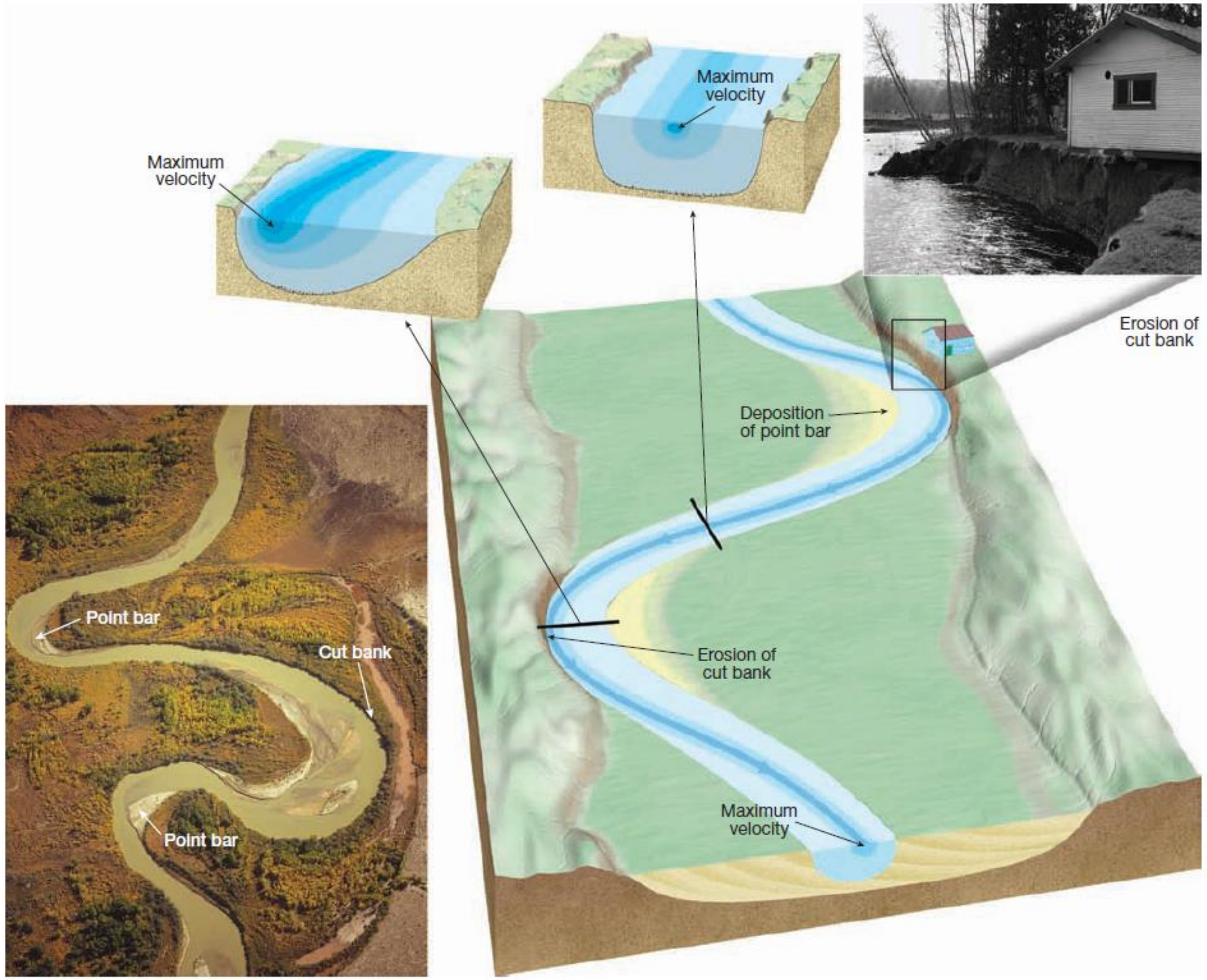
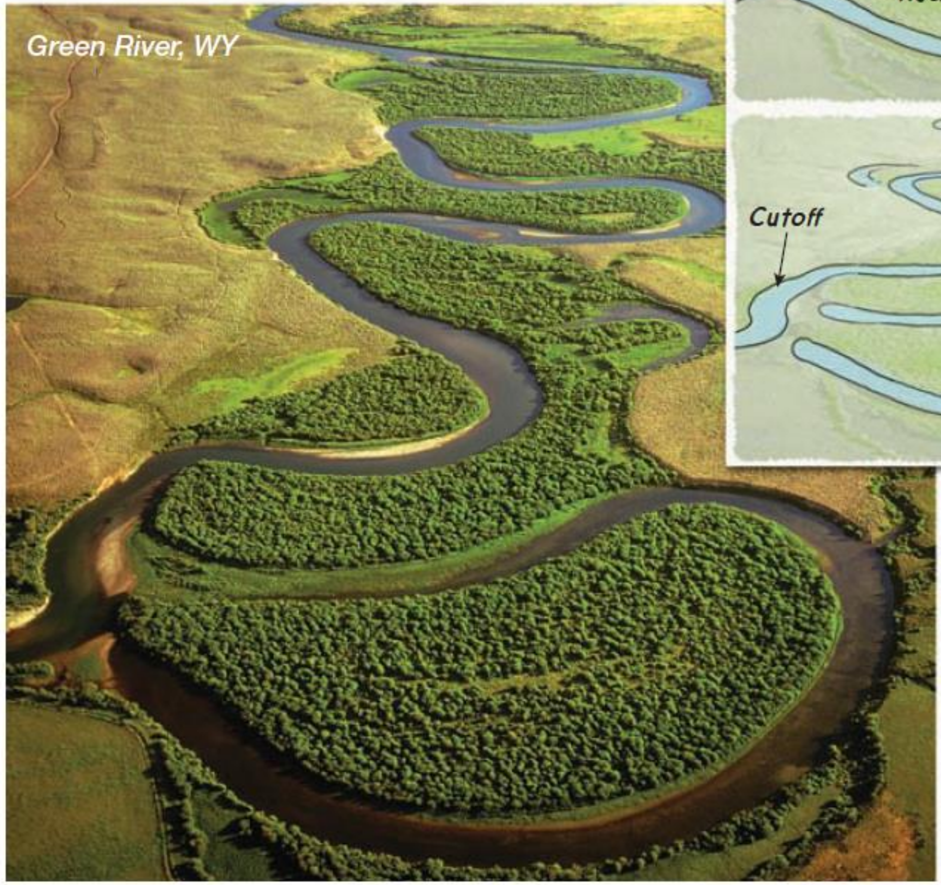


