Chapter 10

Streams and Flooding

- Water shapes the earth's surface
- Water also plays a role in human affairs
- Floods are the most widely experienced catastrophic geologic hazards

Hydrologic Cycle

- **Hydrosphere** – all water at or near the surface of the earth
- Processes involved in the cycle
  - Evaporation
  - Condensation
  - Precipitation
  - Transpiration
  - Runoff
  - **Infiltration**
  - **Percolation**

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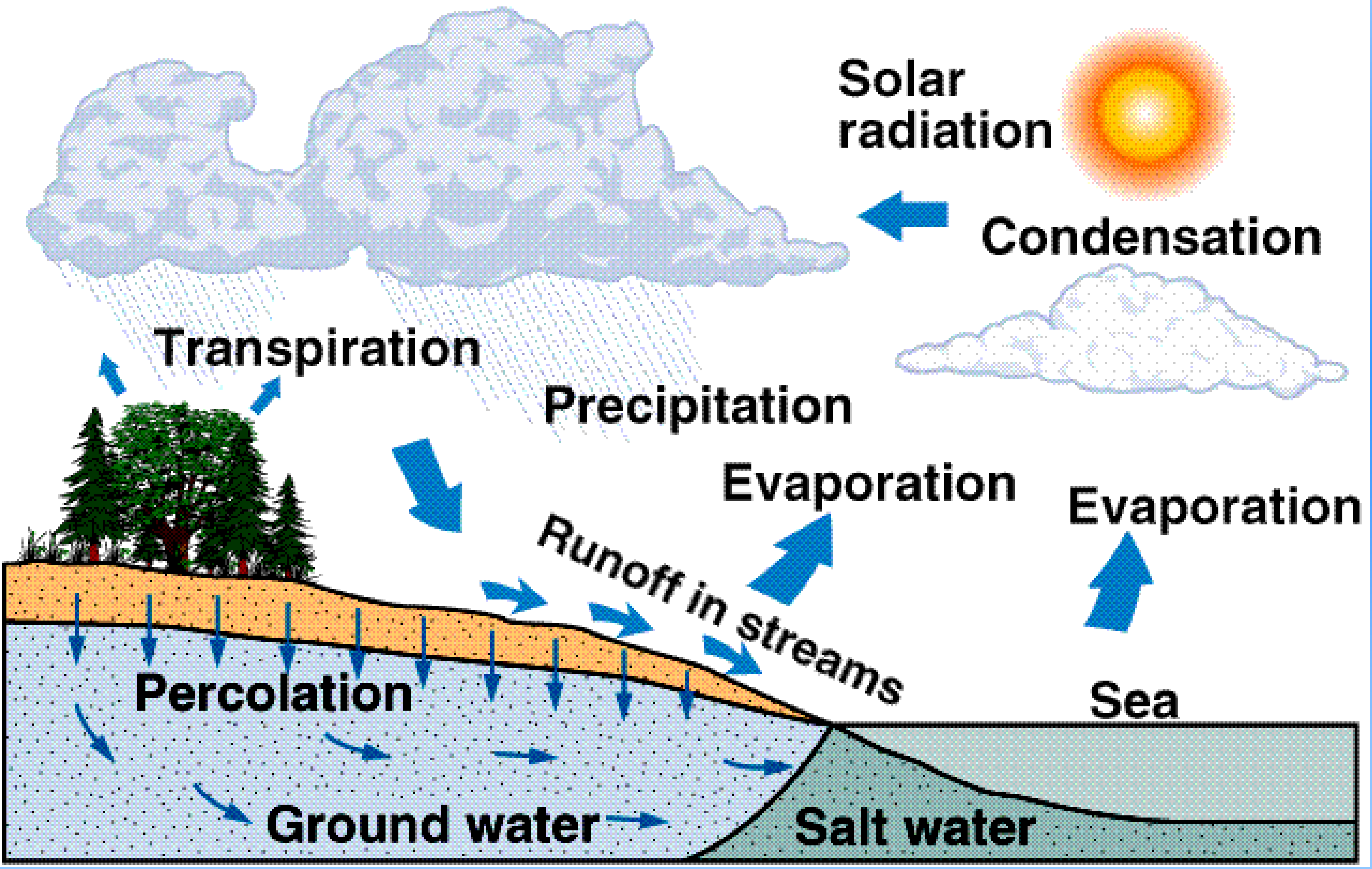
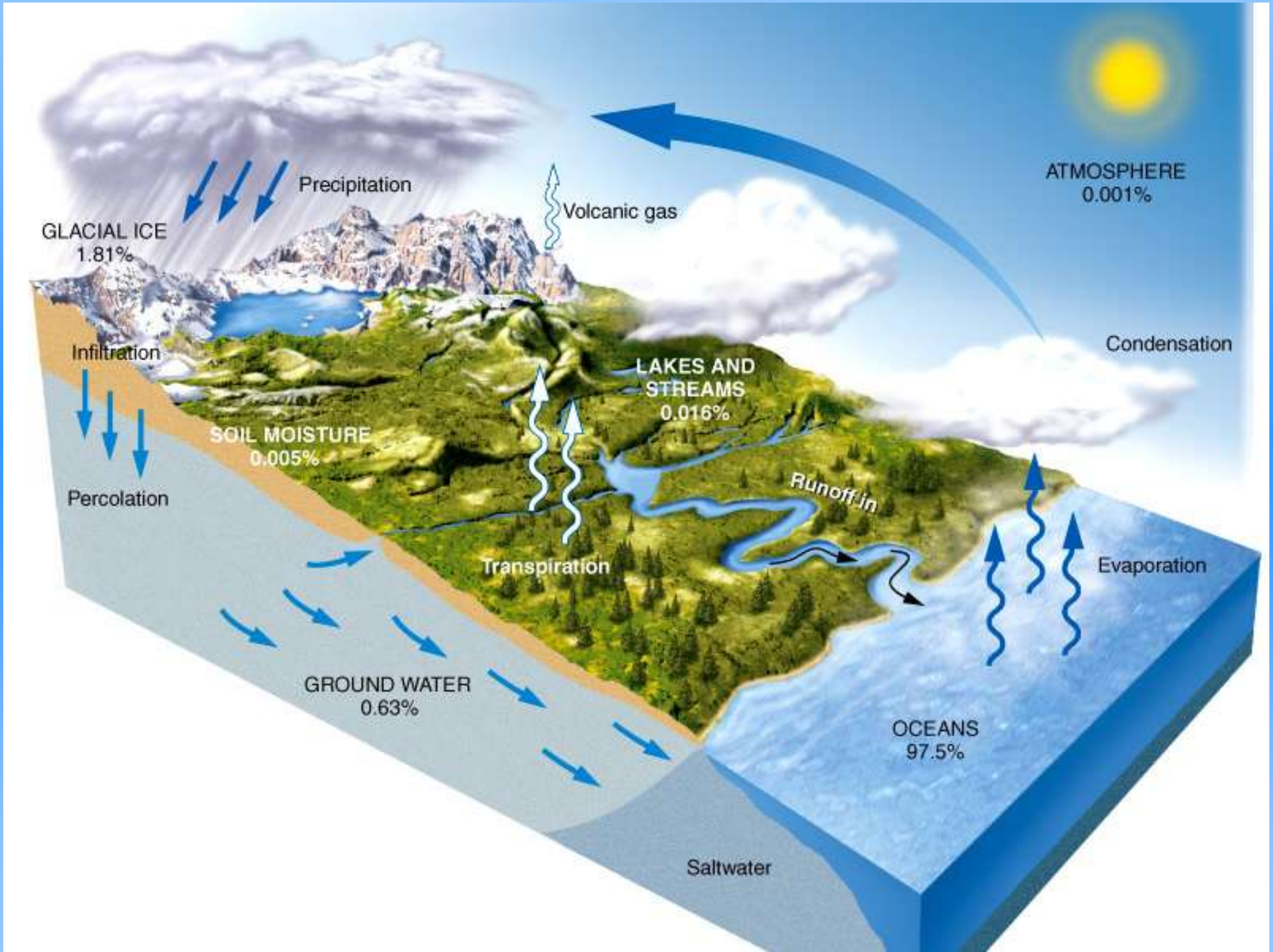
The Hydrologic Cycle



Principal processes and reservoirs of the hydrologic cycle



Water Reservoirs

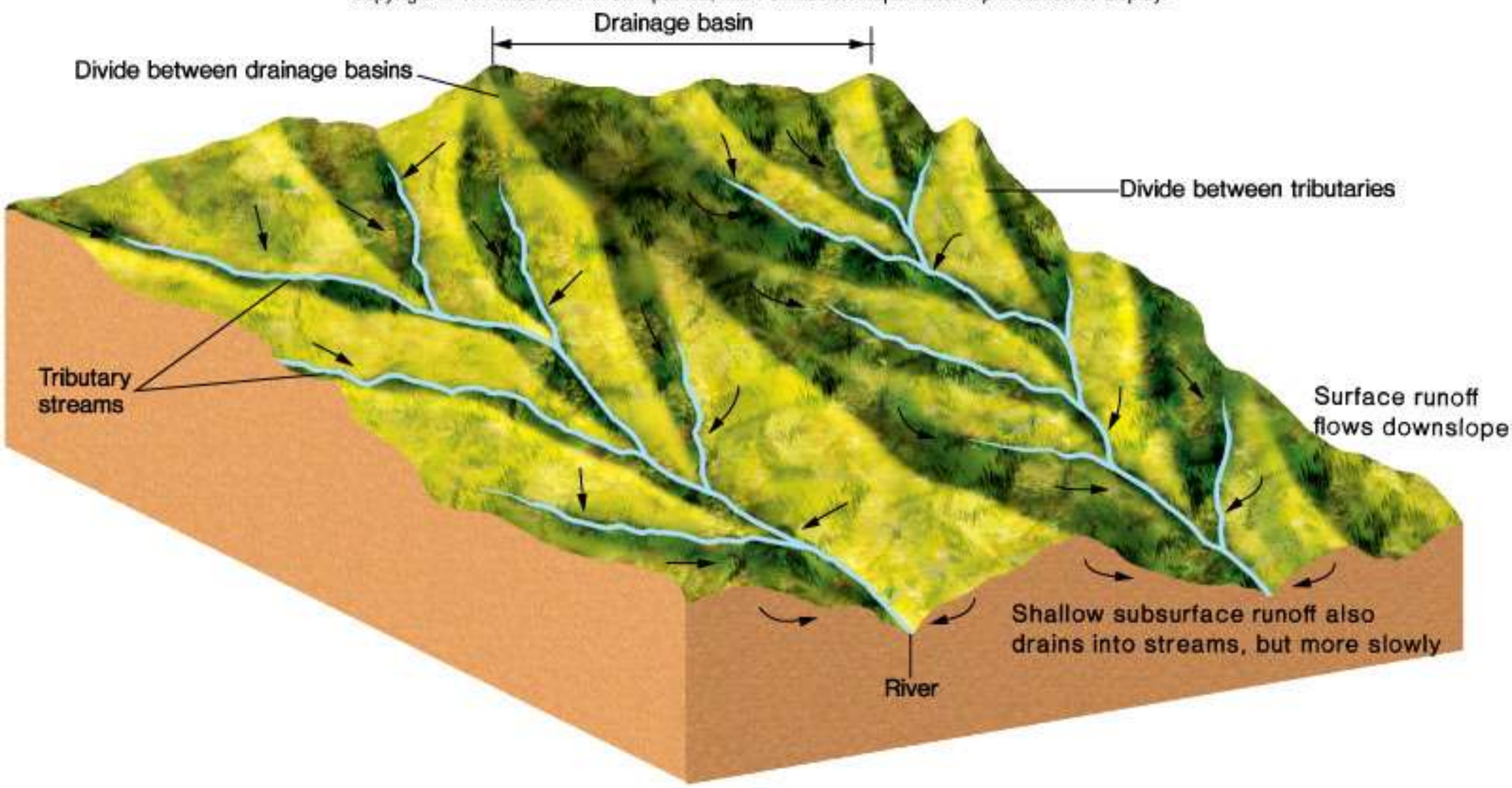
- Oceans – 97.5 %
- Glacial Ice – 1.81 %
- Ground Water – 0.63 %
- Lakes and Streams – 0.016 %
- Atmosphere – 0.001%
- Soil Moisture – 0.005 %

Streams and their Features

- **Stream,** a flowing water within a channel
- **Drainage basin,** a region from which a stream draws water
- **Discharge,** the volume of water flowing past a given point/cross section in a specified length of time
- **Load,** the total quantity of material that a stream transports by all methods (traction, saltation, suspended, and dissolved)
- **Capacity,** a measure of the total load of material a stream can move
- **Gradient,** the steepness of the stream channel
- **Base level,** the lowest elevation to which the stream can erode downward
- **Longitudinal profile,** a sketch of a stream's elevation from source to mouth

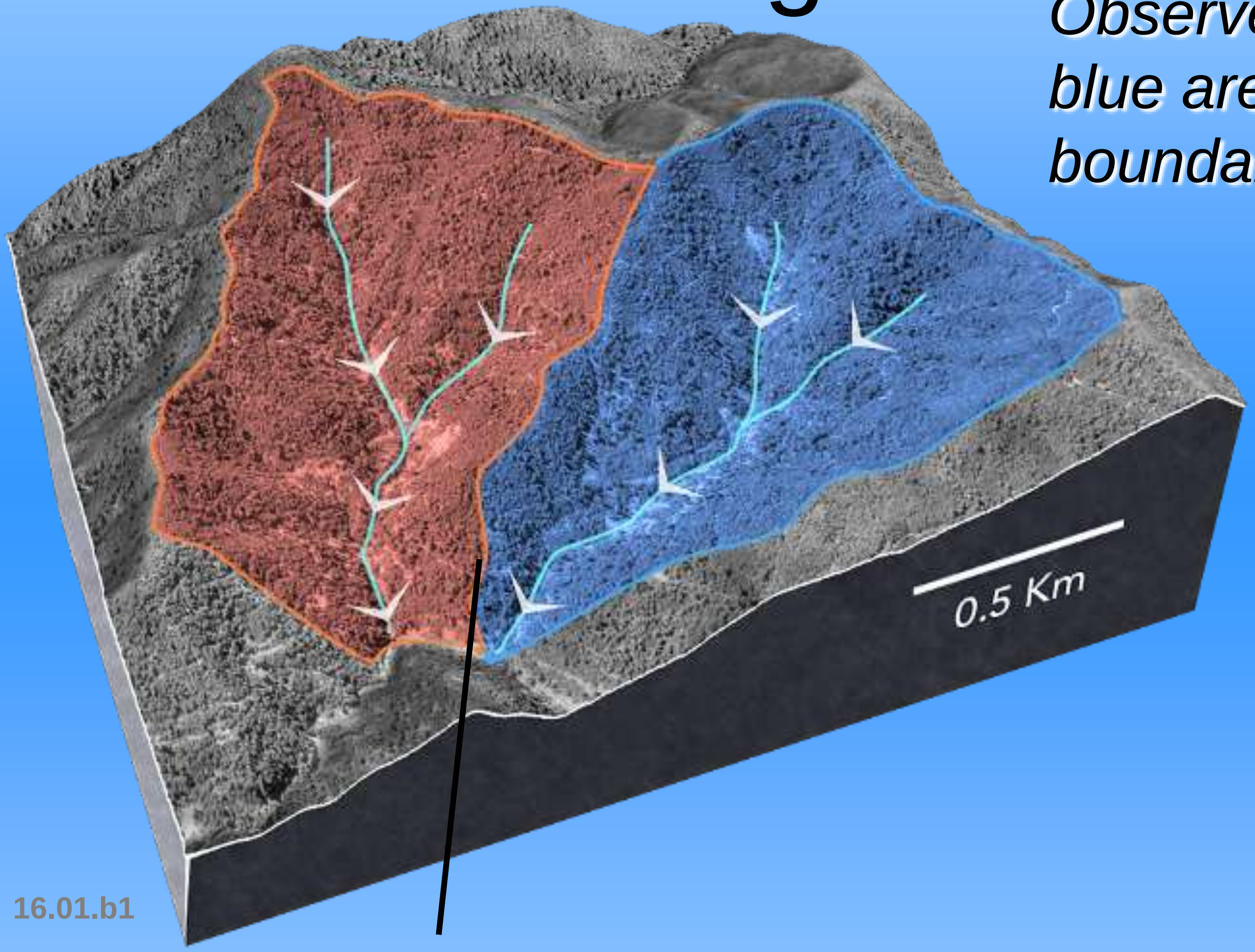
Drainage Basins , a region from which a stream draws water

- Tributary
- Divide



Drainage Basins

Observe the red and blue areas and their boundary



16.01.b1

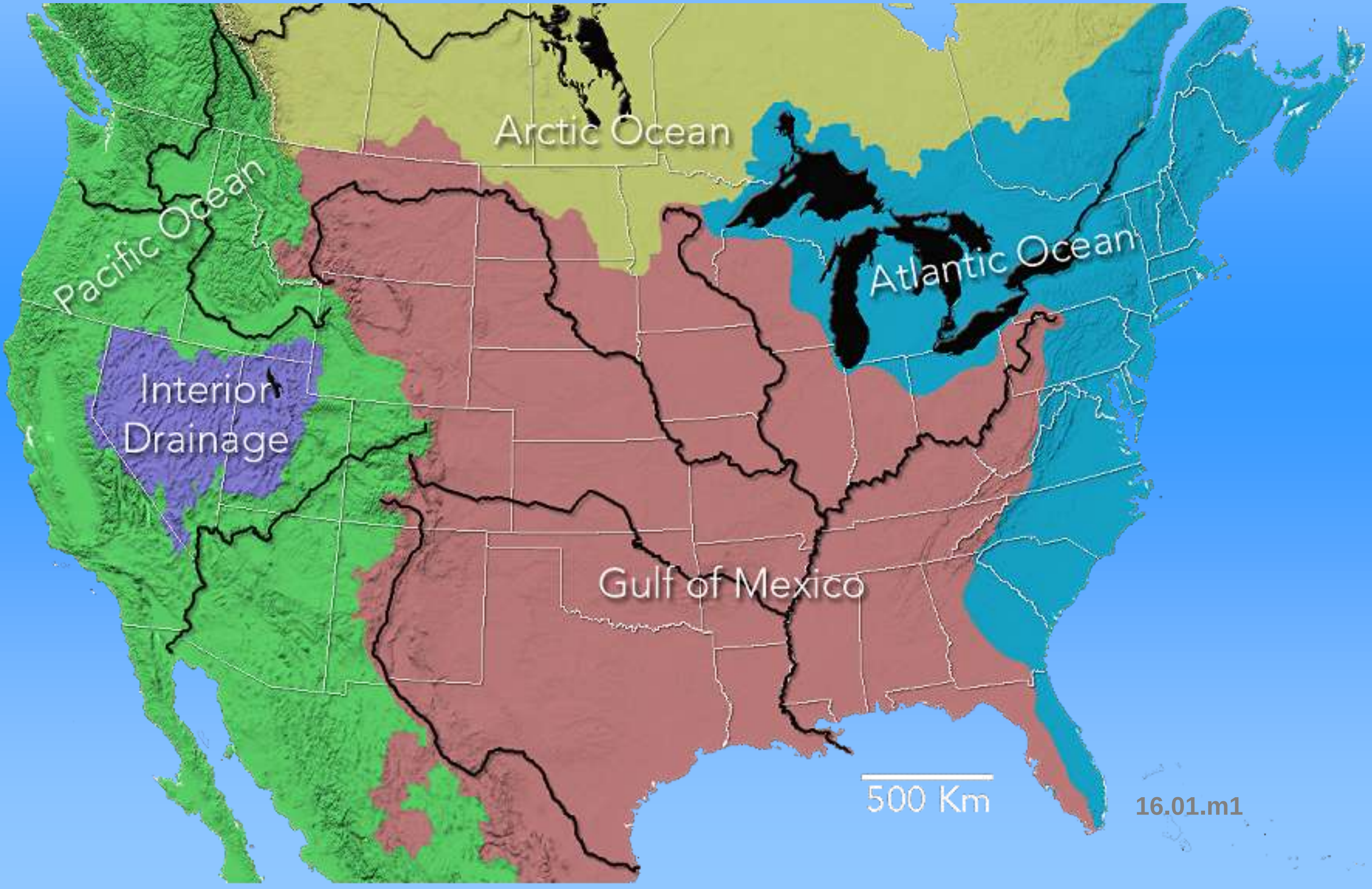
Red area drained by one stream, and blue area by another: each is a *drainage basin*