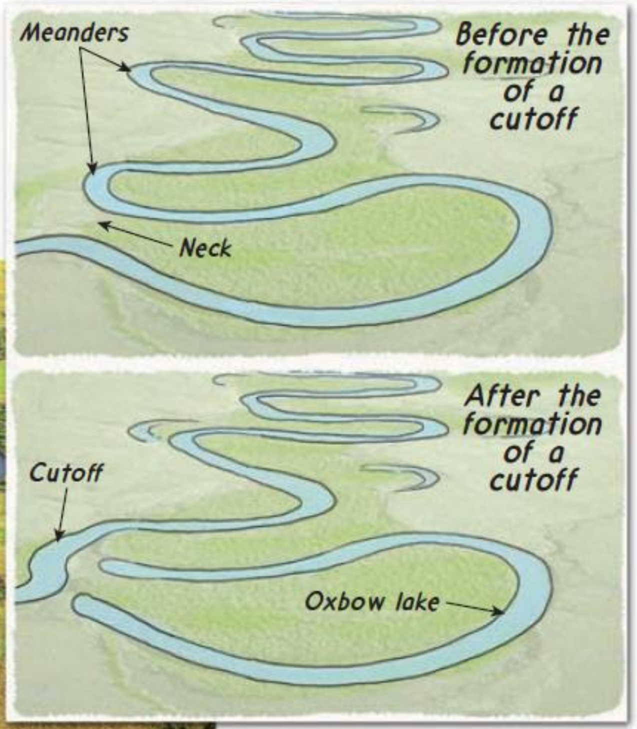
FIGURE 9.14 When a stream meanders, its zone of maximum speed shifts toward the outer bank. The point bars shown here are on the White River near Vernal, Utah. The black and white photo shows erosion of a cut bank along the Newaukum River in Washington State. By eroding its outer bank and depositing material on the inside of the bend, a stream is able to shift its channel. *(Point bar photo by Michael Collier; cut bank photo by P. A. Glancy, U.S. Geological Survey)*

MEANDERING CHANNELS.

Debris acquired by the stream at the cut bank moves downstream where the coarser material is generally deposited as point bars on the insides of bends. Eventually, the river may erode through the narrow neck of land forming a new, shorter channel segment called a cutoff**.** Because of its shape, the abandoned bend is called an oxbow lake**.**

FIGURE 9.15 Oxbow lakes occupy abandoned meanders. As they fill with sediment, oxbow lakes gradually become swampy meander scars. Aerial view of an oxbow lake created by the meandering Green River near Bronx, Wyoming. *(Photo by Michael Collier)*





Geologist's Sketch

BRAIDED CHANNELS.

Some streams consist of a complex network of converging and diverging channels that thread their way among numerous islands or gravel bars (FIGURE 9.16). Because these channels have an interwoven appearance, they are said to be braided.

Braided channels form where a large portion of a stream's load consists of coarse material (sand and gravel) and the stream has a highly variable discharge. Because the bank material is readily erodable, braided channels are wide and shallow.

Shaping Stream Valleys

- A stream valley consists of a channel and the surrounding terrain that directs water to the stream. It includes the *valley floor,* which is the lower, flatter area that is partially or totally occupied by the stream channel, and the sloping *valley walls* that rise above the valley floor on both sides.
- Alluvial channels often flow in valleys that have wide valley floors consisting of sand and gravel deposited in the channel, and clay and silt deposited by floods.
- Bedrock channels, on the other hand, tend to be located in narrow V-shaped valleys.
- Streams, with the aid of weathering and mass wasting, shape the landscape through which they flow. As a result, streams continuously modify the valleys they occupy.

Valley Deepening

When a stream’s gradient is steep and the channel is well above base level, downcutting is the dominant activity. Abrasion caused by bed load sliding and rolling along the bottom and the hydraulic power of fast-moving water slowly lower the streambed. The result is usually a V-shaped valley with steep sides. A classic example of a V-shaped valley is the section of the shown in FIGURE 9.19.

The most prominent features of V-shaped valleys are *rapids* and *waterfalls.*

FIGURE 9.19 V-shaped valley of the Yellowstone River. The rapids and waterfalls indicate that the river is vigorously downcutting. *(Photo by Jorgen Larsson/ agefotostock)*

Valley Widening

As a stream approaches a graded condition, downcutting becomes less dominant. At this point the stream’s channel takes on a meandering pattern, and more of its energy is directed from side to side. As a result, the valley widens as the river cuts away at one bank and then the other.

The continuous lateral erosion caused by shifting meanders gradually produces a broad, flat valley floor covered with alluvium (FIGURE 9.20). This feature, called a floodplain, is appropriately named because when a river overflows its banks during flood stage, it inundates the floodplain.