Boundary between basins is a drainage divide

3D

North American Drainage Basins

Observe these drainage basins and find where runoff in your area ends up



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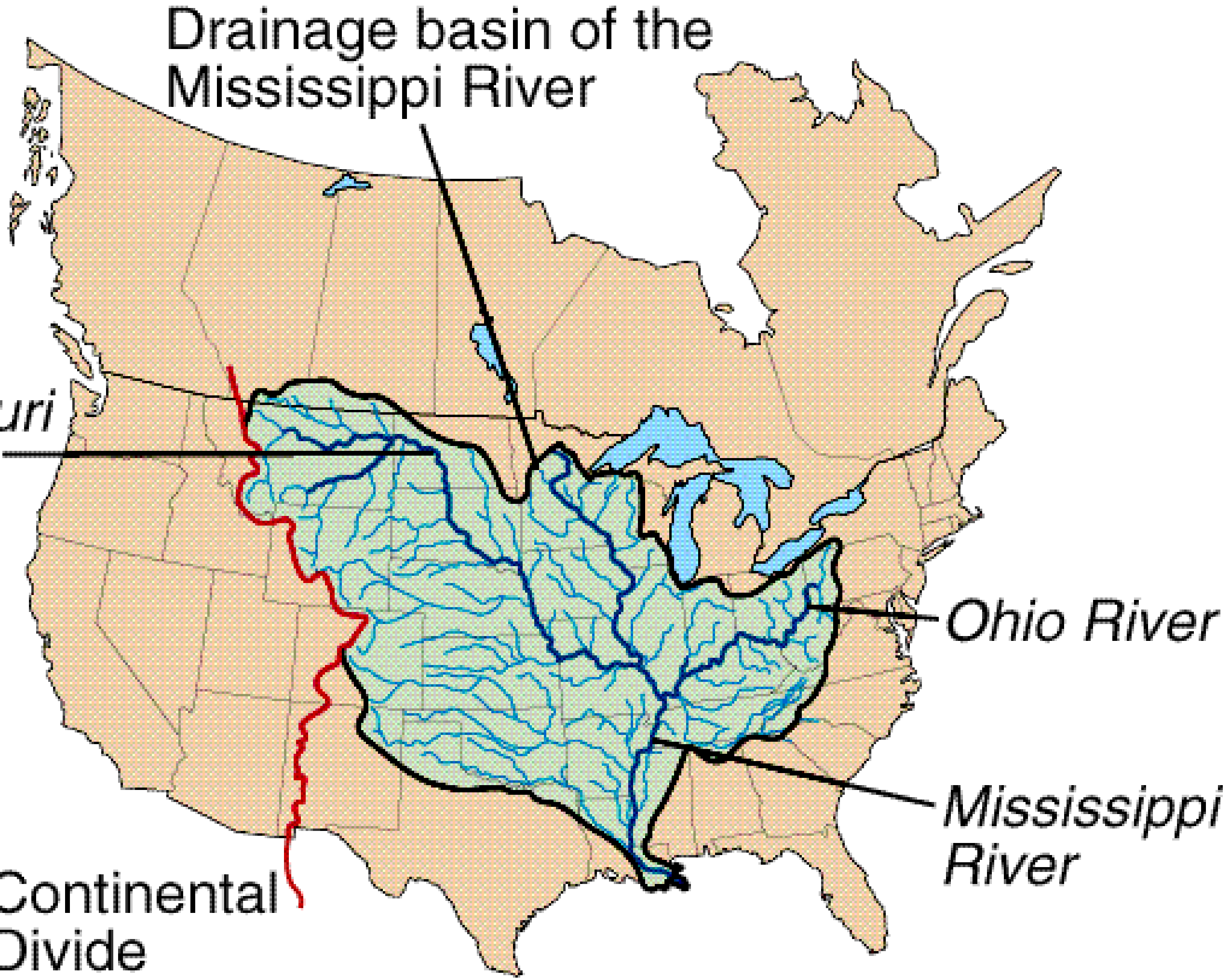
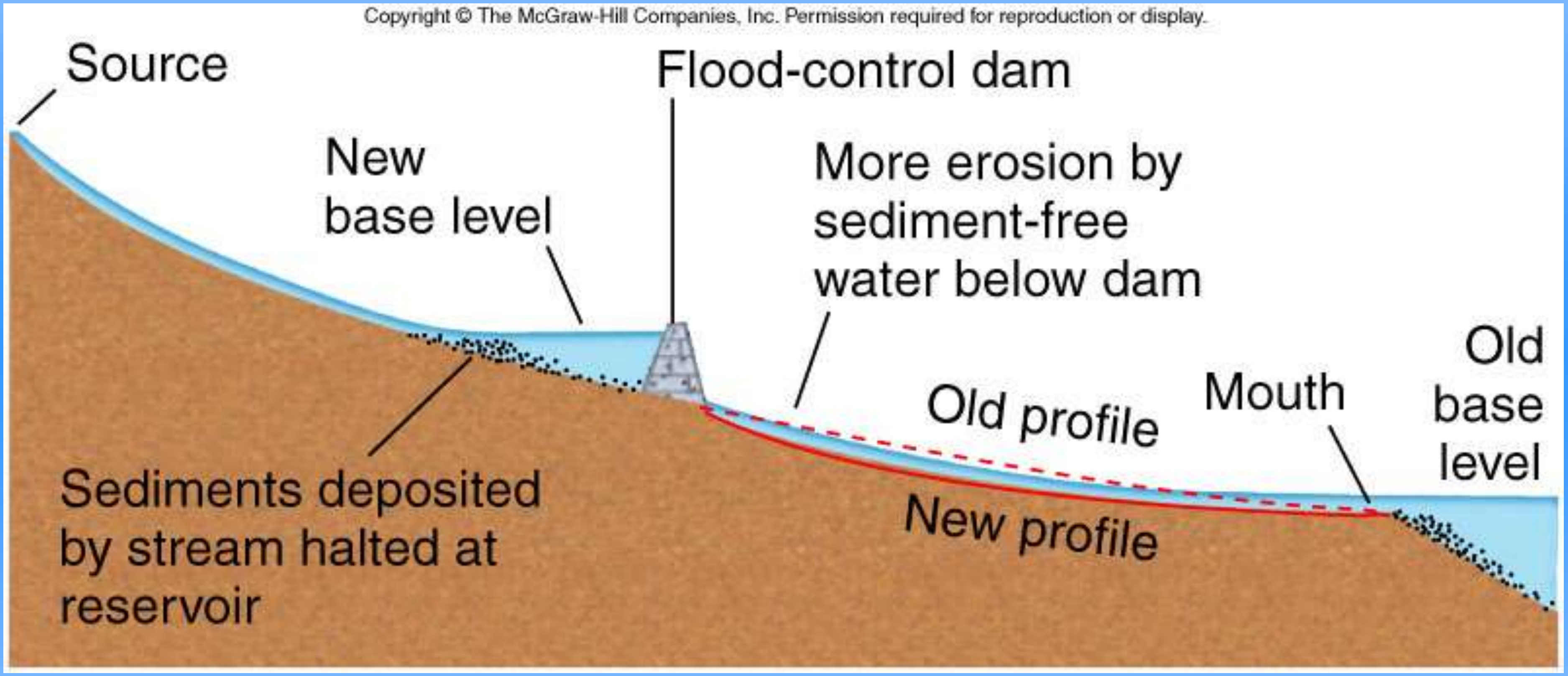
Drainage Basin of Mississippi River



Base level = the lowest elevation to which the stream can erode downward

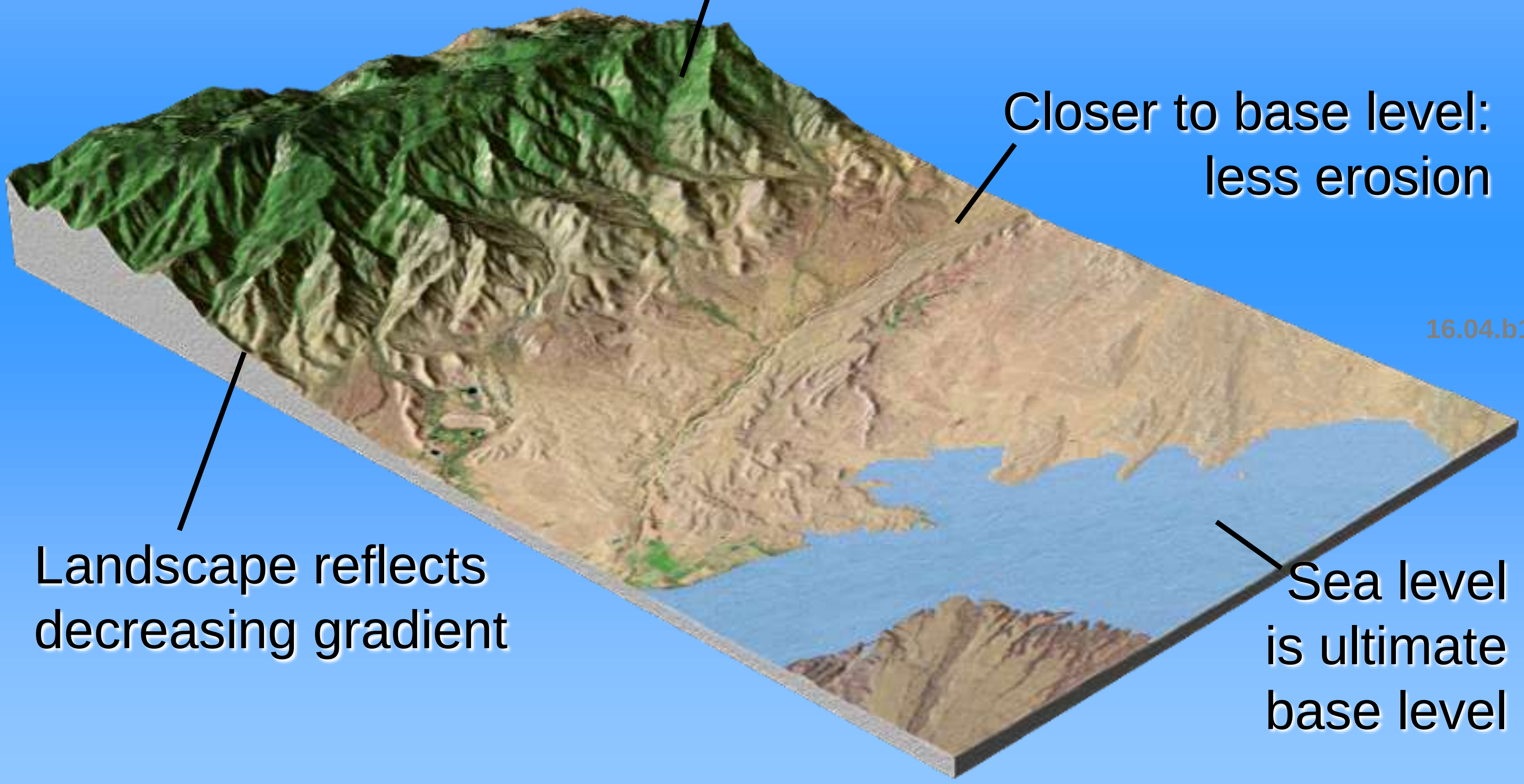


Base Level

The lowest level to which a river can erode: *base level*

High above base level: much erosion

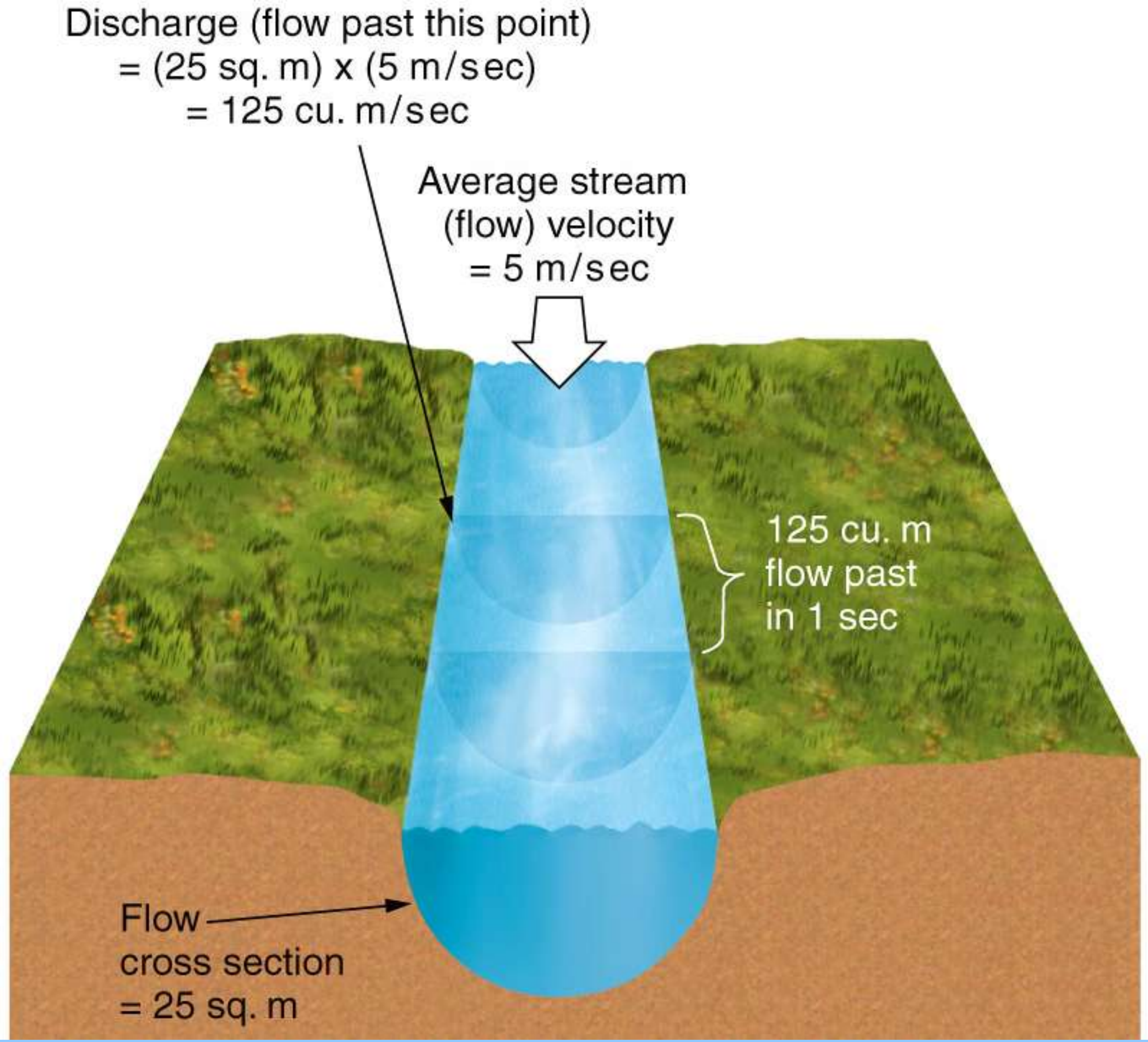
Closer to base level: less erosion



Landscape reflects decreasing gradient

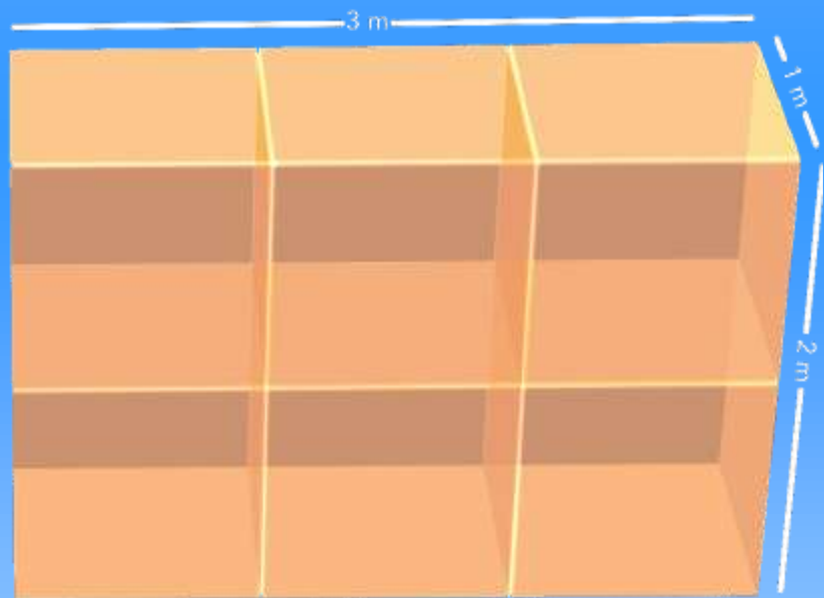
Sea level is ultimate base level

Discharge = the volume of water flowing past a given point/cross section in a specified length of time



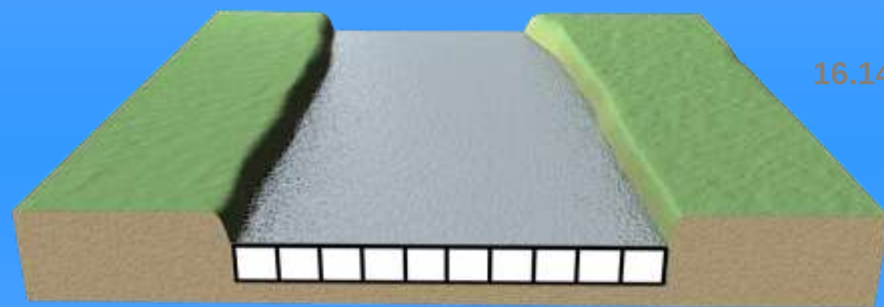
How Do We Measure the Volume of Water that Flows Through a Channel?

To calculate volume, multiply width X height X 3rd dimension



What is the volume here?

Amount of water flowing through a channel over a given time is *discharge*



16.14.a2

Discharge calculated by multiplying channel width X depth X velocity of water: units are cubic meters/sec or cubic feet/sec

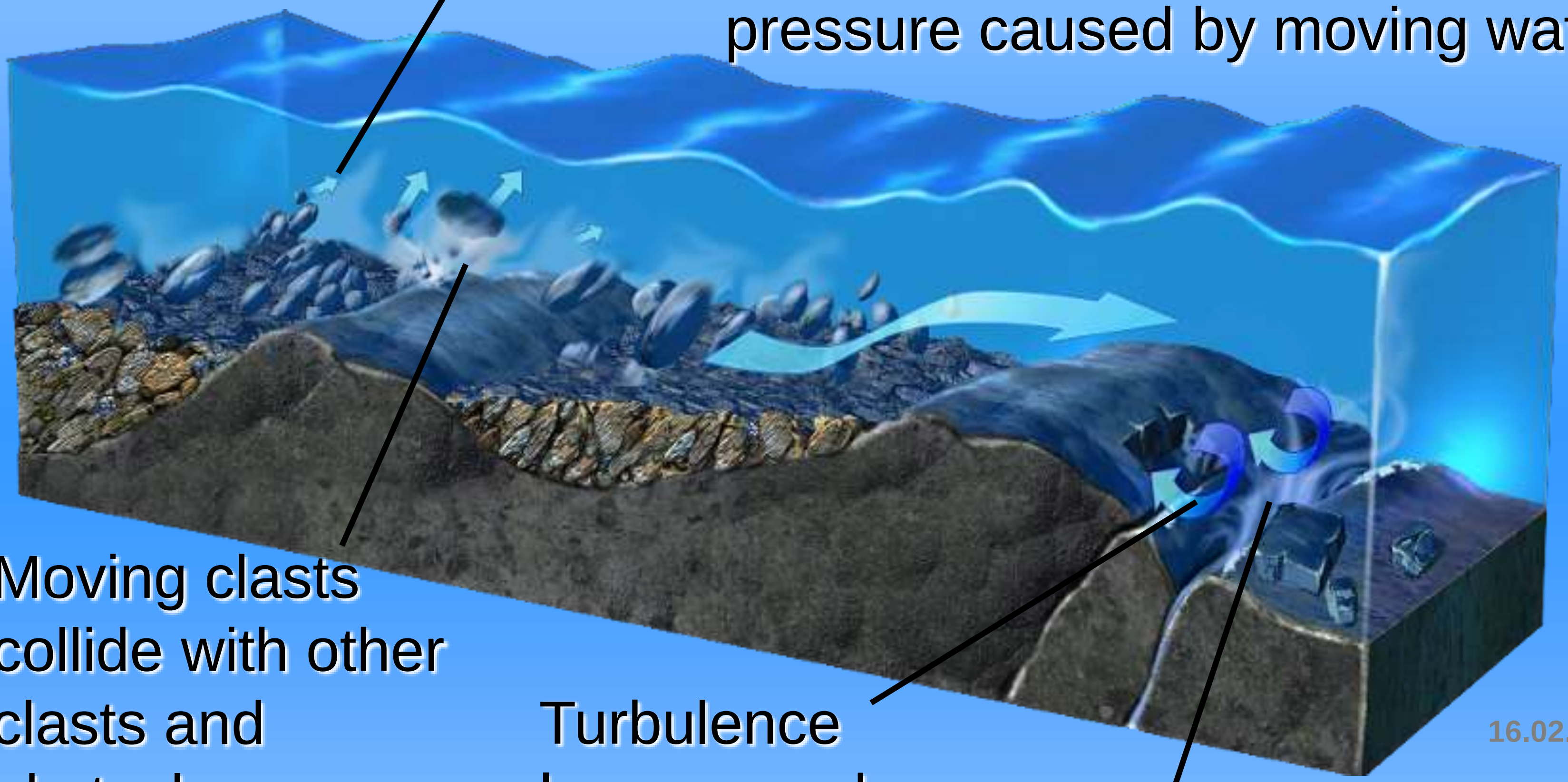
02.08.c4

Stream Erosion

- Hydraulic Action
- Solution
- Abrasion
  - Potholes

What Processes Erode Material?