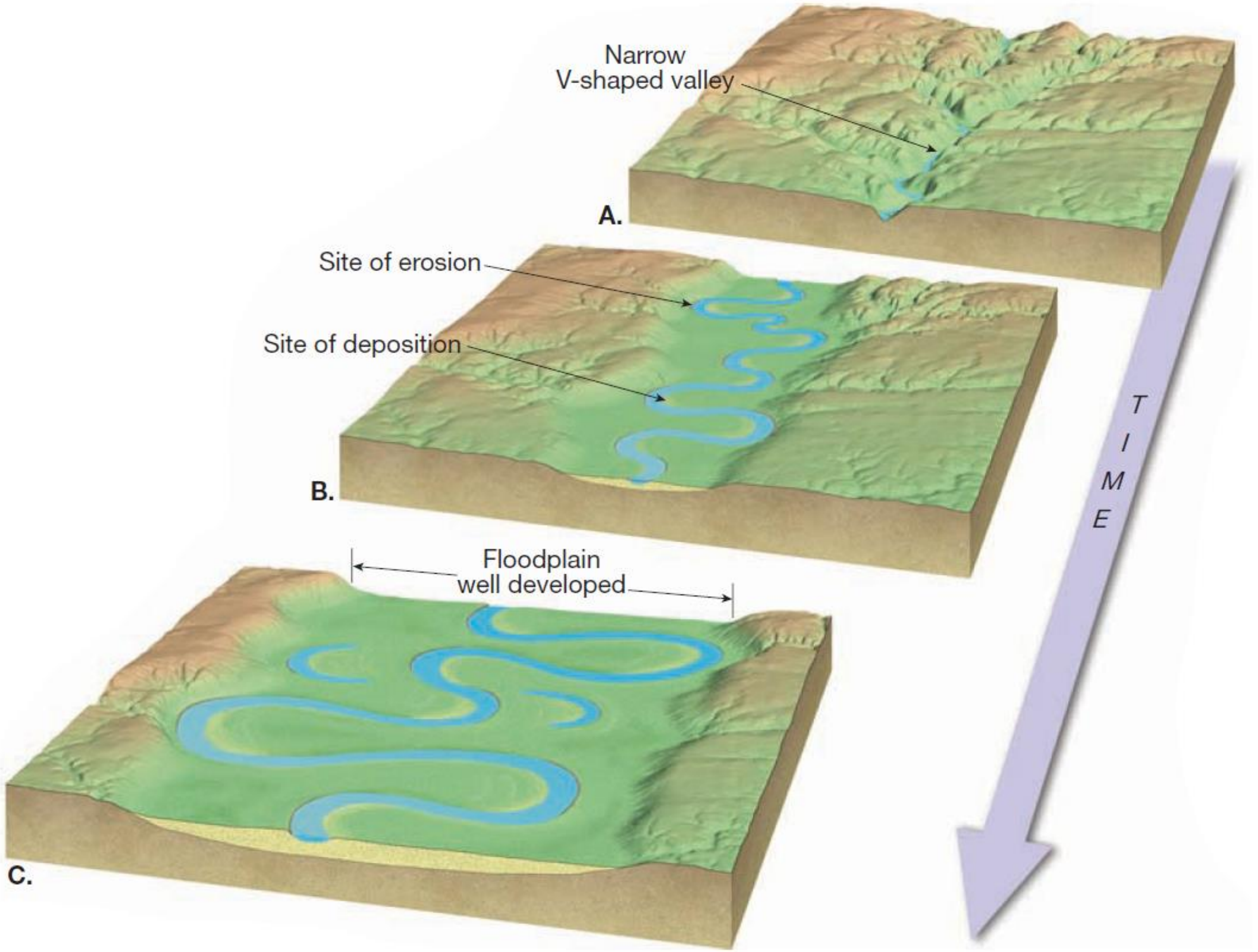


FIGURE 9.20 Development of an erosional floodplain.

Incised Meanders and Stream Terraces

We usually find streams with highly meandering courses on floodplains in wide valleys. However, some rivers have meandering channels that flow in steep, narrow, bedrock valleys. Such meanders are called incised meanders

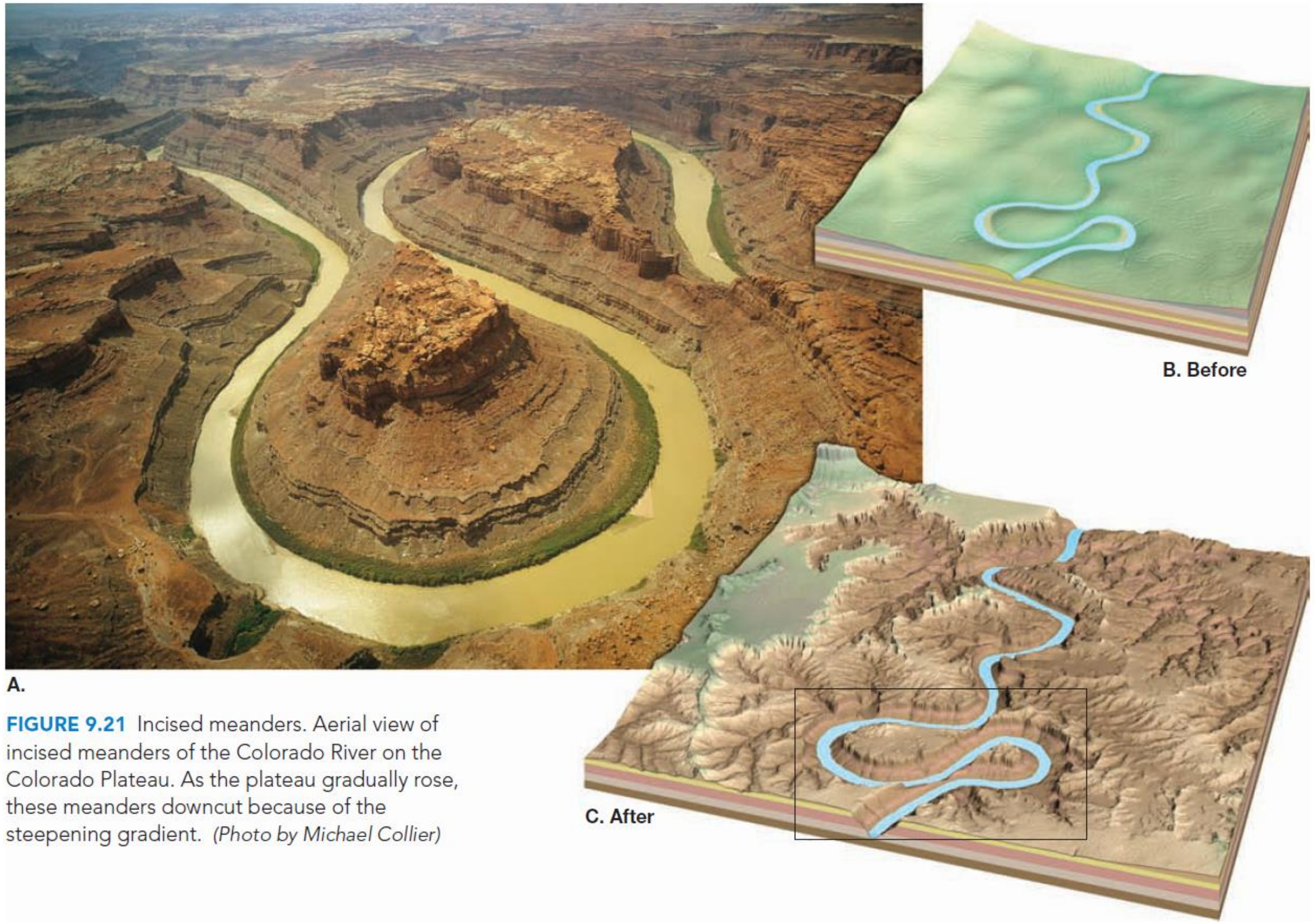


FIGURE 9.21 Incised meanders. Aerial view of incised meanders of the Colorado River on the Colorado Plateau. As the plateau gradually rose, these meanders downcut because of the steepening gradient. *(Photo by Michael Collier)*

Incised Meanders and Stream Terraces

After a river has adjusted in this manner, it may once again produce a floodplain at a level below the old one. The remnants of a former floodplain are sometimes present as relatively flat surfaces called terraces (FIGURE 9.22).