Clasts can be picked up by turbulence and low pressure caused by moving water



Moving clasts collide with other clasts and obstacles, chipping away or launching pieces

Turbulence loosens and lifts pieces of streambed

Soluble material is dissolved and removed

Stream Transportation of Sediment

- Bed Load
  - Traction
  - Saltation
- Suspended Load
- Dissolved Load

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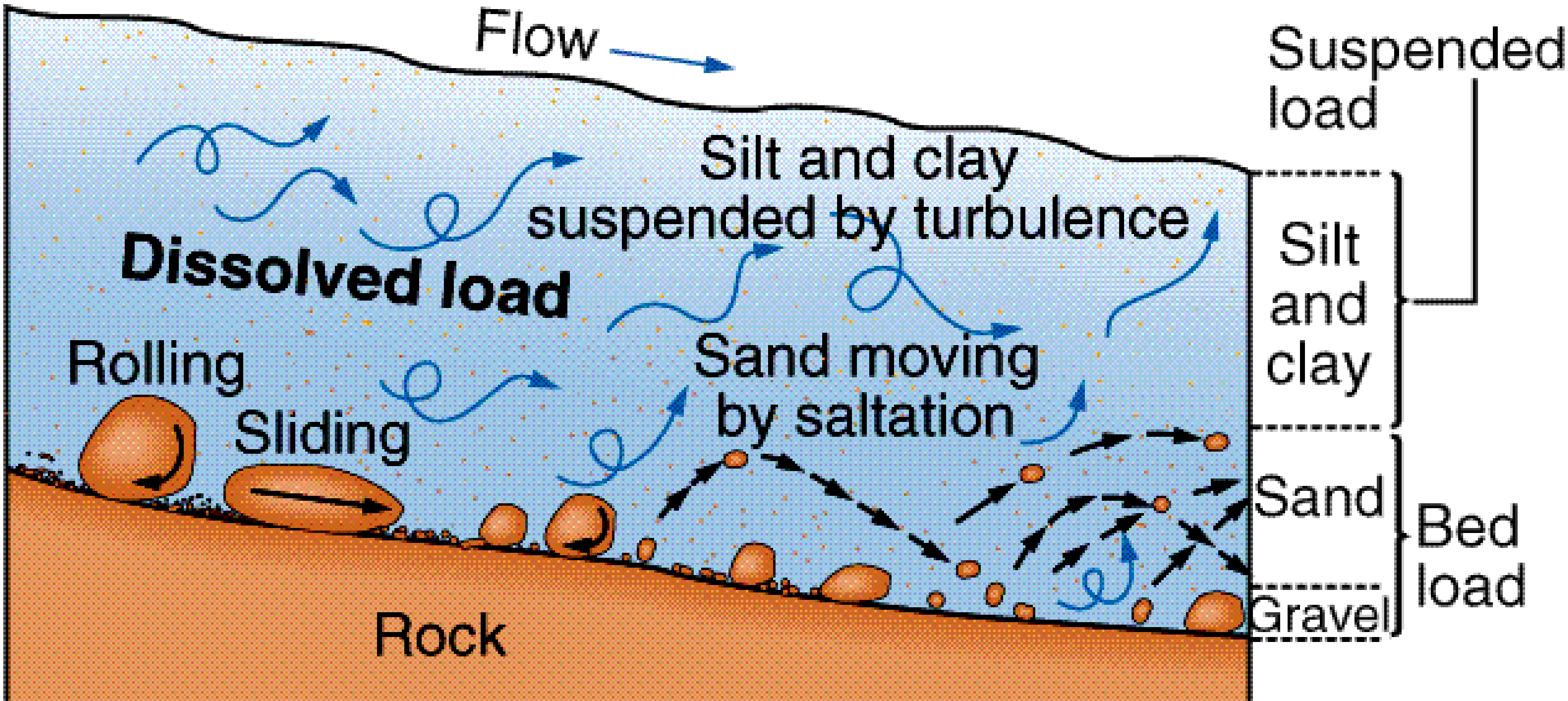
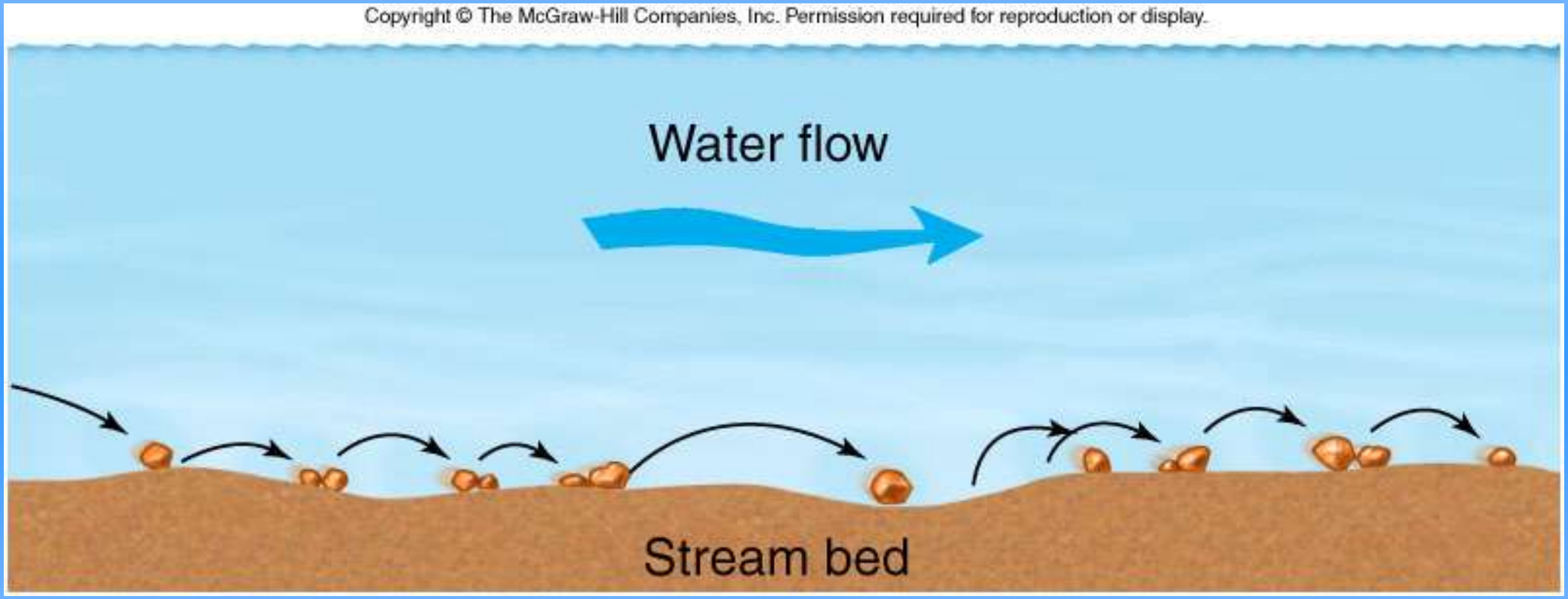
Contents of a Stream Bed



saltation



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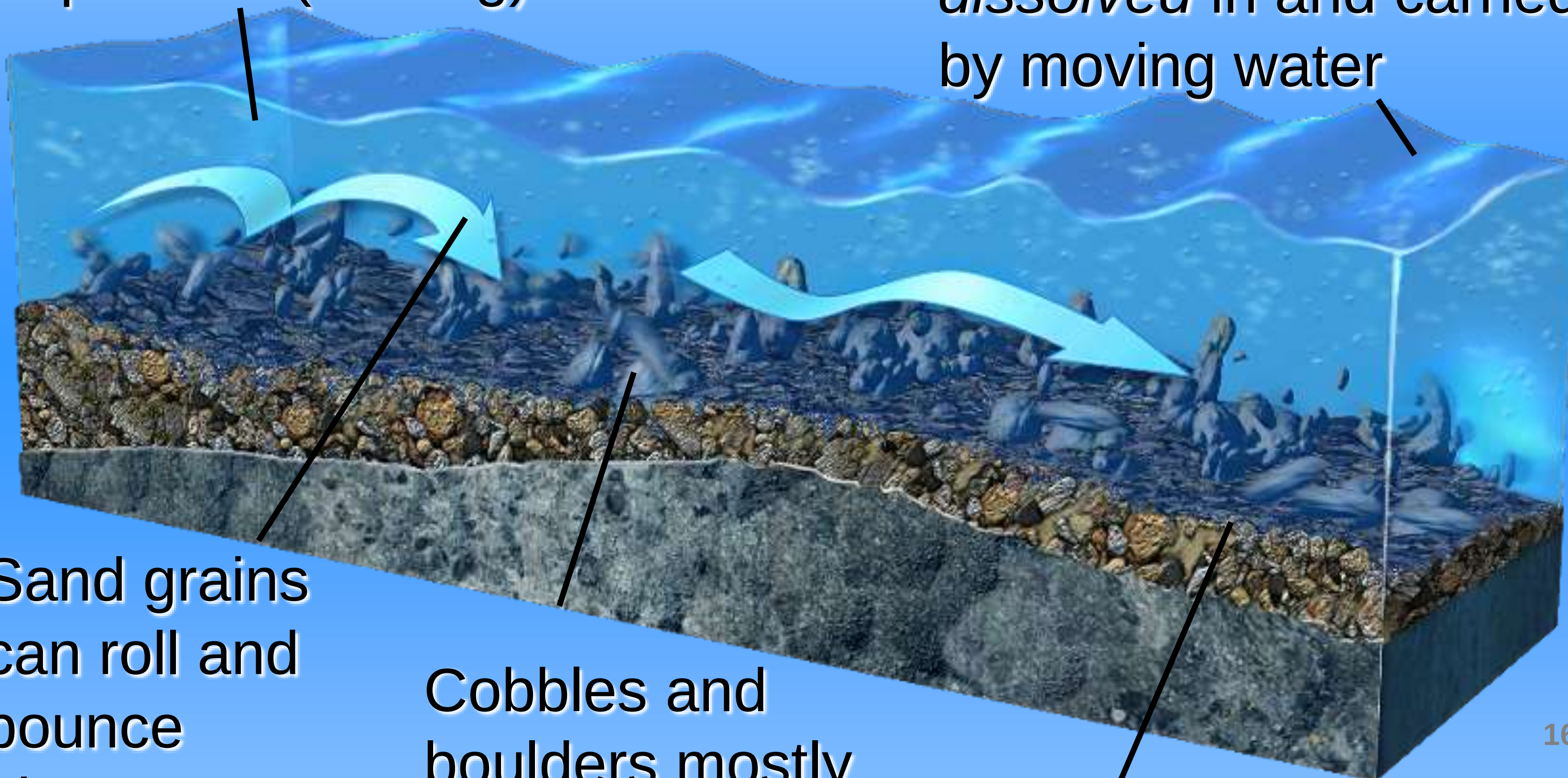
Water flow
Stream bed

How is Material Transported and Deposited?

Fine particles can be carried in suspension (floating) in water

Soluble ions are *dissolved* in and carried by moving water



Sand grains can roll and bounce along

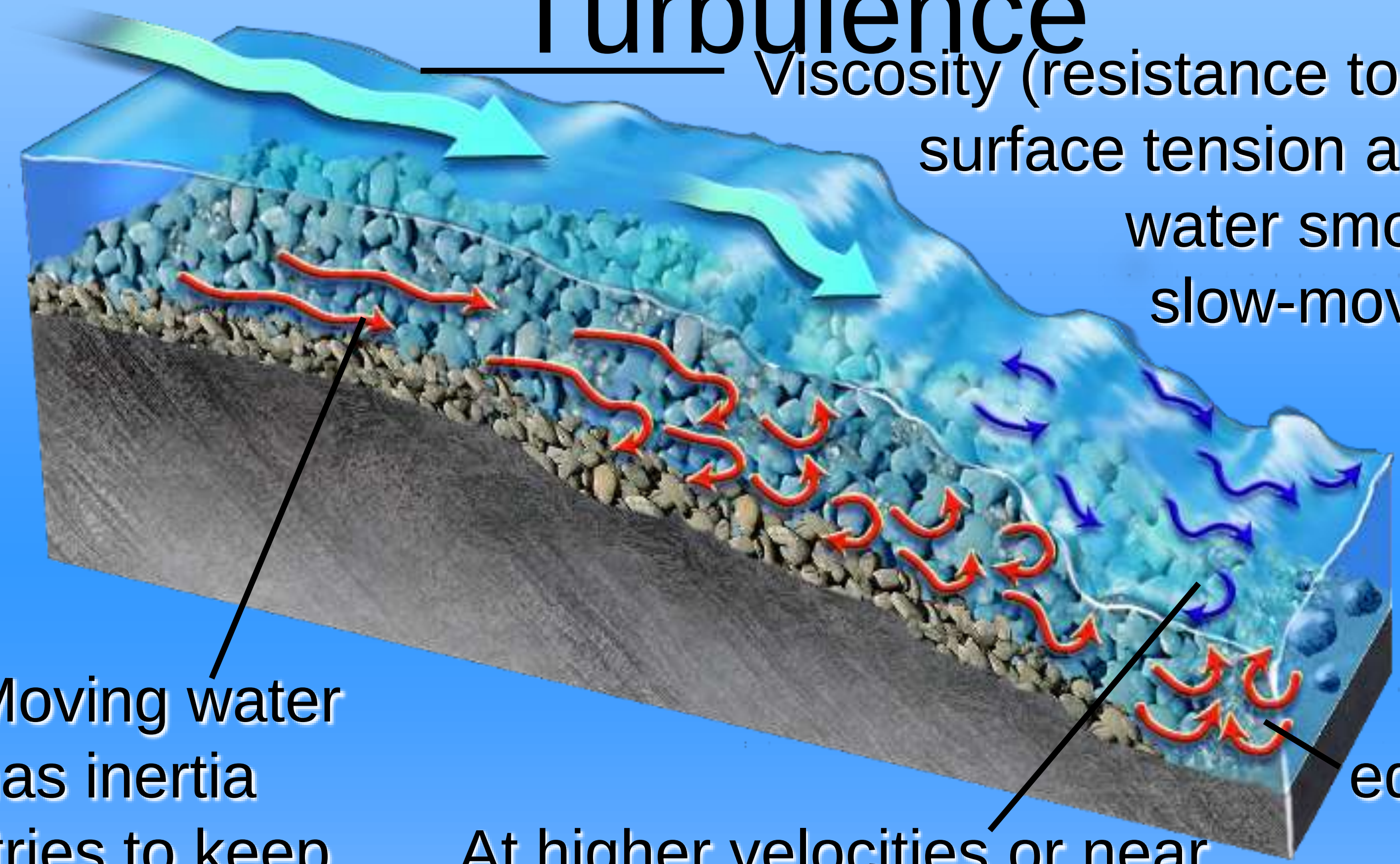
Cobbles and boulders mostly roll and slide during high flows

16.02.a1

Material moving on river bed is *bed load*

Turbulence

Viscosity (resistance to flow) and surface tension act to keep water smooth, as in slow-moving water



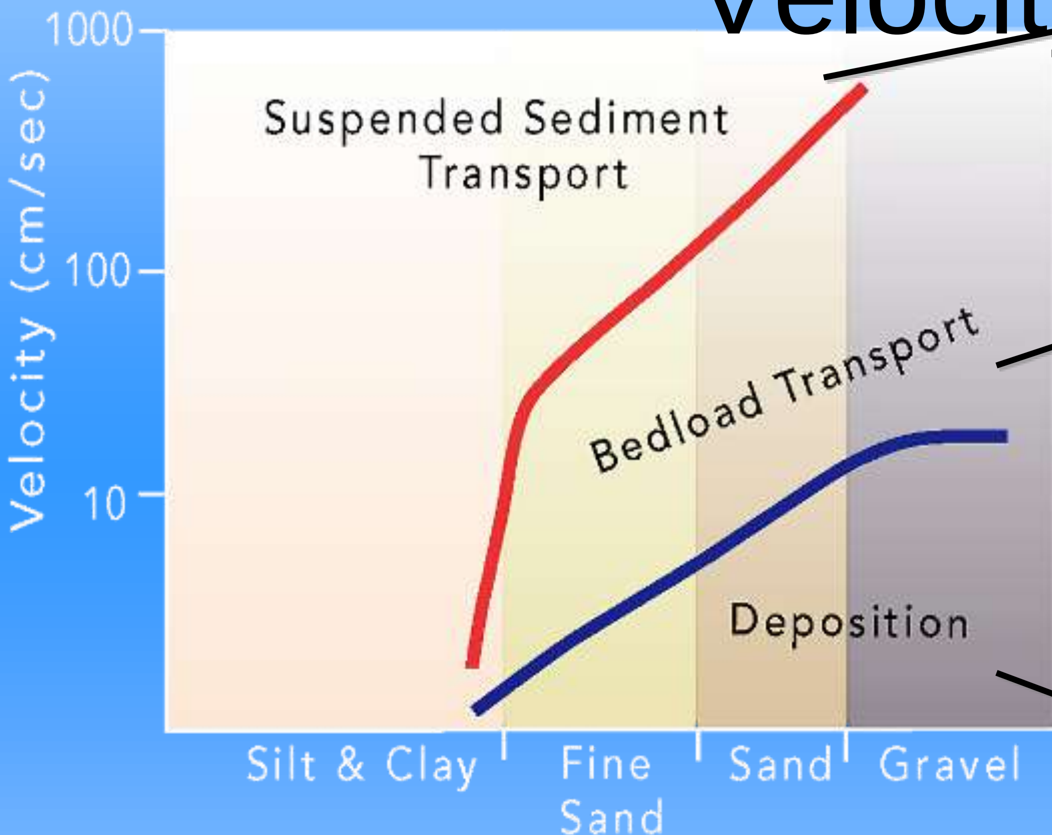
Moving water has inertia (tries to keep moving with same speed and direction)

At higher velocities or near obstacles, flow becomes more chaotic (turbulent), forming a swirl called an *eddy*

Upward-flowing eddies can pick up loose material

16.02.c1

Sediment Size Versus Current Velocity



At high velocity, sand and smaller particles carried in suspension

At moderate velocity, silt and clay remain suspended but sand moves as bed load (rolls, etc.)

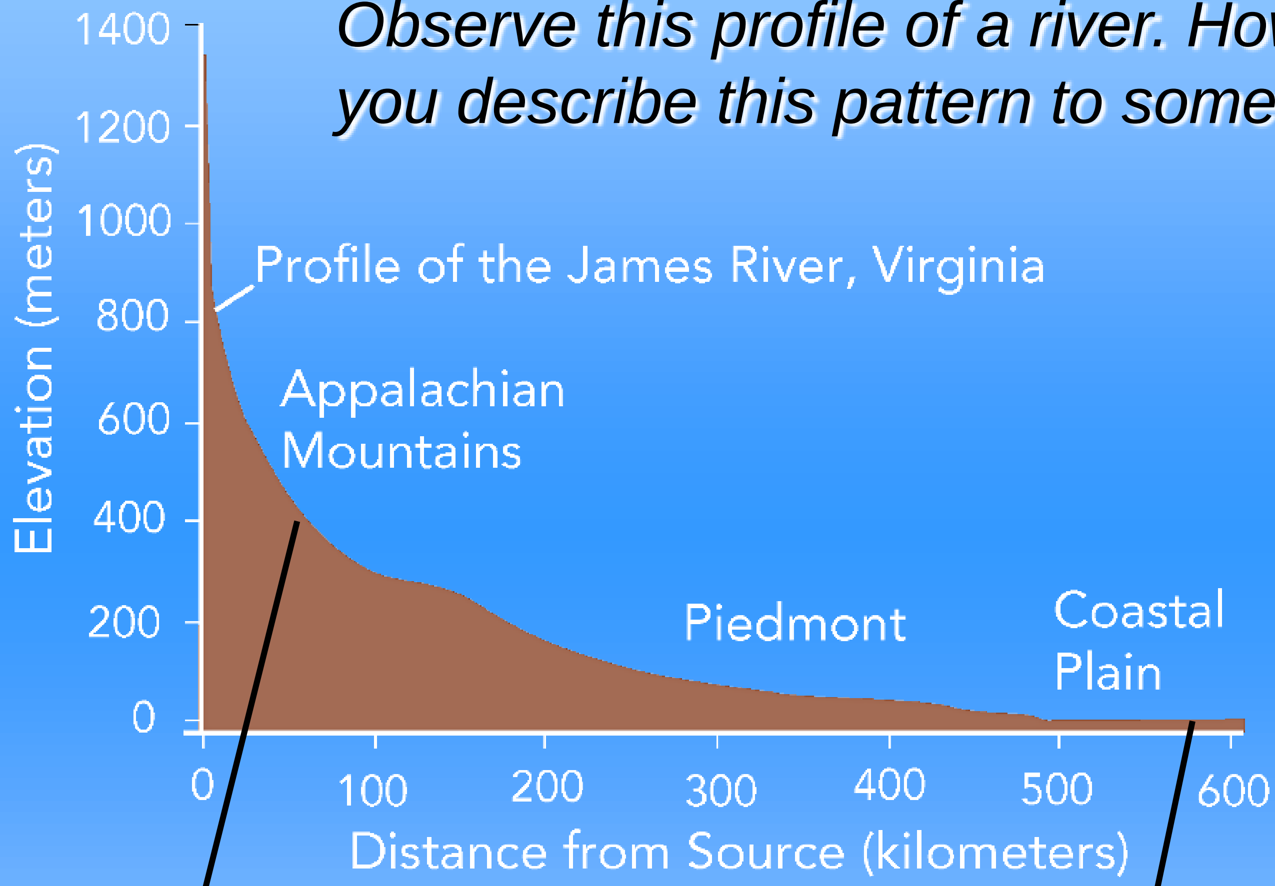
At lowest velocity, sand dropped but silt and clay remain in suspension

Observe and interpret this graph of stream velocity versus mode of transport for different sizes of sediment

16.03.b1

How Do Rivers Change Downstream?

Observe this profile of a river. How would you describe this pattern to someone?