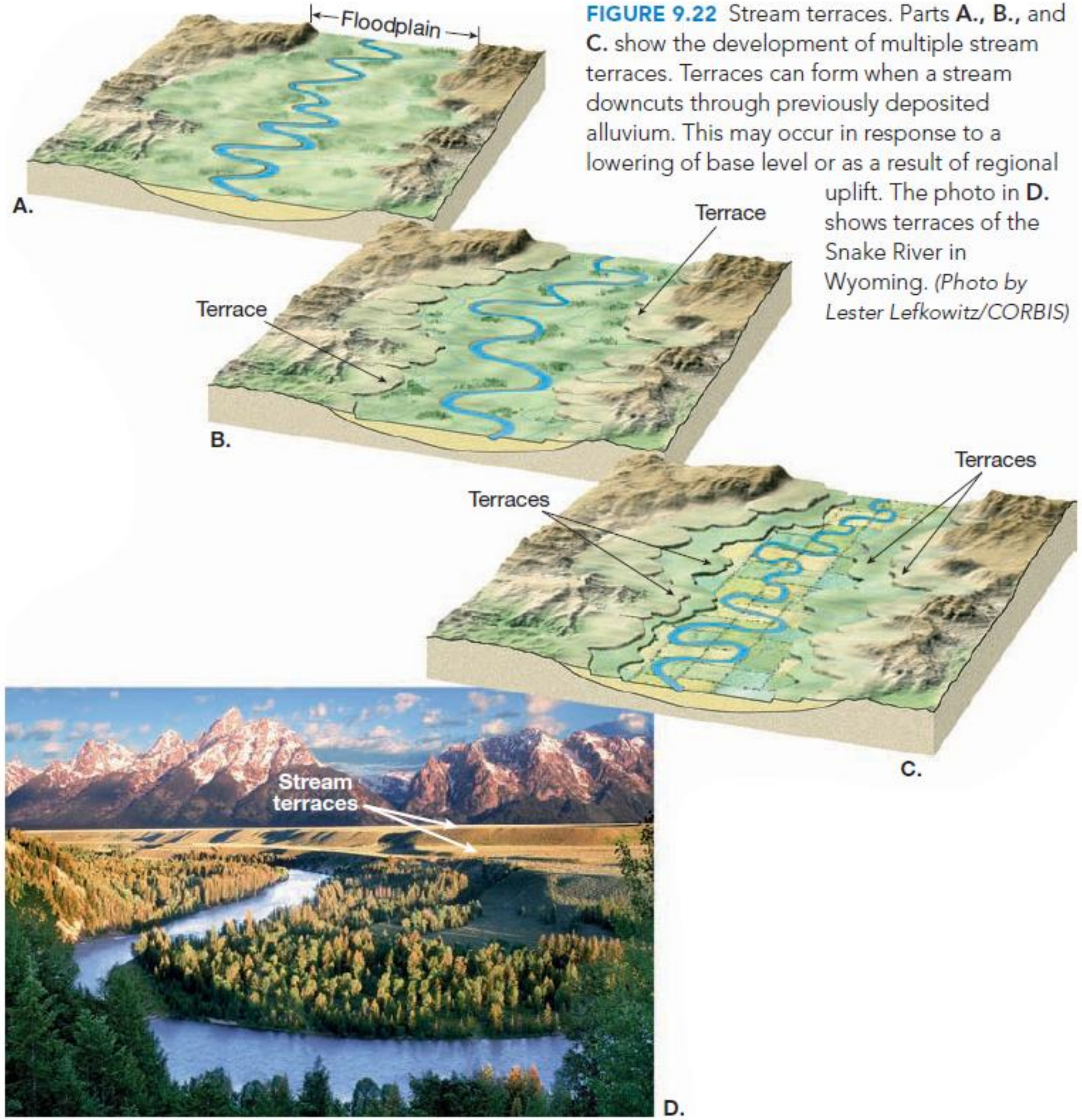


FIGURE 9.22 Stream terraces. Parts **A.**, **B.**, and **C.** show the development of multiple stream terraces. Terraces can form when a stream downcuts through previously deposited alluvium. This may occur in response to a lowering of base level or as a result of regional uplift. The photo in **D.** shows terraces of the Snake River in Wyoming. *(Photo by Lester Lefkowitz/CORBIS)*

Depositional Landforms

These include

- *deltas,*
- *natural levees,* and
- *alluvial fans.*

Deltas

Deltas form where sediment-charged streams enter the relatively still waters of a lake, an inland sea, or the ocean (FIGURE 9.23A). As the stream's forward motion is slowed, sediment is deposited by the dying current.