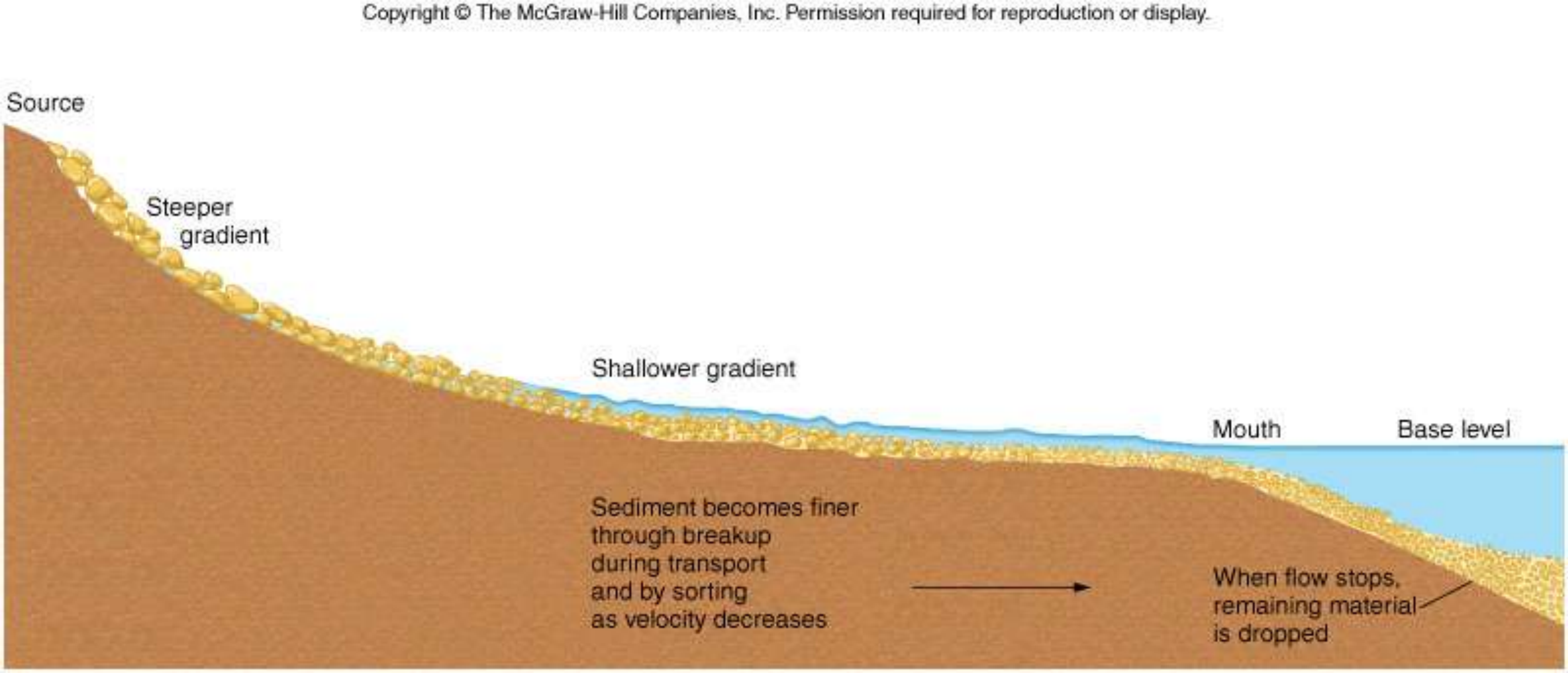


Rivers tend to be steep near their origin, such as in hills and mountains

A river generally becomes less steep (more gentle) down stream

16.04.a2

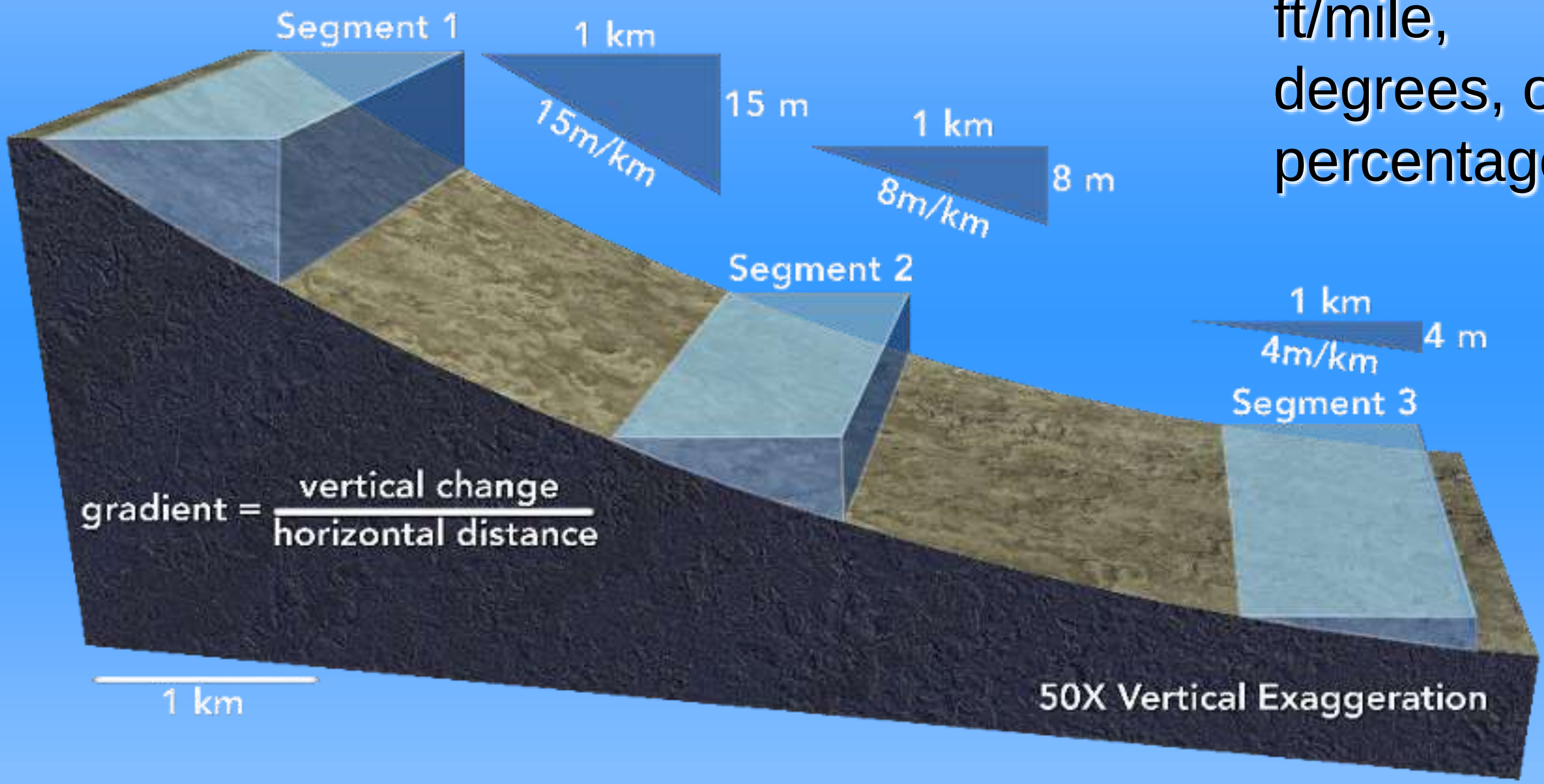
Gradient = the steepness of the stream channel



Observe how river gradient changes downstream

Gradient = change in elevation for a horizontal distance (small blue triangles)

Expressed as m/km or ft/mile, degrees, or percentage



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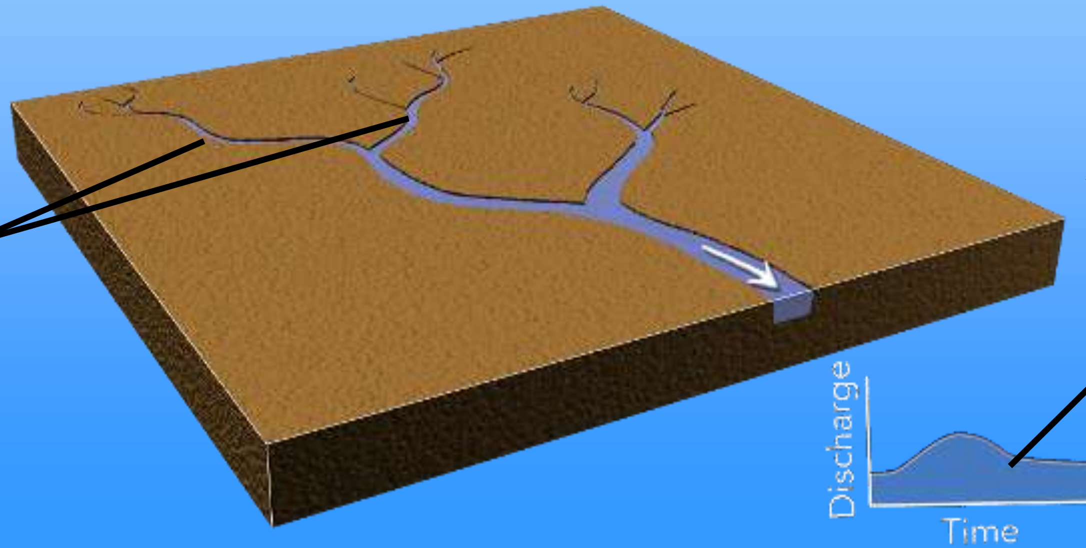
Steeper gradient: river drops more for a certain distance

Tributaries and Drainage Networks

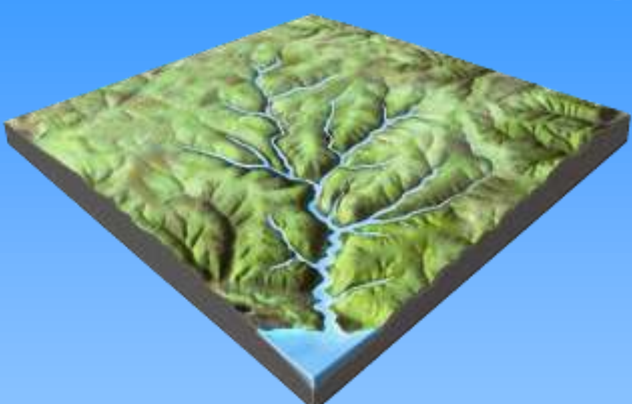
Smaller subsidiary channels are *tributaries*

Tributaries spread out discharge over time

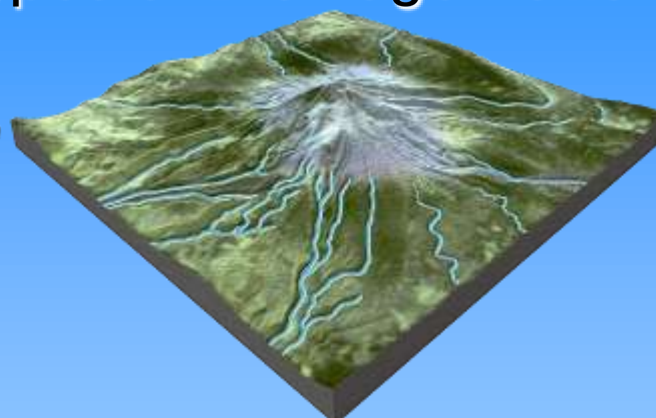


Types of Drainage Patterns

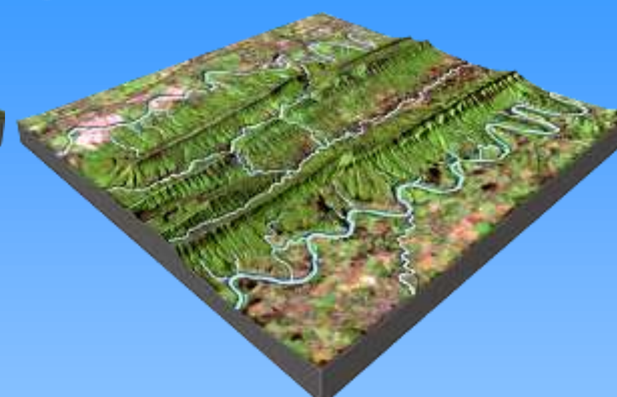
16.01.c-d



Dendritic



Radial



Structurally controlled

Factors Affecting Stream Erosion and Deposition

- Velocity
- Gradient
- Channel Shape and Roughness
- Discharge

Velocity and Sediment Sorting and Deposition

- Stream velocity impacts sediment sorting
  - Slow moving water only carries fine-grained sediments
  - Swift moving water carries a wider range of grain sizes
- Sediments are commonly **well sorted** by size and density
- Depositional features of a stream
  - **Delta,** a large, fan-shaped pile of sediment in still waters created by a stream
  - **Alluvial fan,** a fan-shaped pile of sediment in a larger stream or a region between mountains and a plain formed by a small tributary stream

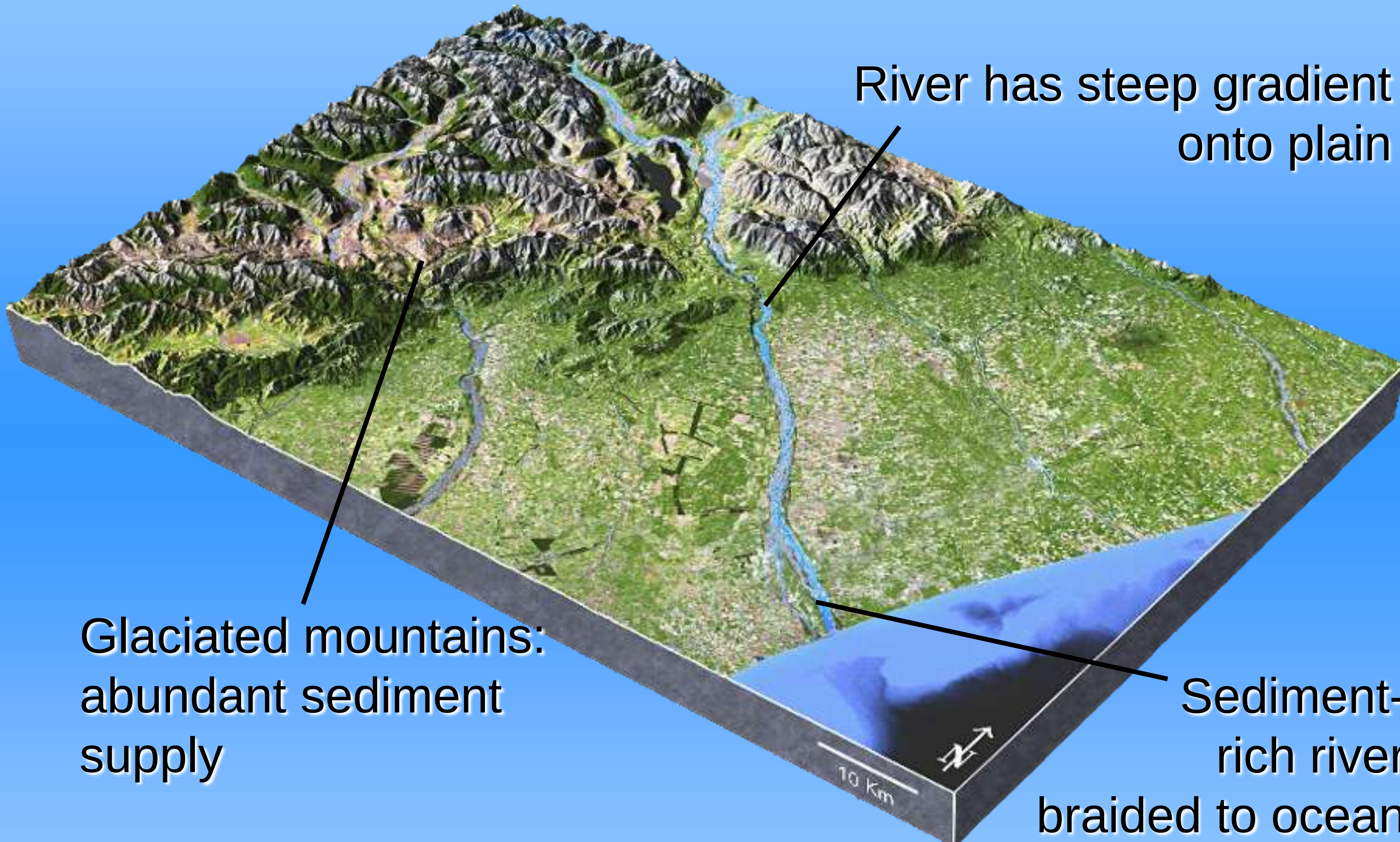
Stream Valley Development

- Downcutting and Base Level
- The Concept of a Graded Stream
- Lateral Erosion
- Headward Erosion and Stream Piracy
- Stream Terraces
- Incised Meanders
- Superposed Streams

Channel and Floodplain Evolution

- **Meanders,** streams don’t flow in straight lines and erode old banks and create new banks, and thus bends form in the streams. Meanders are curves in a stream (or river)
- **Cut bank,** the outside and downstream side of the meander. Faster water flows
- **Point bar,** sediment deposited on the insides of meanders
- **Braided stream,** localized sediments developed in the channel with obstacles and the localized sediments divide the channel into a complex system of many channels.
- **Floodplain,** a broad, fairly flat expanse of land covered with sediment around the stream channel. An area into which the stream spills over during floods
- **Oxbows,** meanders don’t broaden or enlarge indefinitely. Streams may make a shortcut, or cut off a meander, abandoning the old, twisted channel for a direct downstream route

Observe this view of a braided river



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3D

Drainage Patterns

- Dendritic
- Radial
- Rectangular
- Trellis

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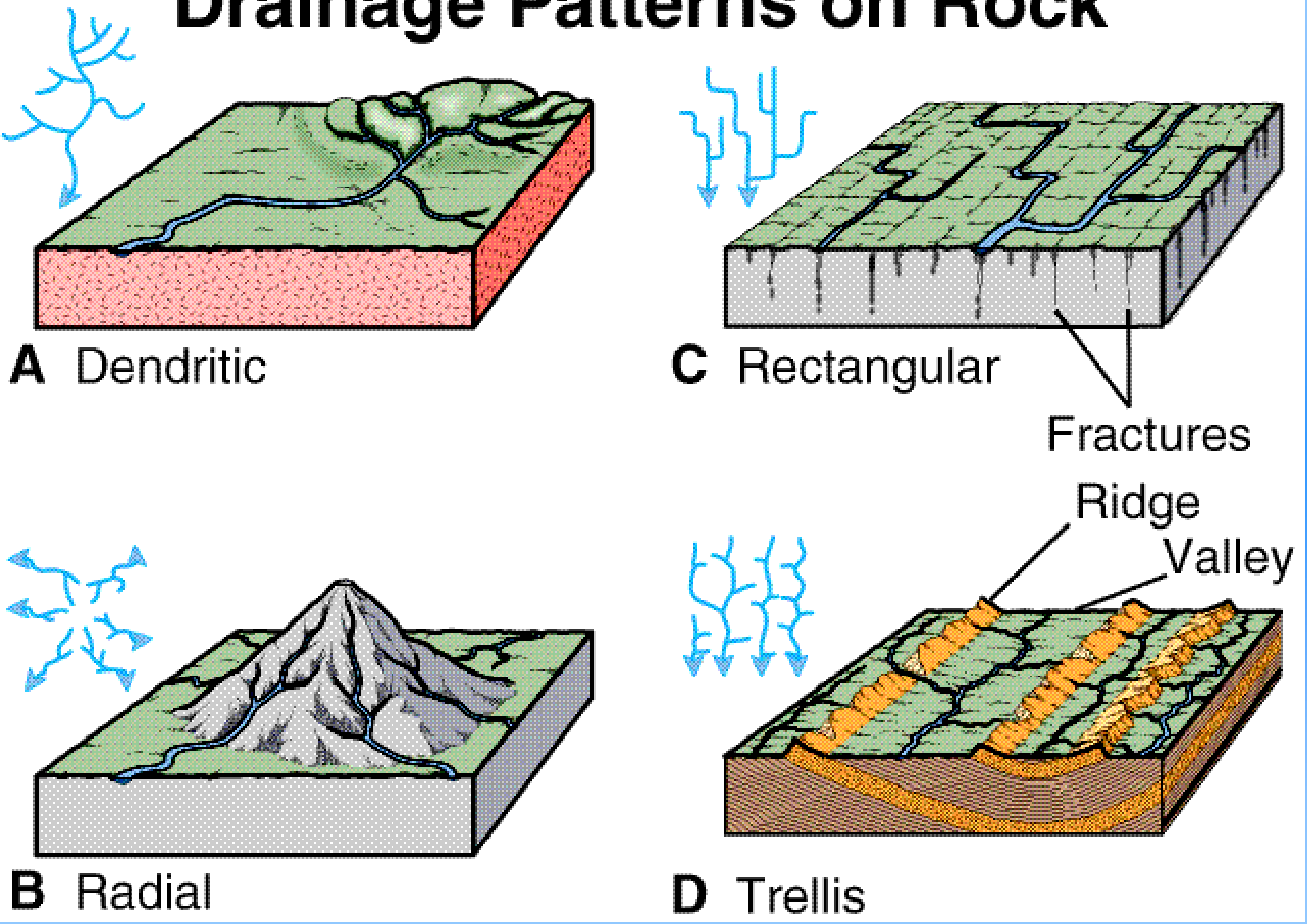
Drainage Patterns on Rock



Channel Flow and Sheet Flow

- Stream
  - Longitudinal Profile
  - Headwaters; mouth
  - V-shaped cross section
- Floodplain
- Stream channel; bank; bed
- Sheetwash
  - Sheet erosion

Stream Deposition

- Bars
  - Placer Deposits
- Braided Streams

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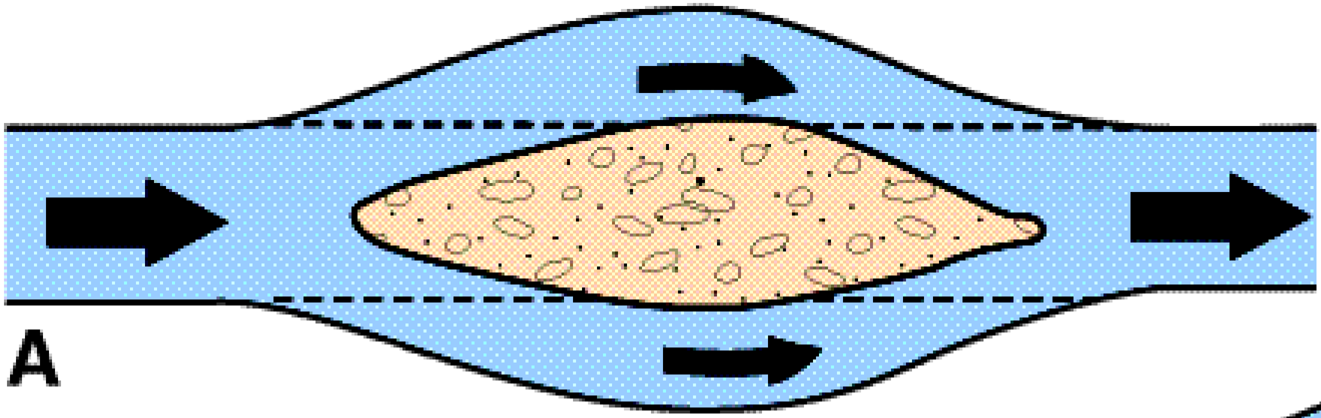
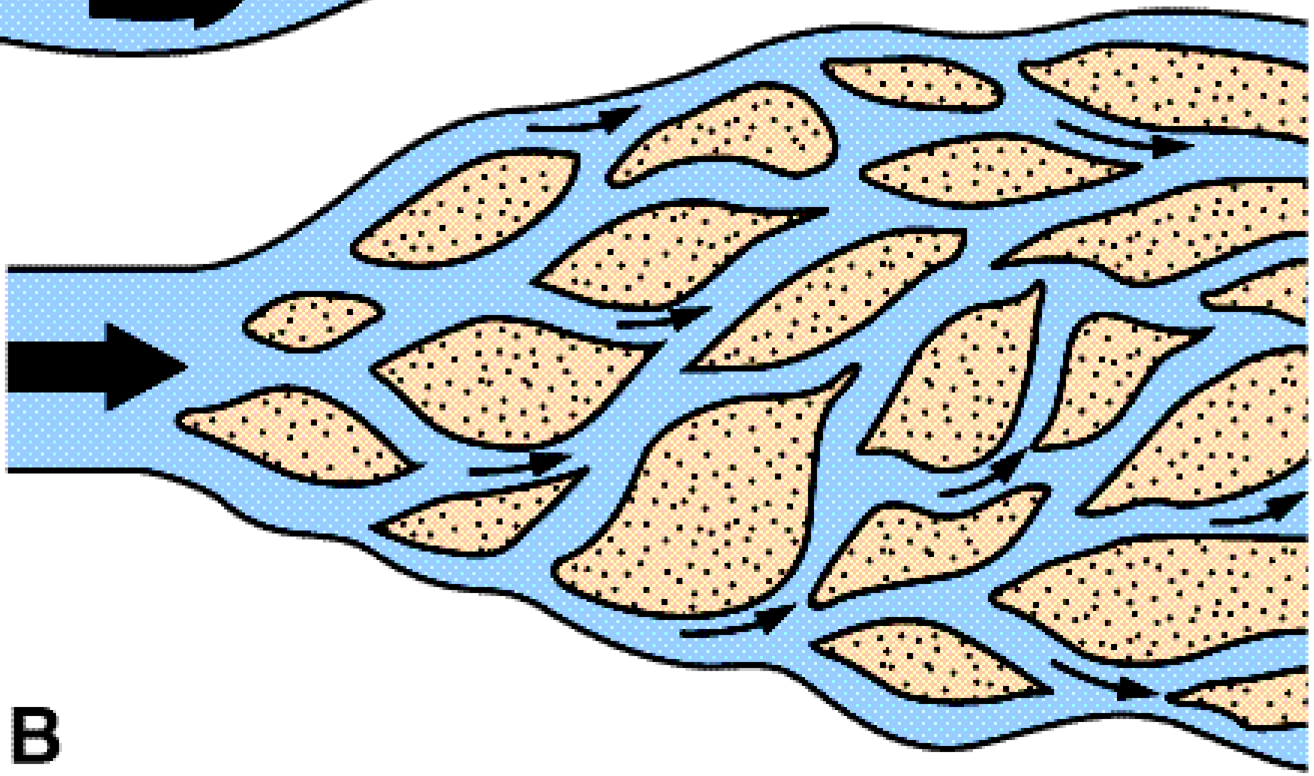
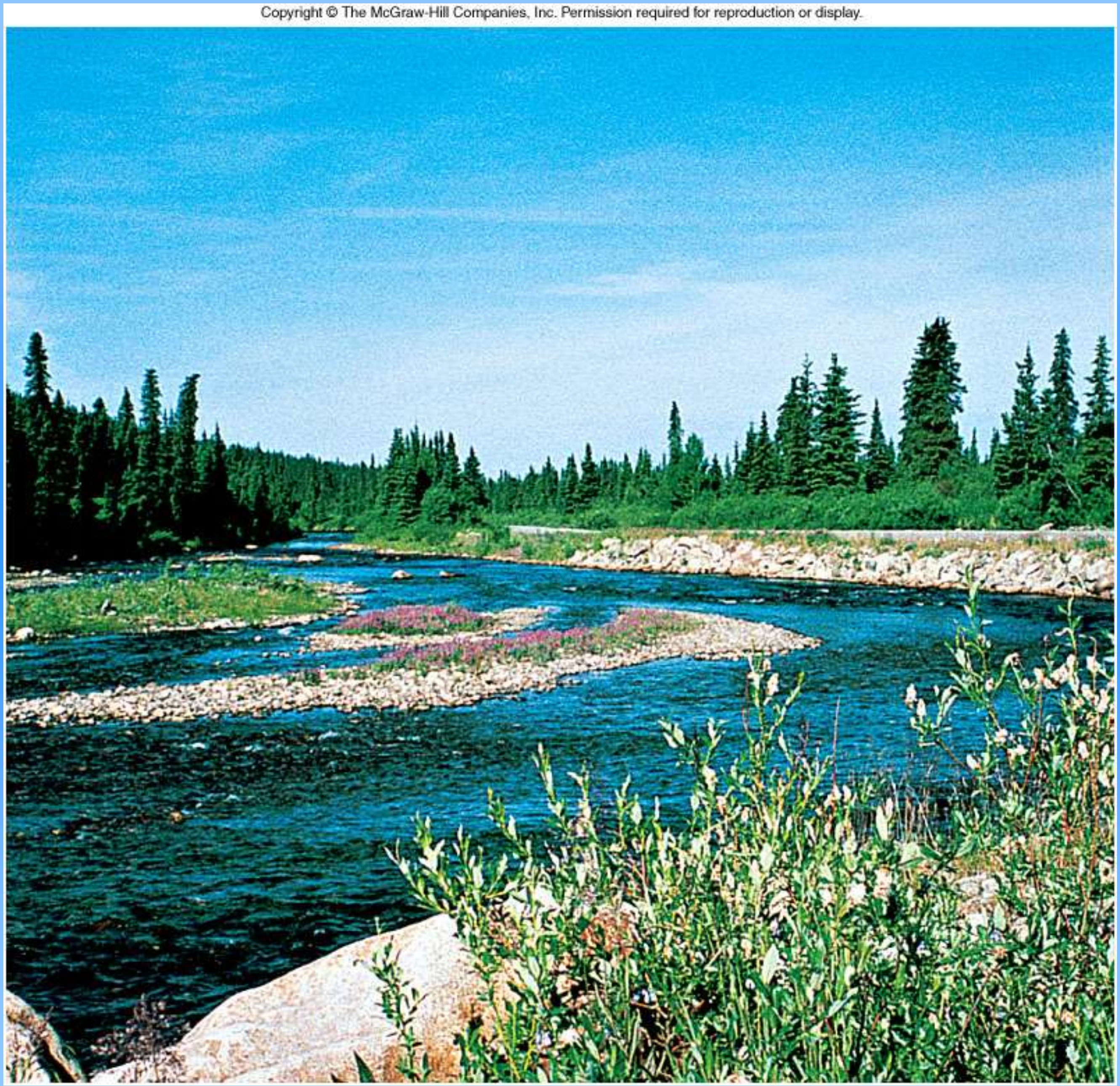
Midchannel Bar and Braided Stream





Midchannel bar



Braided stream = more sediment than water can carry

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Close-Up Views of Braided River

Braided channels: steep gradients, abundant supply of sediment, and variable flows

Part of fairly straight river

16.07.a

Meanders

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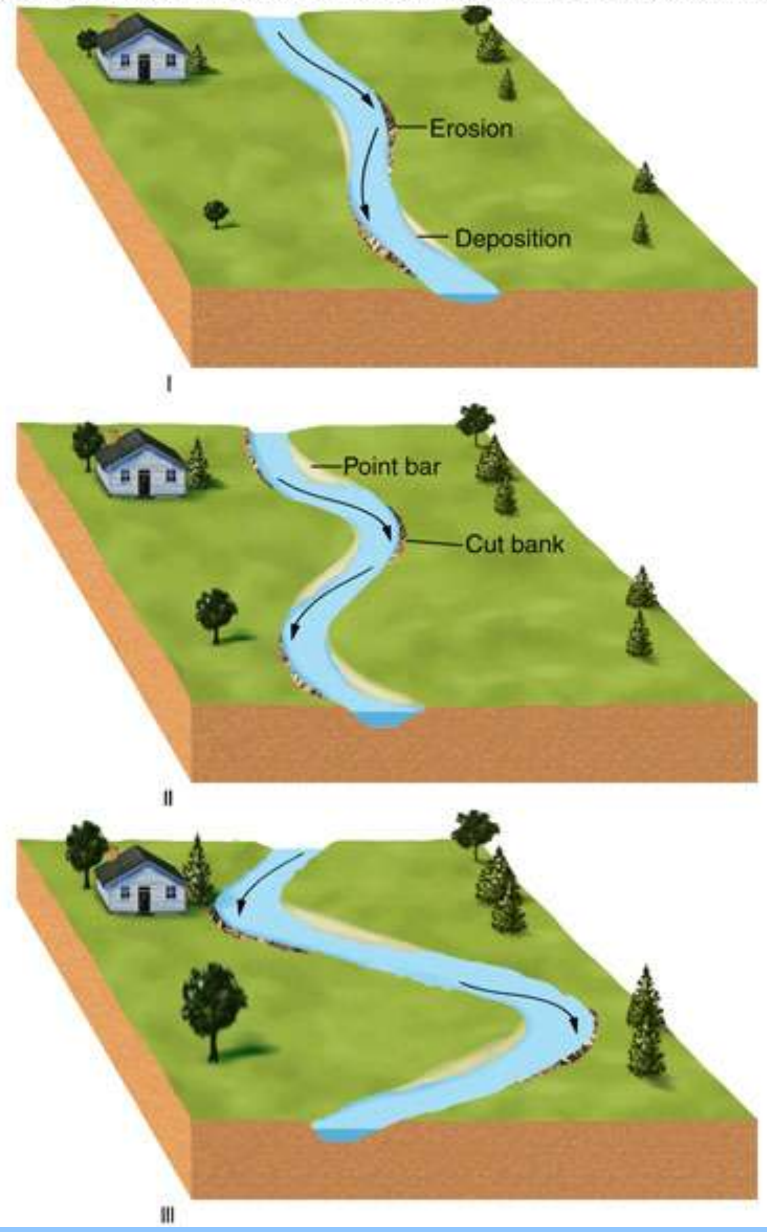

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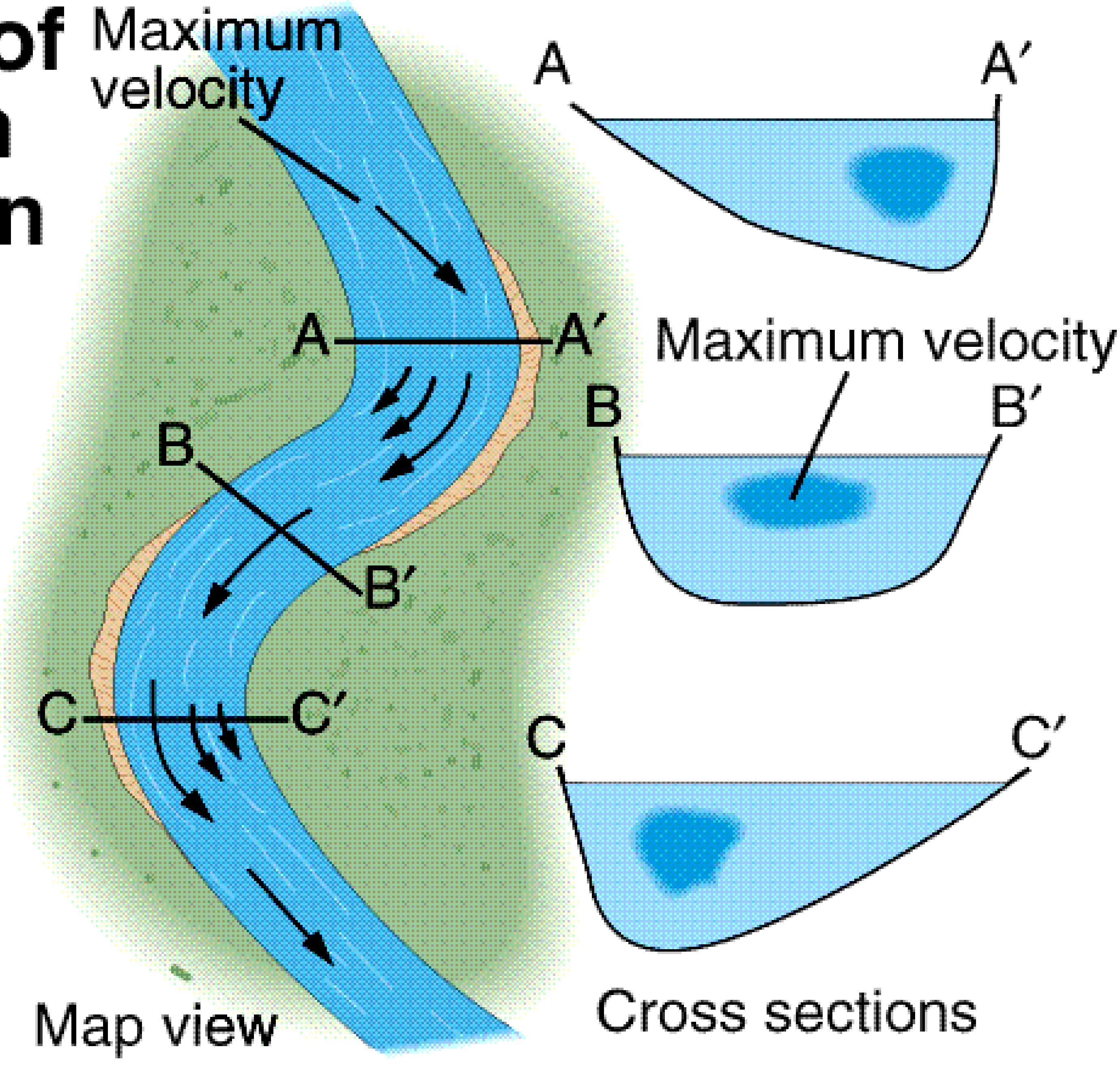
Regions of Maximum Velocity in a Stream



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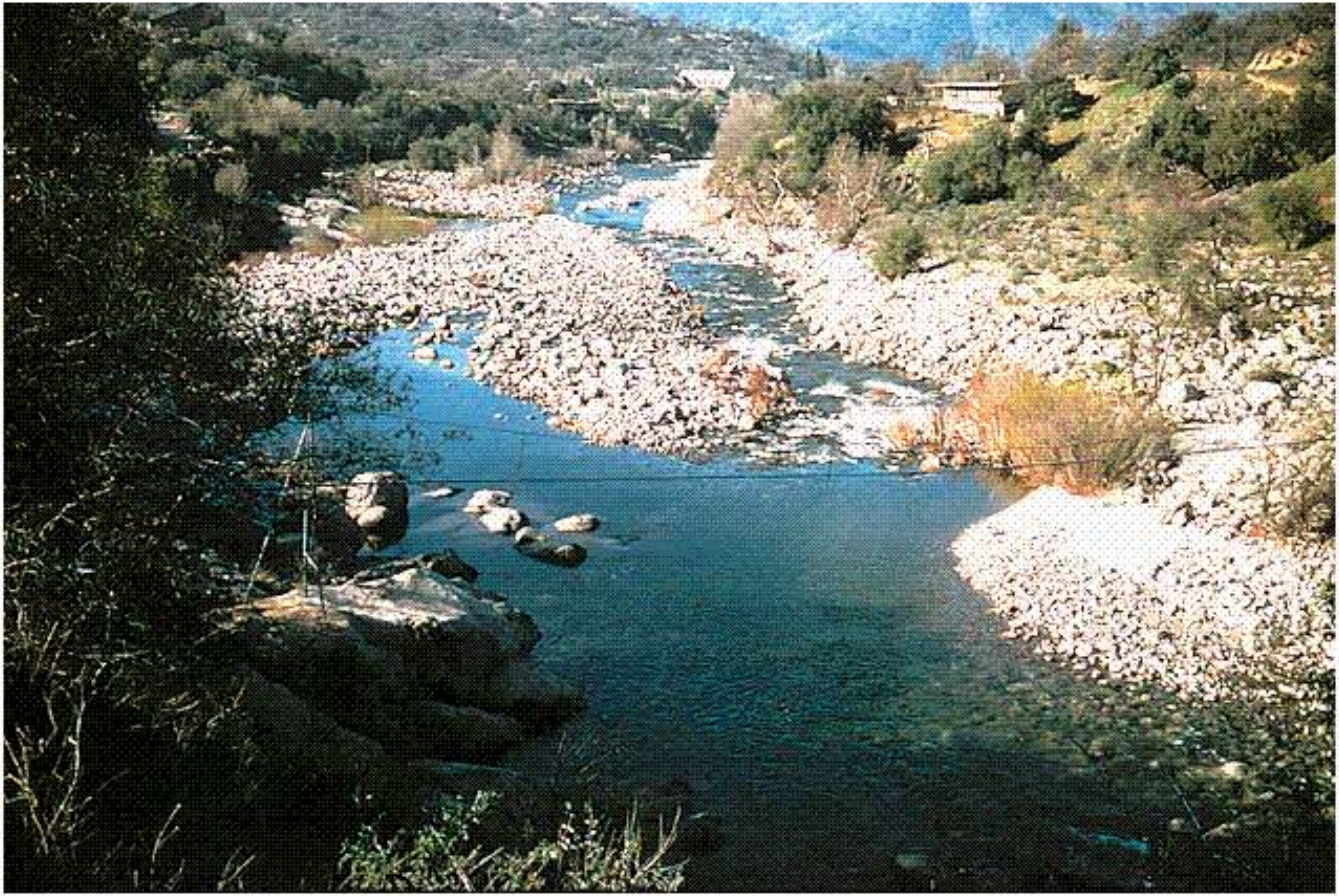
Gravel Bars in Stream Bed



Meandering Streams and Point Bars

- Meanders
- Point Bar
- Meander Cutoff
  - Oxbow Lake
- Flood Plains
  - Natural Levees

How Do Meanders Form and Move?