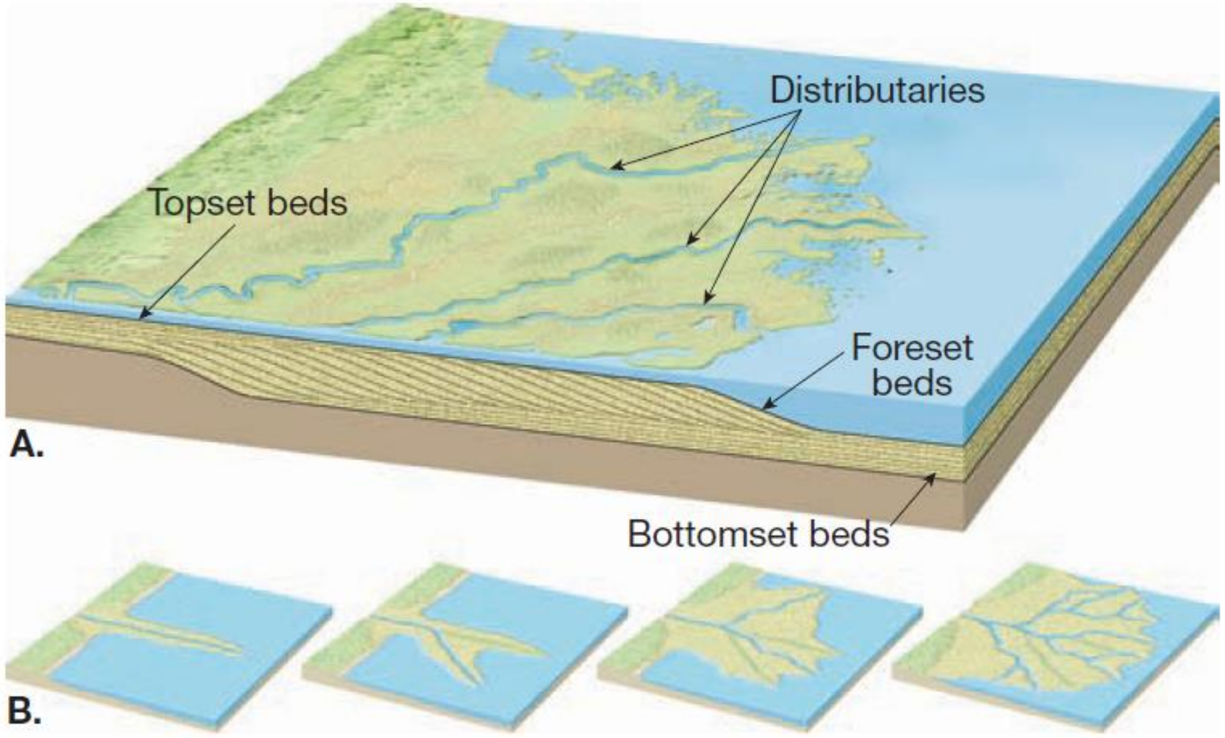


FIGURE 9.23 Formation of a simple delta. **A.** Structure of a simple delta that forms in relatively quiet waters. **B.** Growth of a simple delta. As a stream extends its channel, the gradient is reduced. Frequently, during flood stage the river is diverted to a higher-gradient route, forming a new distributary. Old, abandoned distributaries are gradually invaded by aquatic vegetation and filled with sediment.

Natural Levees

Meandering rivers that occupy valleys with broad floodplains tend to build natural levees that parallel their channels on both banks. Natural levees are built by years of successive floods. When a stream overflows onto the floodplain, the water flows over the surface as a broad sheet. Because the flow velocity drops significantly, the coarser portion of the suspended load is immediately deposited adjacent to the channel. As the water spreads across the floodplain, a thin layer of fine sediment is laid down over the valley floor. This uneven distribution of material produces the gentle, almost imperceptible, slope of the natural levee (FIGURE 9.25).