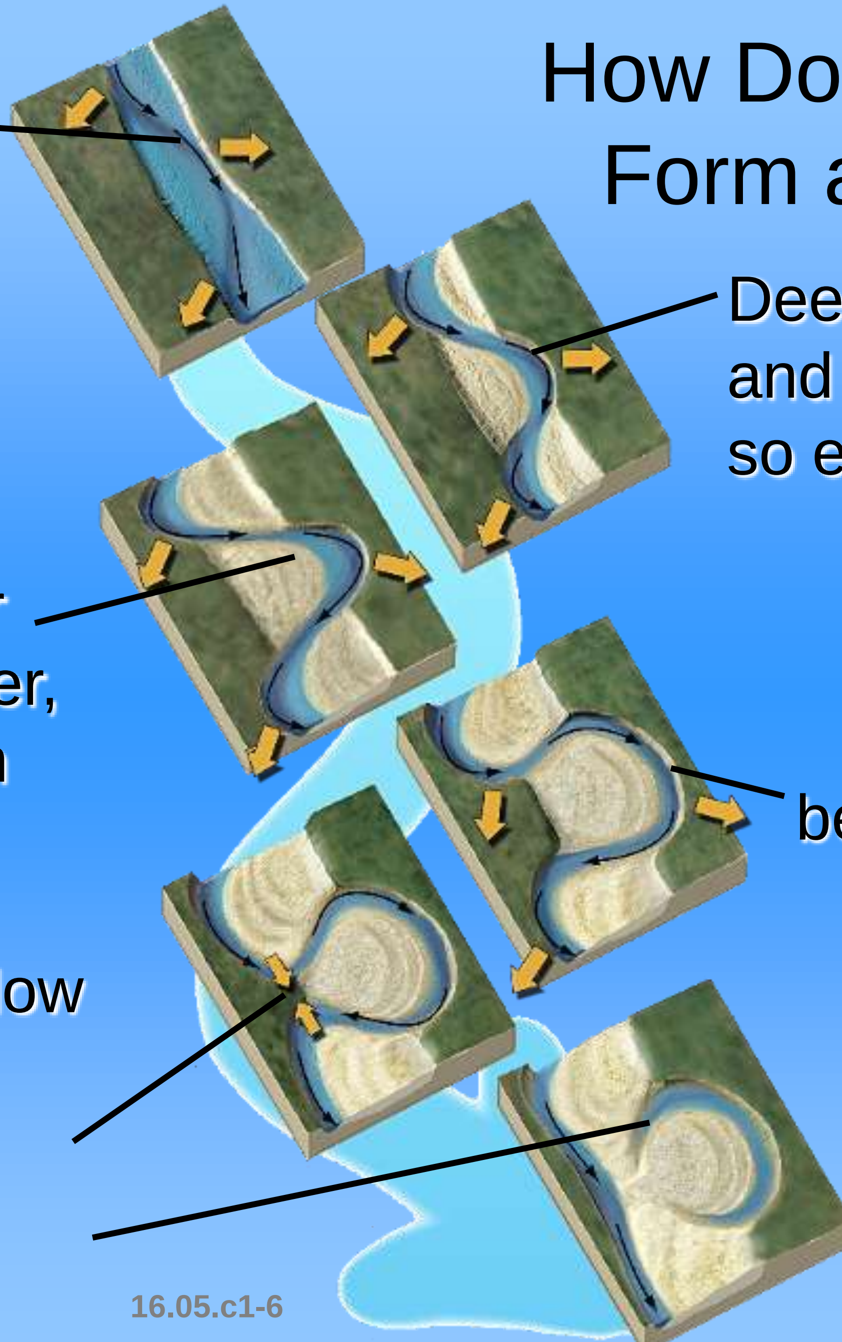
Faster side erodes and deepens

Deep side faster and more water, so erosion

Inside slower and less water, so deposition

Erode outside bend, increasing curvature; migration outward and downstream

Erosion or overflow erosion: *cutoff meander* and *oxbow lake*



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Figures 6.10 a, b, and c

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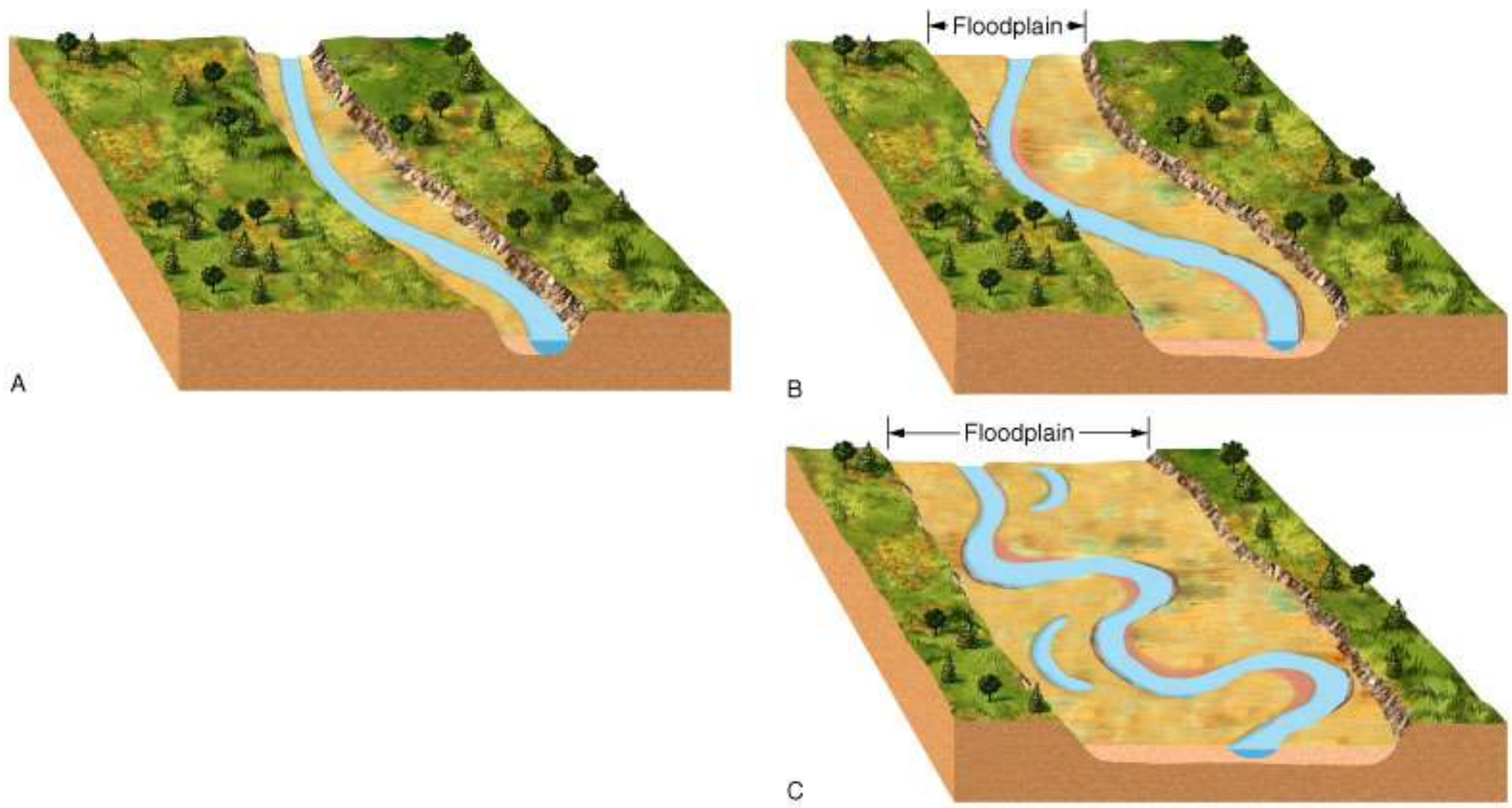

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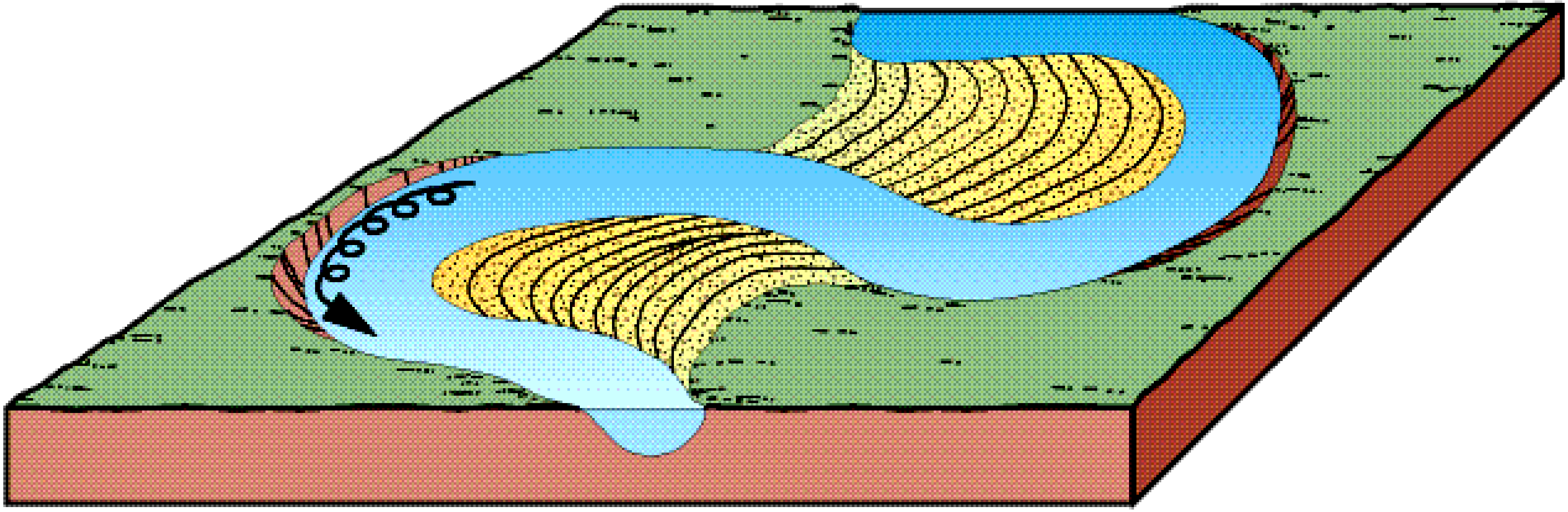
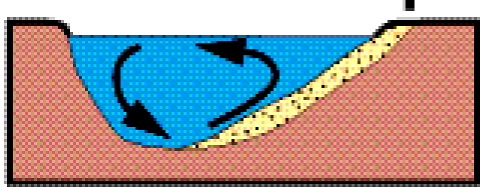
Development of River Meanders



Erosion Deposition



Cross section

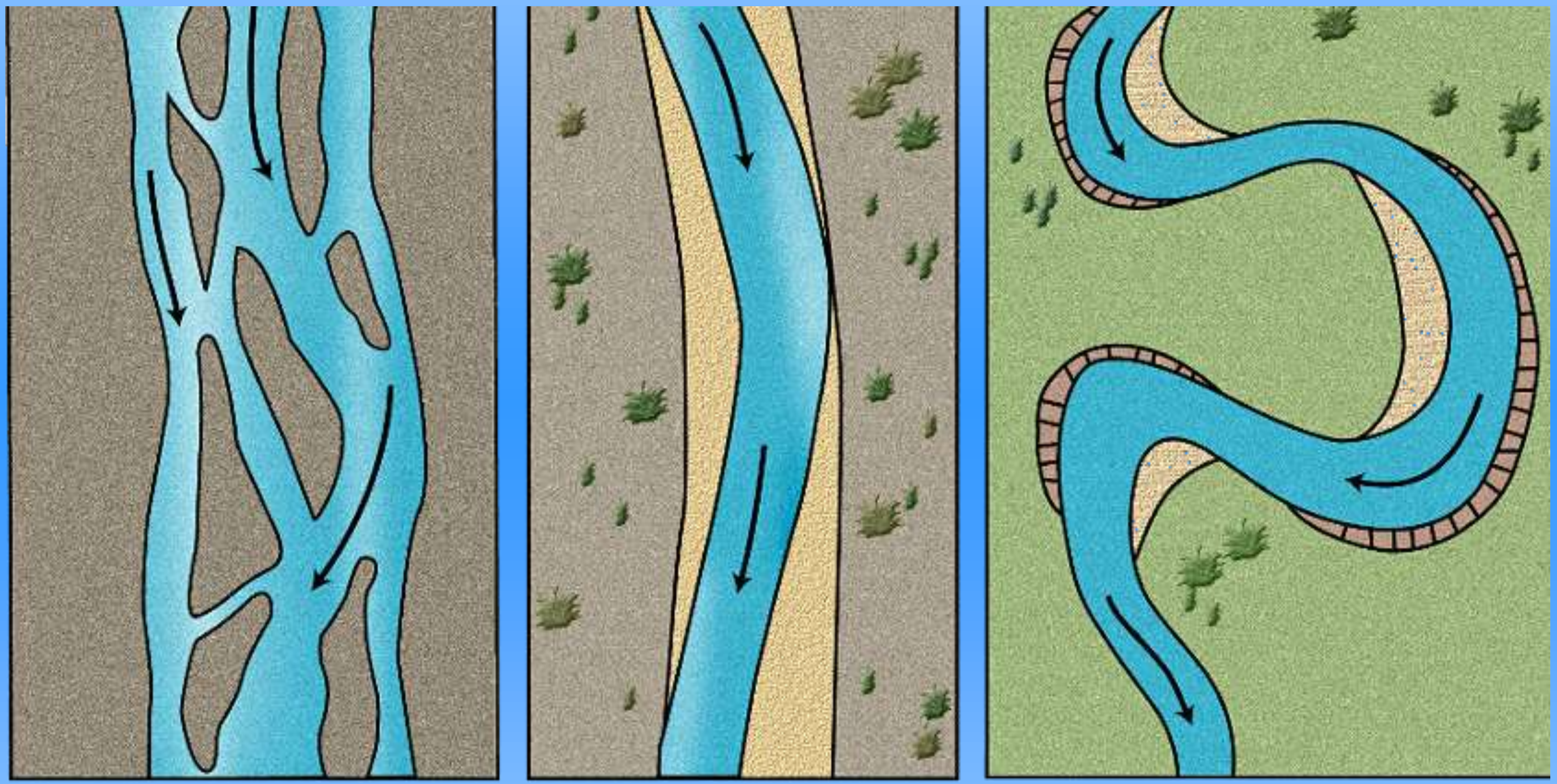
Corkscrew water motion on a curve helps cause erosion and deposition.

A

Curves in Rivers and Streams

Observe the channels in three rivers

16.05.a2-4



Braided: network of interweaving channels

Low sinuosity: gently curved

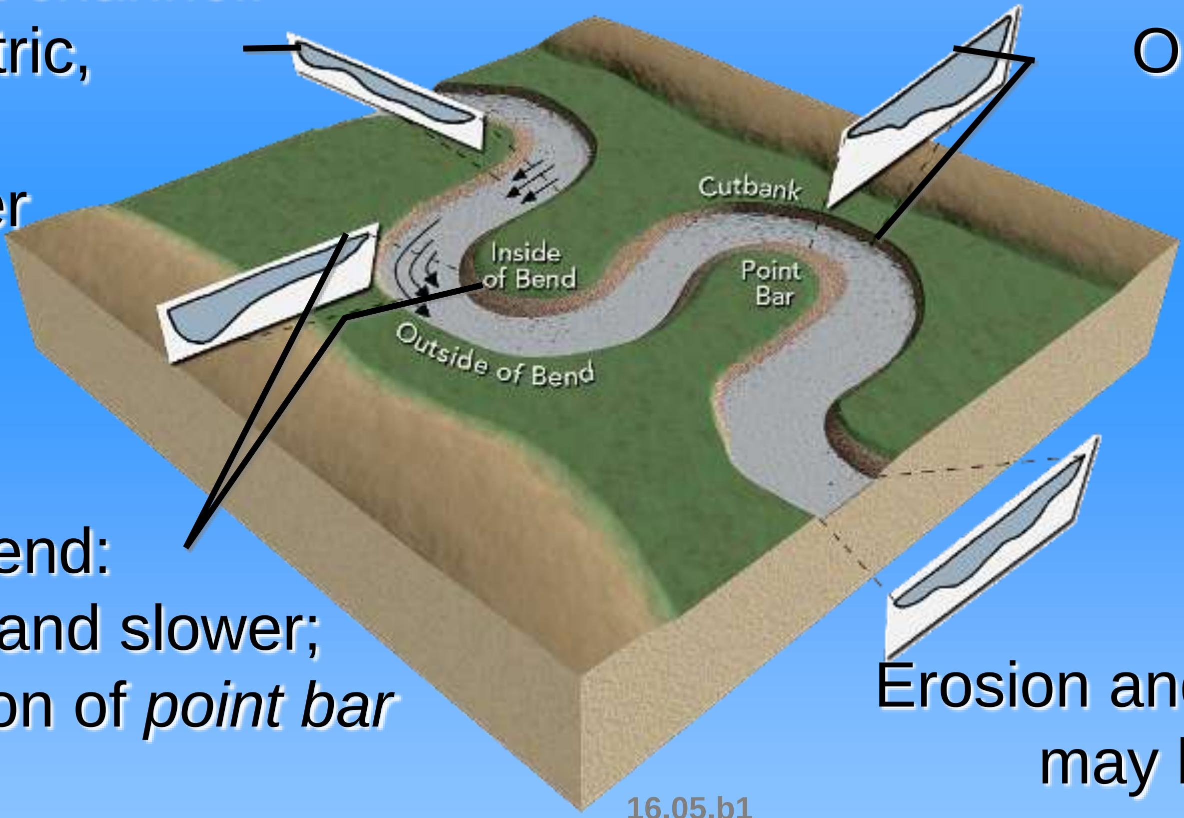
Meandering: very curved; high sinuosity

What Processes Operate on Meanders?

Small graphs show profiles across the river channel; observe the channel profiles for different parts of the river

Straight channel: symmetric, fastest in center

Outside bend: deeper and faster; erosion of *cutbank*



Inside bend: shallow and slower; deposition of *point bar*

Erosion and deposition may be balanced

16.05.b1

Curves in Rivers and Streams

Observe these satellite images of rivers

16.05.a

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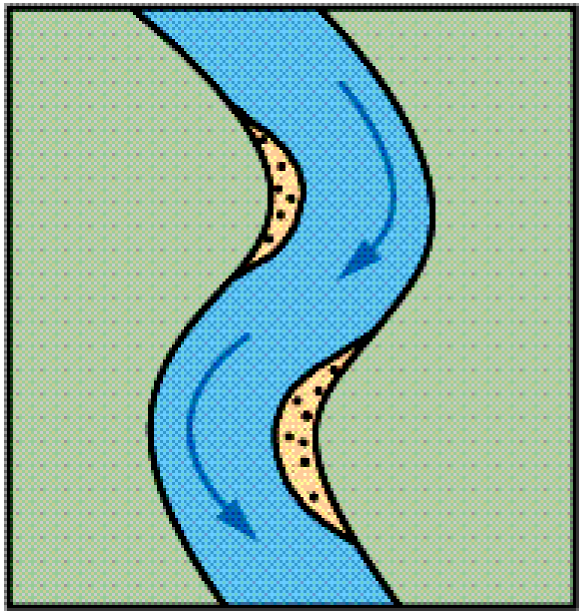
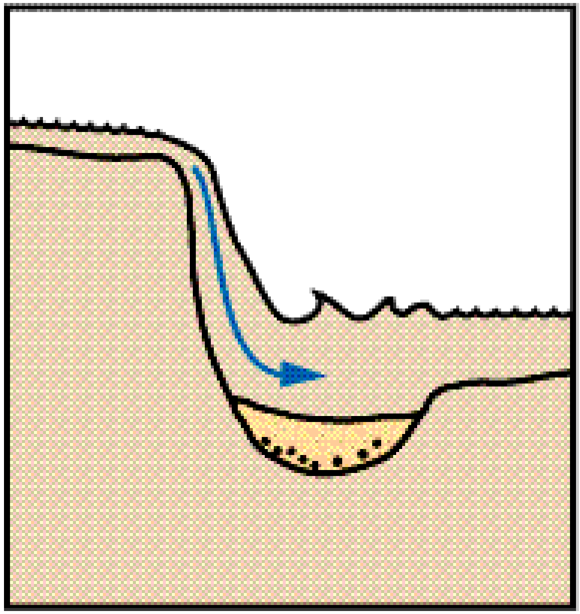
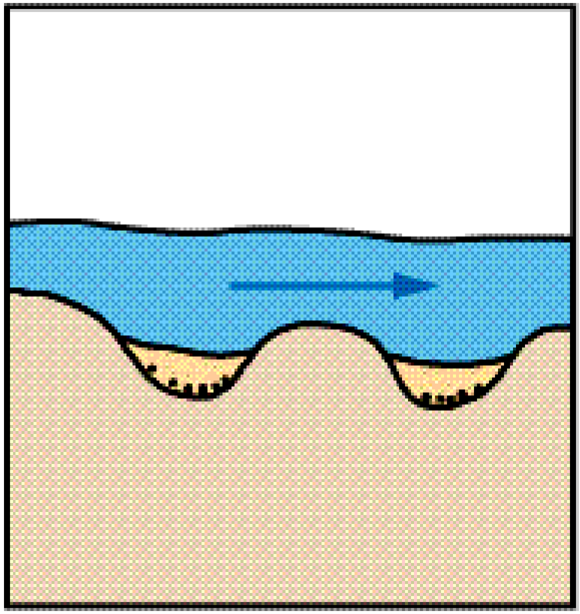
Types of Placer Deposits



A Map view



B Side view



C Side view

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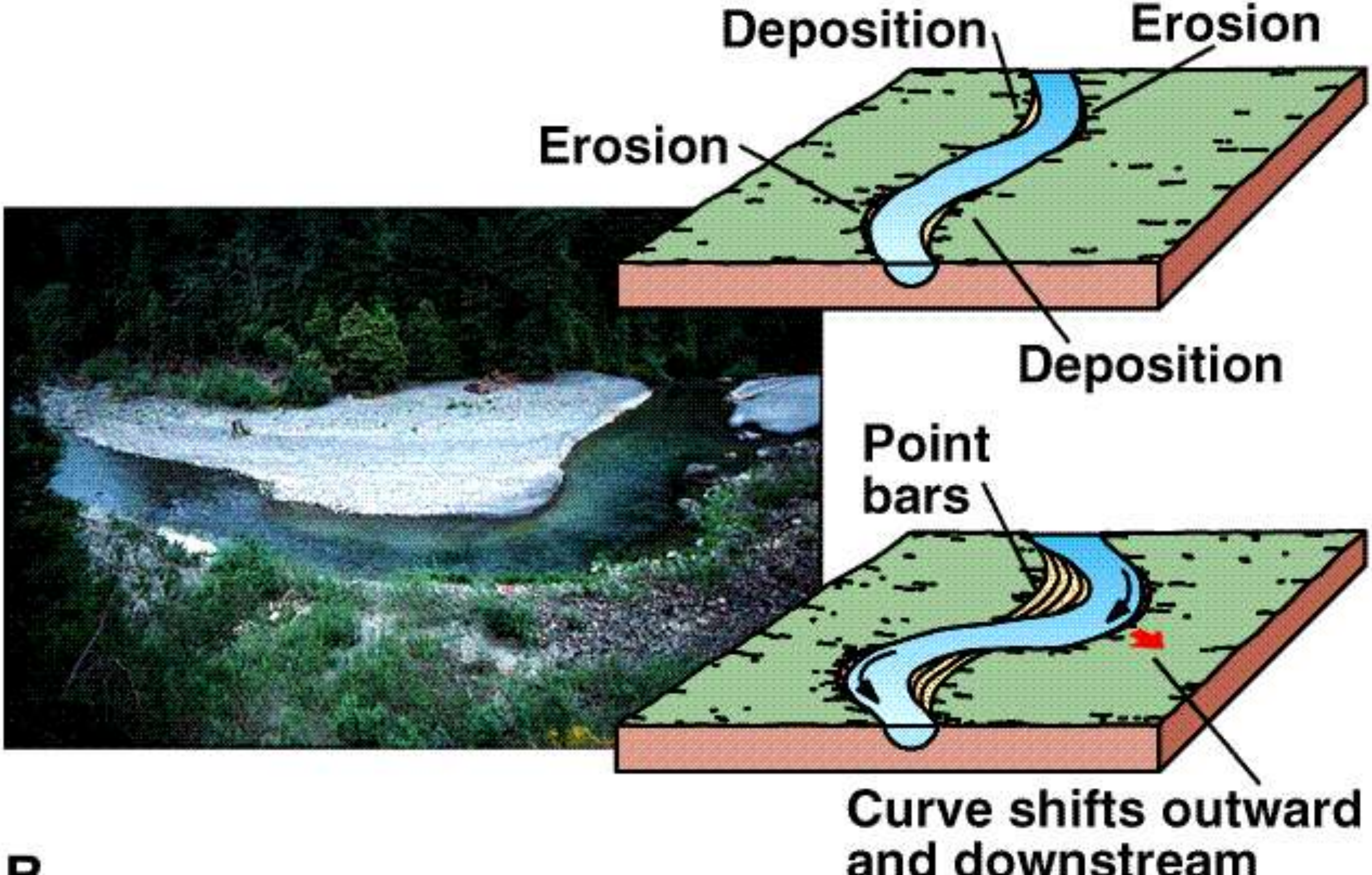
Erosion and Deposition on Curves



B

Oxbow lake = cut off meanders

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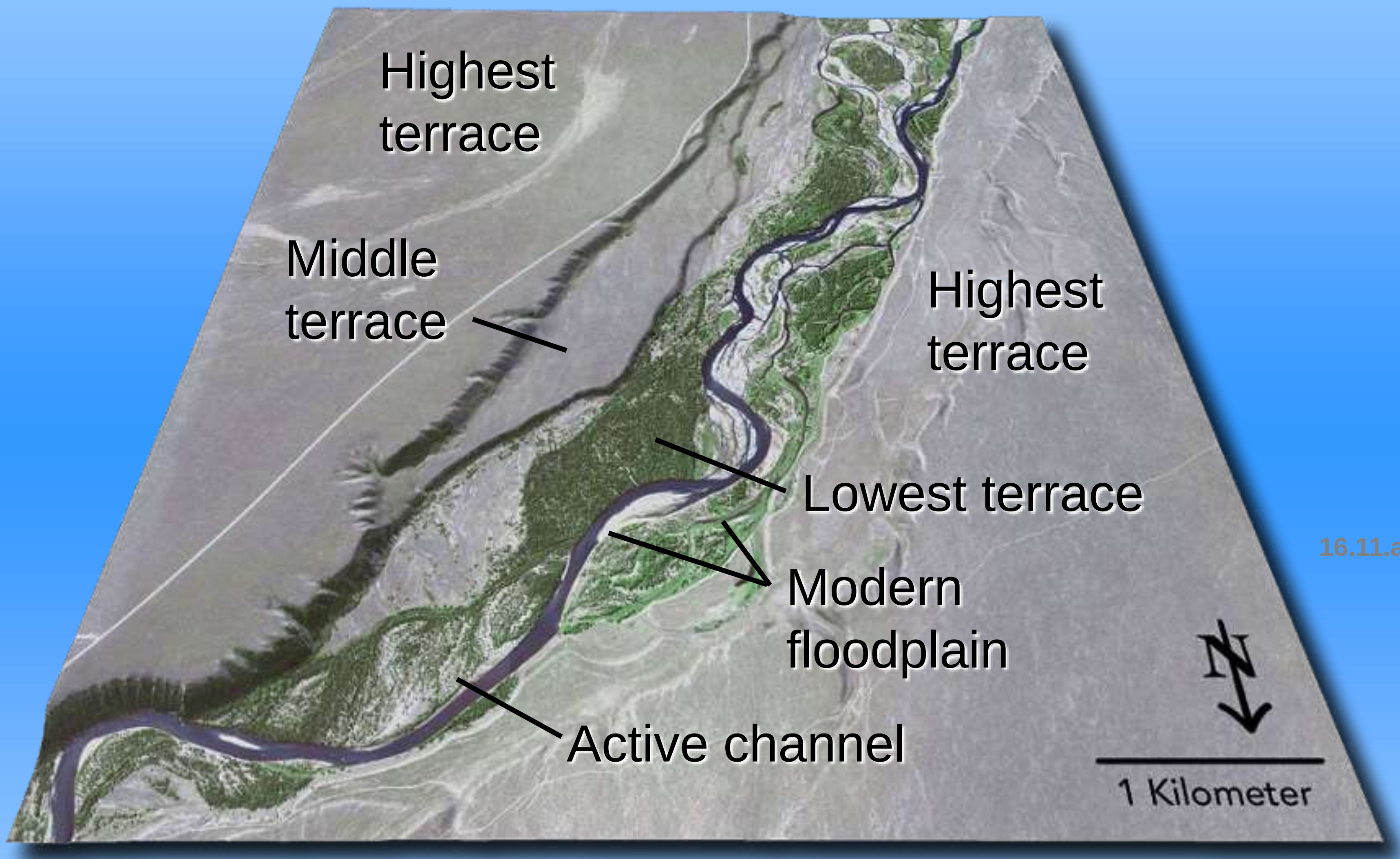
River Terraces



16.11.a2

Many rivers flanked by relatively flat benches (terraces)

3D

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Incised Meanders

Deltas & Alluvial Fans

- Distributaries
- Wave Dominated
- Tide Dominated
- Birdfoot Delta
- Stream Dominated
- Bedding Types
  - Foreset Beds
  - Topset Beds
  - Bottomset Beds
- Alluvial Fans

Delta

Alluvial fans

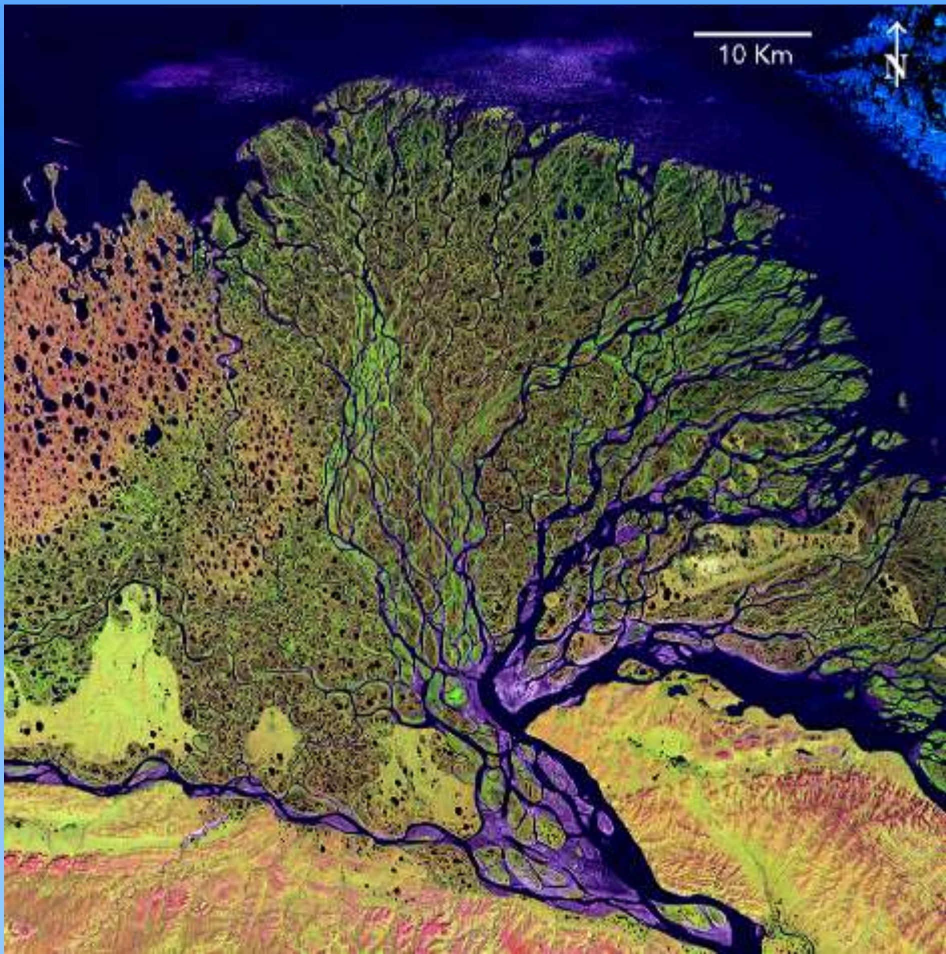
When a River Approaches Base Level

Nile River spreads out and deposits sediment

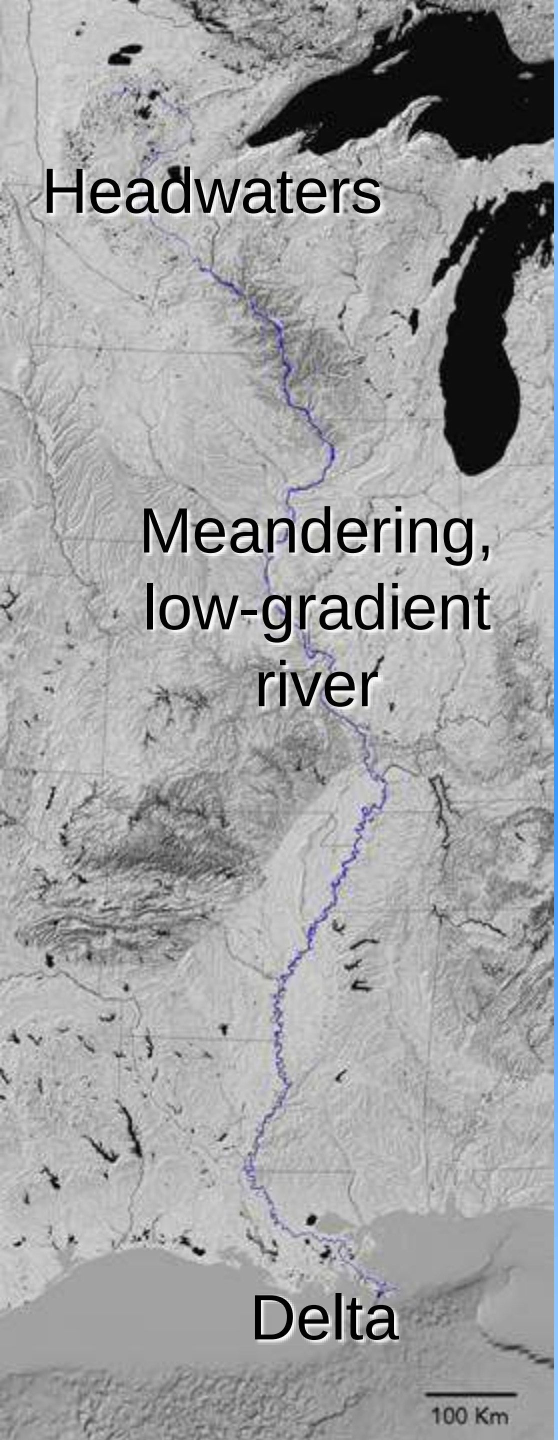
(*delta* – *Greek D*= Δ)

Lena River splits into *distributary system*

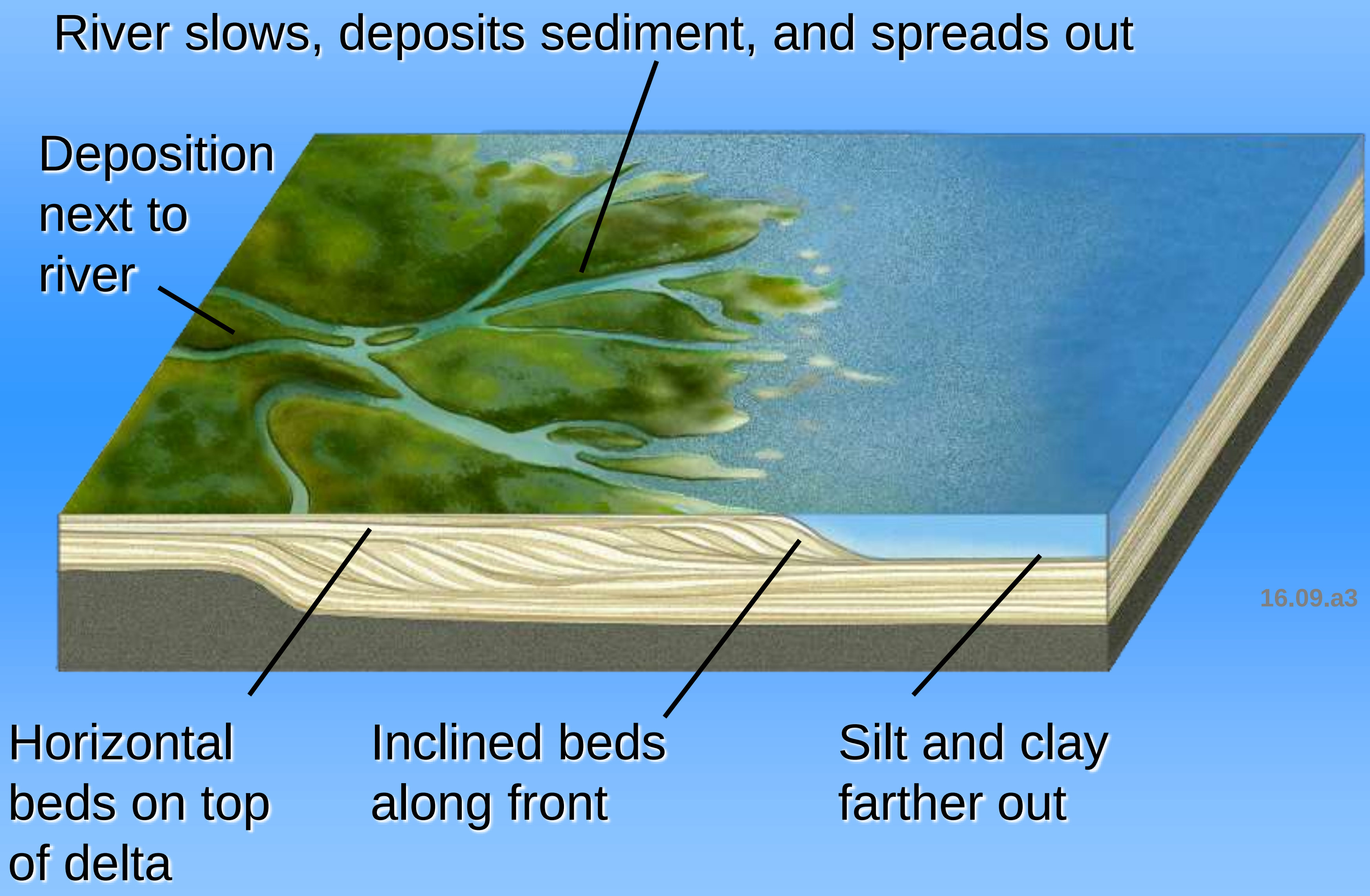
16.09.b



Mississippi River



Sediment Deposition in a Delta



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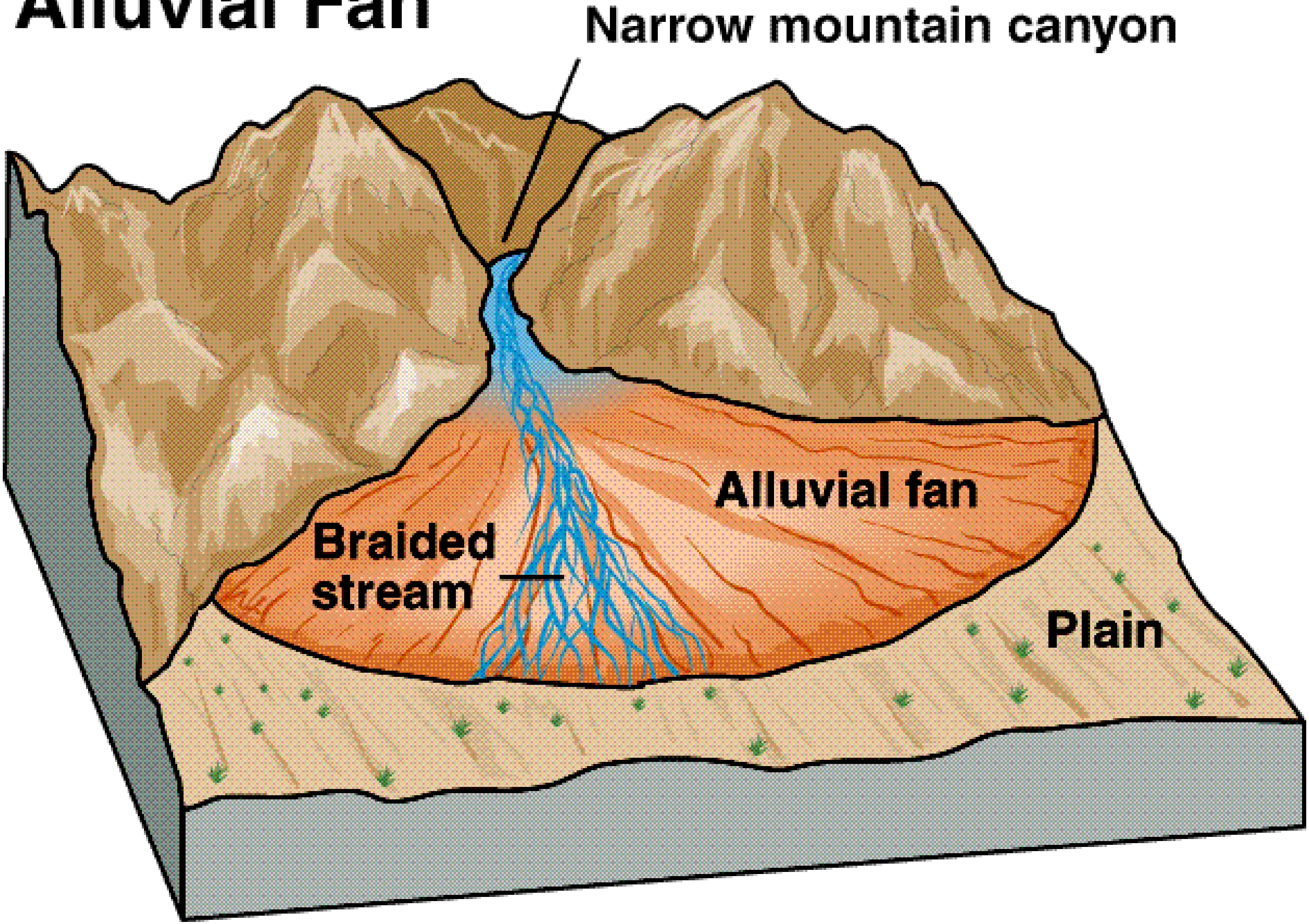
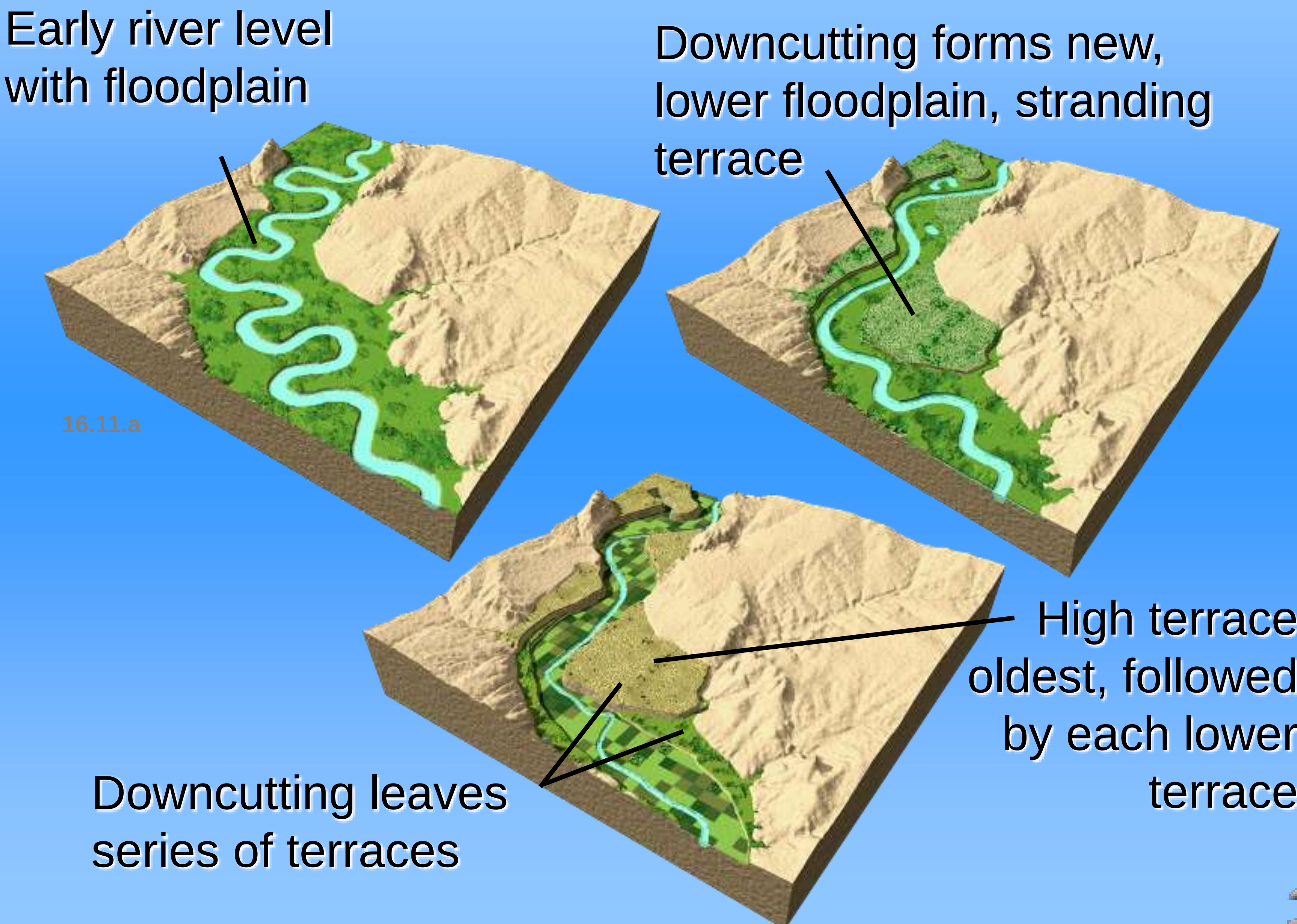
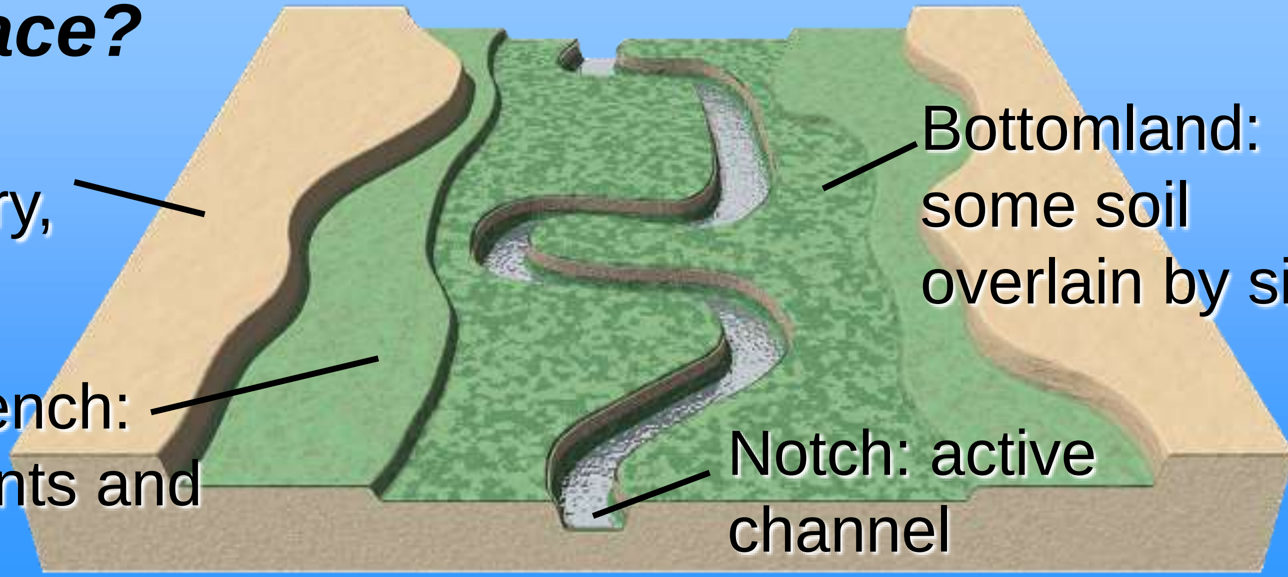
Alluvial Fan



Formation of River Terraces



Investigation: How Would Flooding Affect This Place?