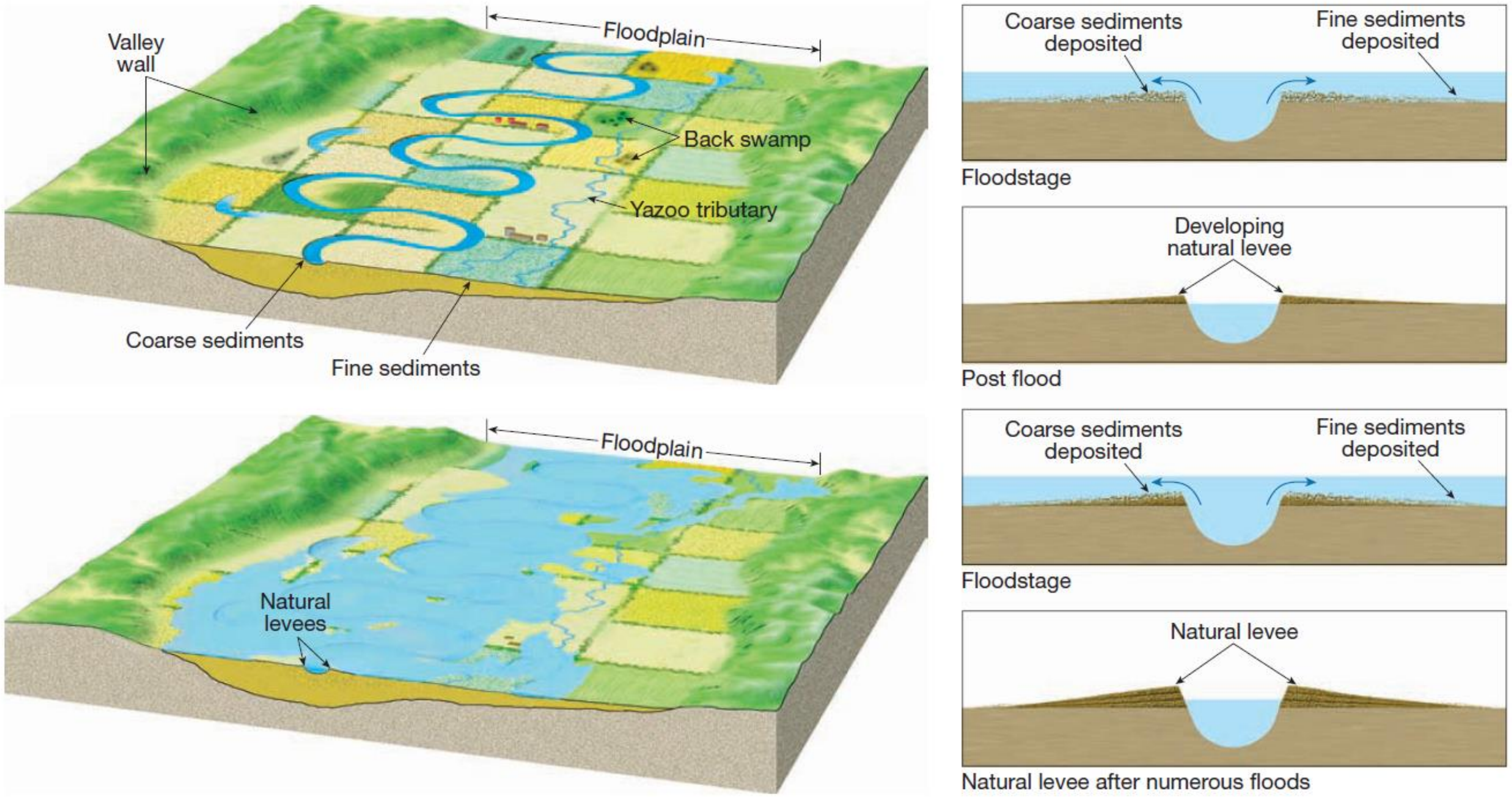
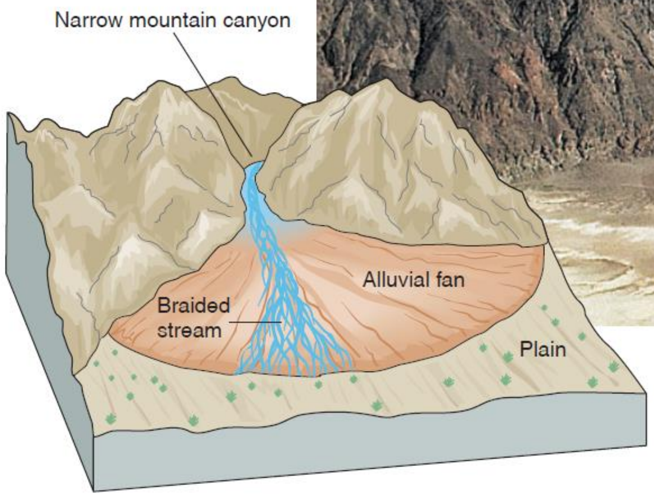


FIGURE 9.25 Natural levees are gently sloping structures that are created by repeated floods. The diagrams on the right show the sequence of development. Because the ground next to the stream channel is higher than the adjacent floodplain, back swamps and yazoo tributaries may develop.

Alluvial Fans

Some streams, particularly in dry climates, do not reach the sea or any other body of water. They build alluvial fans instead of deltas. An **alluvial fan** is a large, fan- or cone-shaped pile of sediment that usually forms where a stream's velocity decreases as it emerges from a narrow mountain canyon onto a flat plain (figure 16.28).



A

B

FIGURE 16.28

(*A*) An alluvial fan at the mouth of a desert canyon. (*B*) This alluvial fan formed on the salt-encrusted floor of Death Valley, California, as sediment was washed out of the canyon by thunderstorms. *Photo by Frank M. Hanna*