Upper bench: dry, dusty

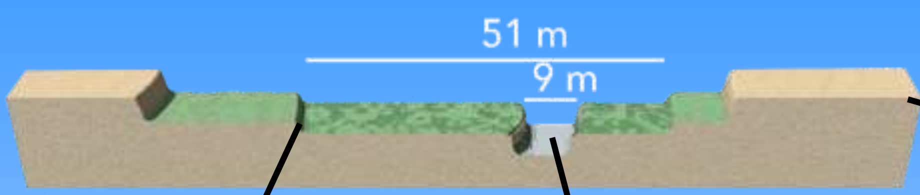
Middle bench: some plants and good soil

Bottomland: some soil overlain by silt

Notch: active channel

16.16.a

Profile across center of area



The step up to the middle bench is 3 m high

The notch is 5 m high from its base

The profile crosses the area in this location

3D

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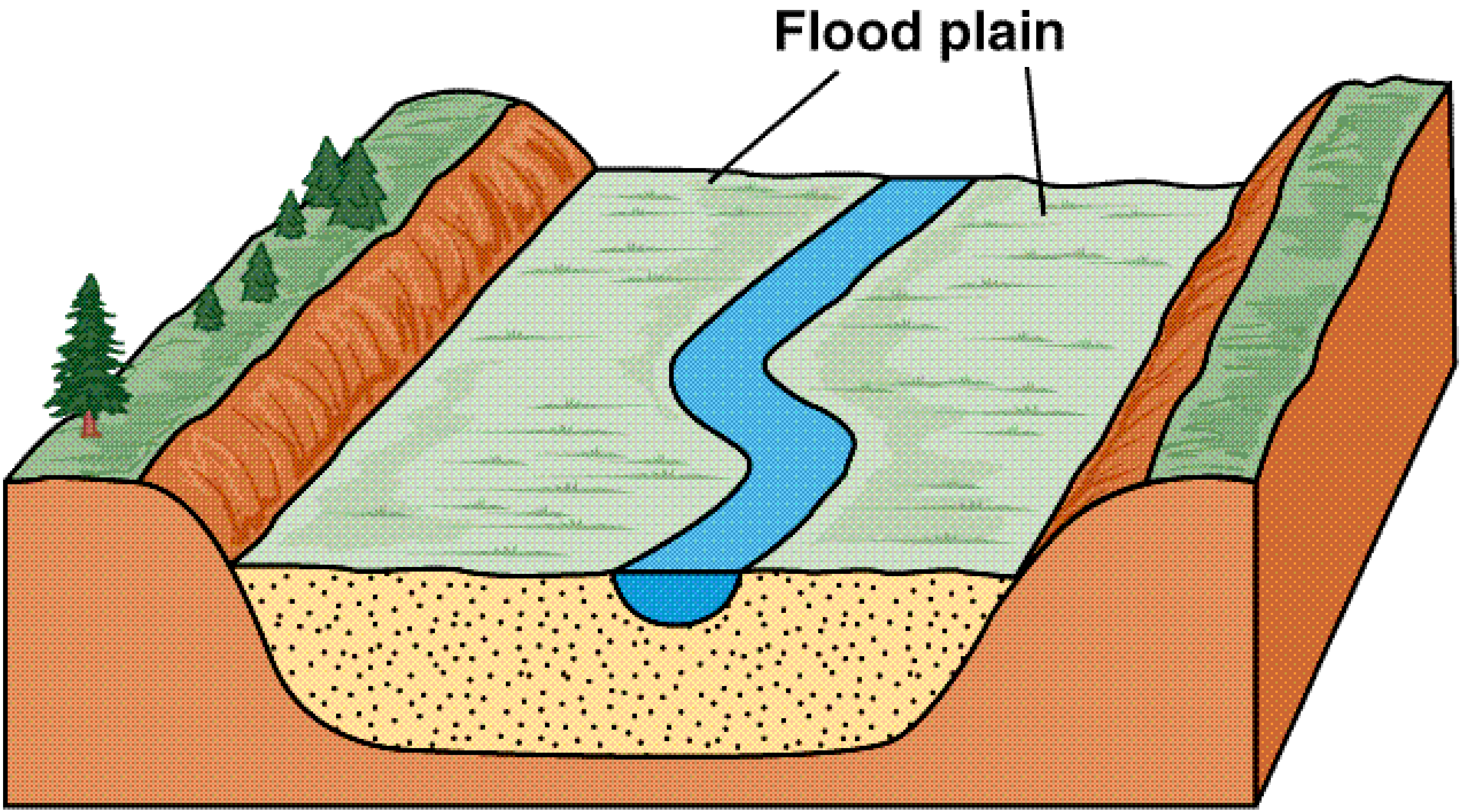
Terrace Formation, Stage 1



A

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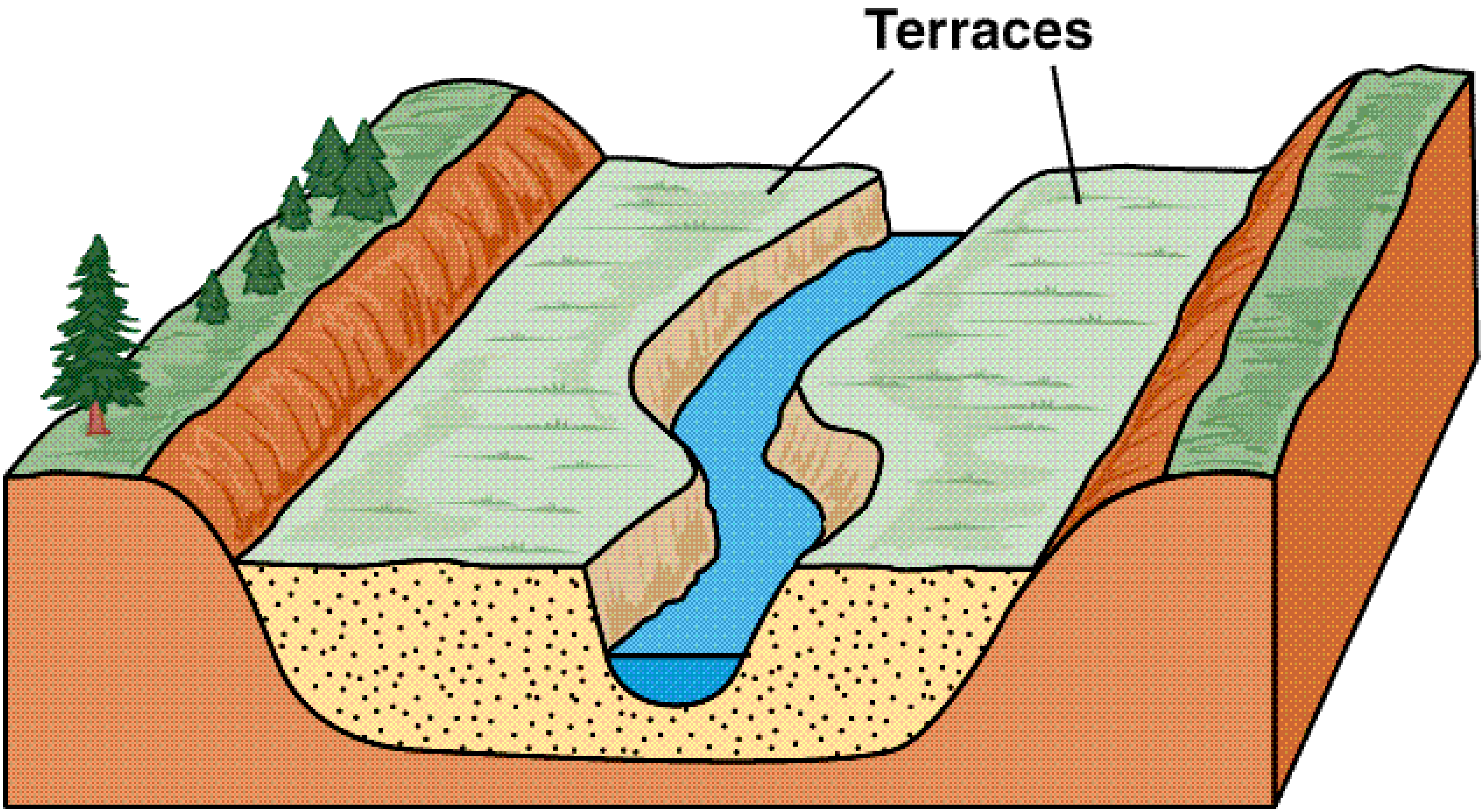
Terrace Formation, Stage 2



B

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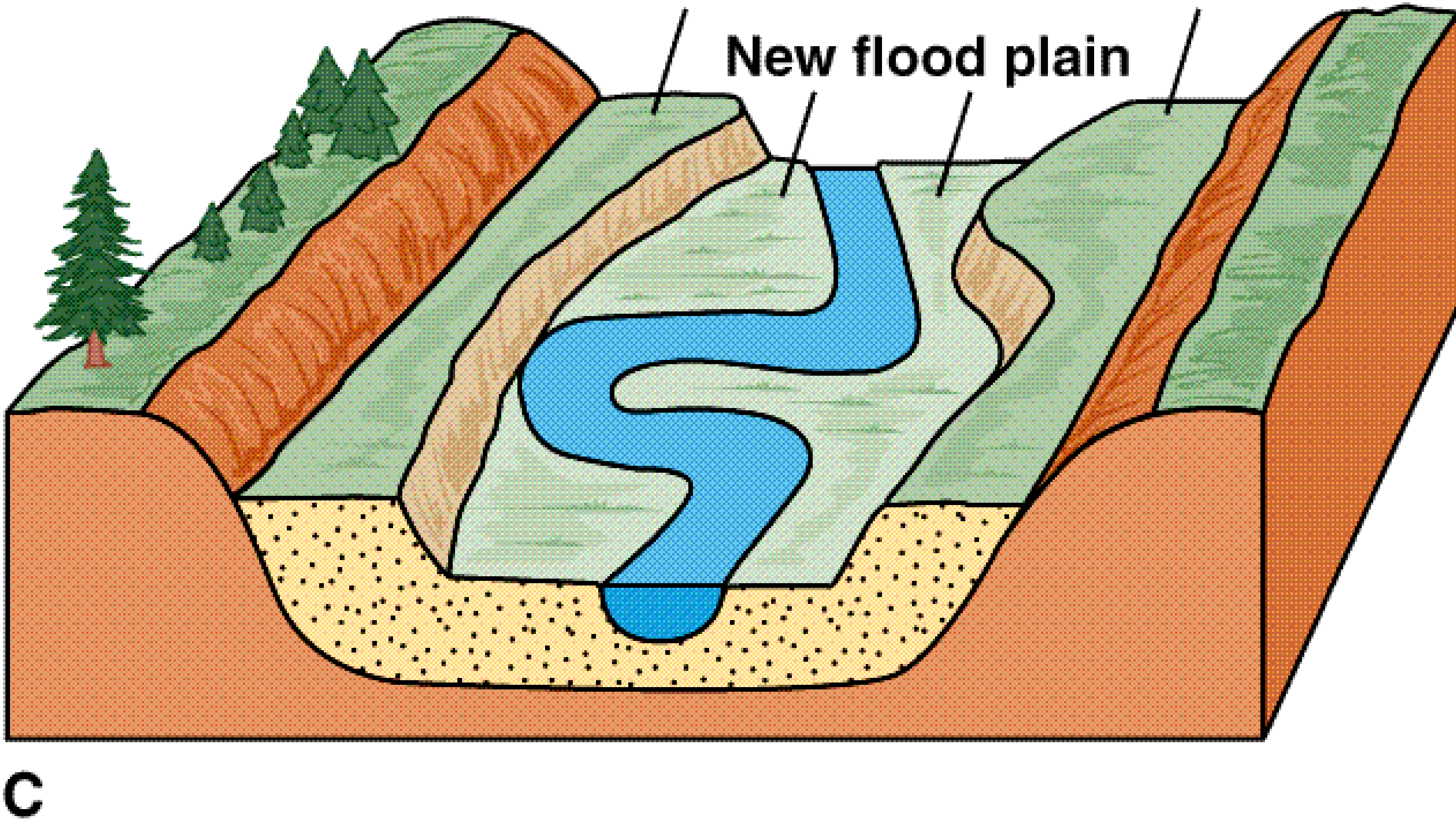
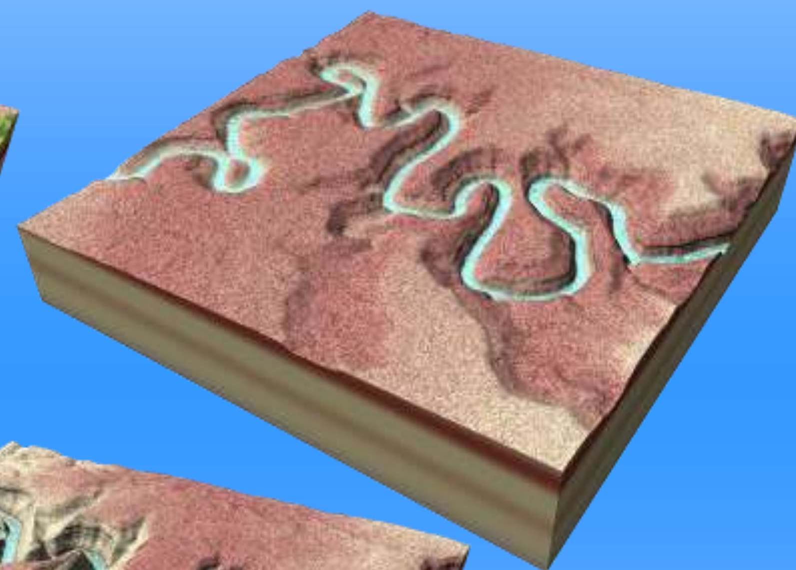
Terrace Formation, Stage 3

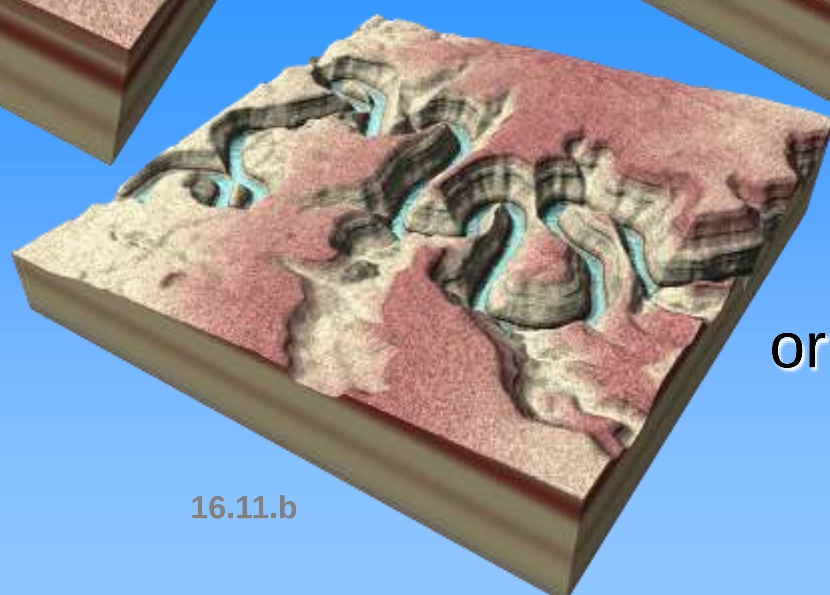


Entrenched Meanders

Early river level with floodplain

River cuts into hard rock





Canyon deepens with original meander shapes

16.11.b

3D

Factors Governing Flooding

- Input exceeds output will cause a flood
  - Too much water entering a stream system
- Factors:
  - Excessive rainfall
  - Snowmelt off in mountains
  - Severe storms
  - Hazardous blockage of stream channel
    - Trees
    - Rock avalanches

Floods

Flooding

  - Recurrence Interval
  - Flood Erosion
  - Flood Deposits
- Urban Flooding
- Flash Floods
- Controlling Floods
- The Great Flood of 1993

Flood Characteristics

- Velocity, height, and discharge of a stream increase during a **flood**
  - **Stage** - the elevation of the water
    - Flood stage – stream exceeds the bank height
  - **Crest** – maximum stage is reached
  - **Upstream flood** –occurs in a small, localized, upper part of a basin
  - **Downstream flood** – occurs in a larger, lower part of a drainage basin
  - Flash flood – type of upstream flood characterized by a rapid rise of stream stage

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January River Erosion

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March 1965 River Erosion

B

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Flood Damage in Big Thompson Canyon

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Flood Damage at Fort Collins

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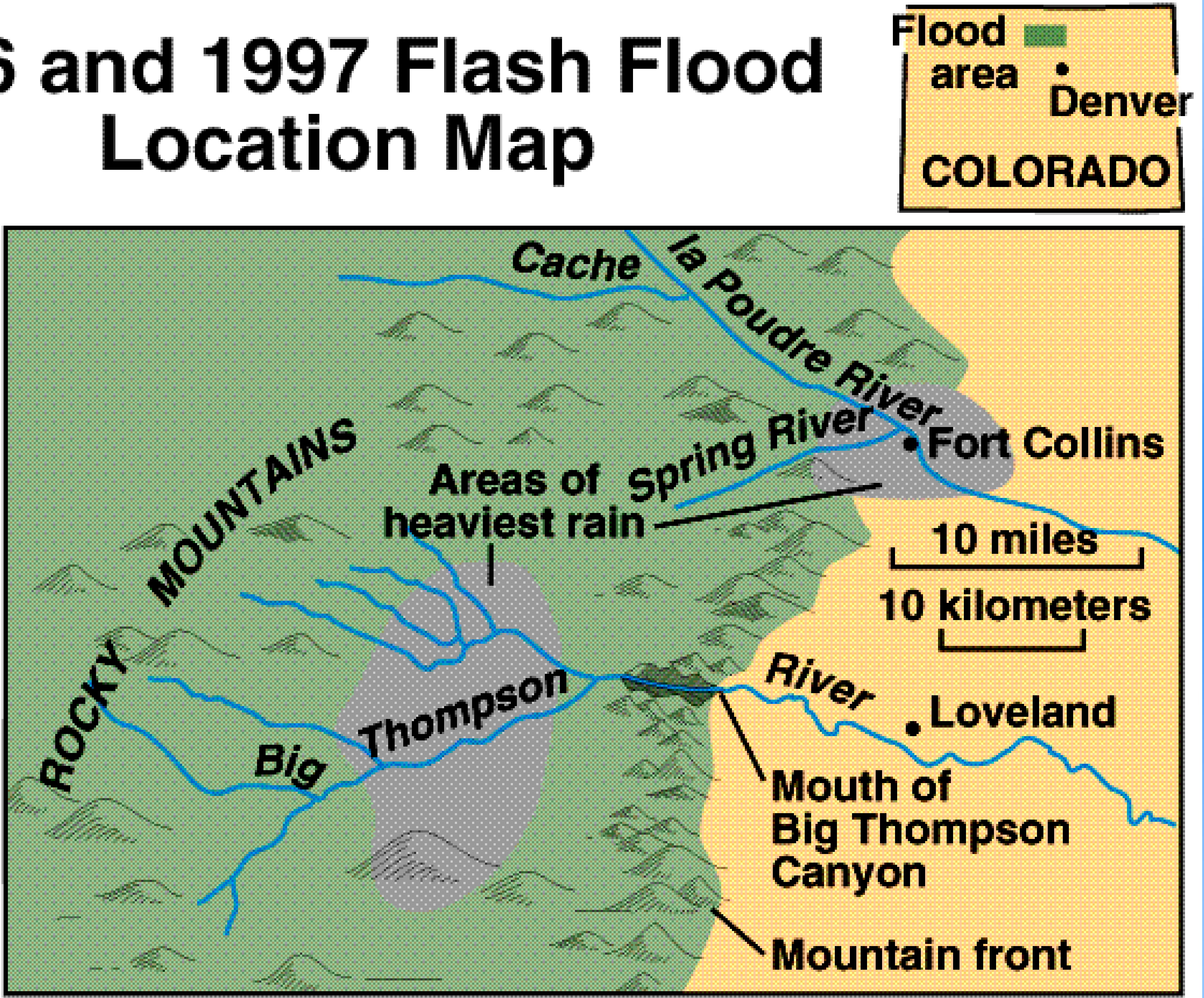
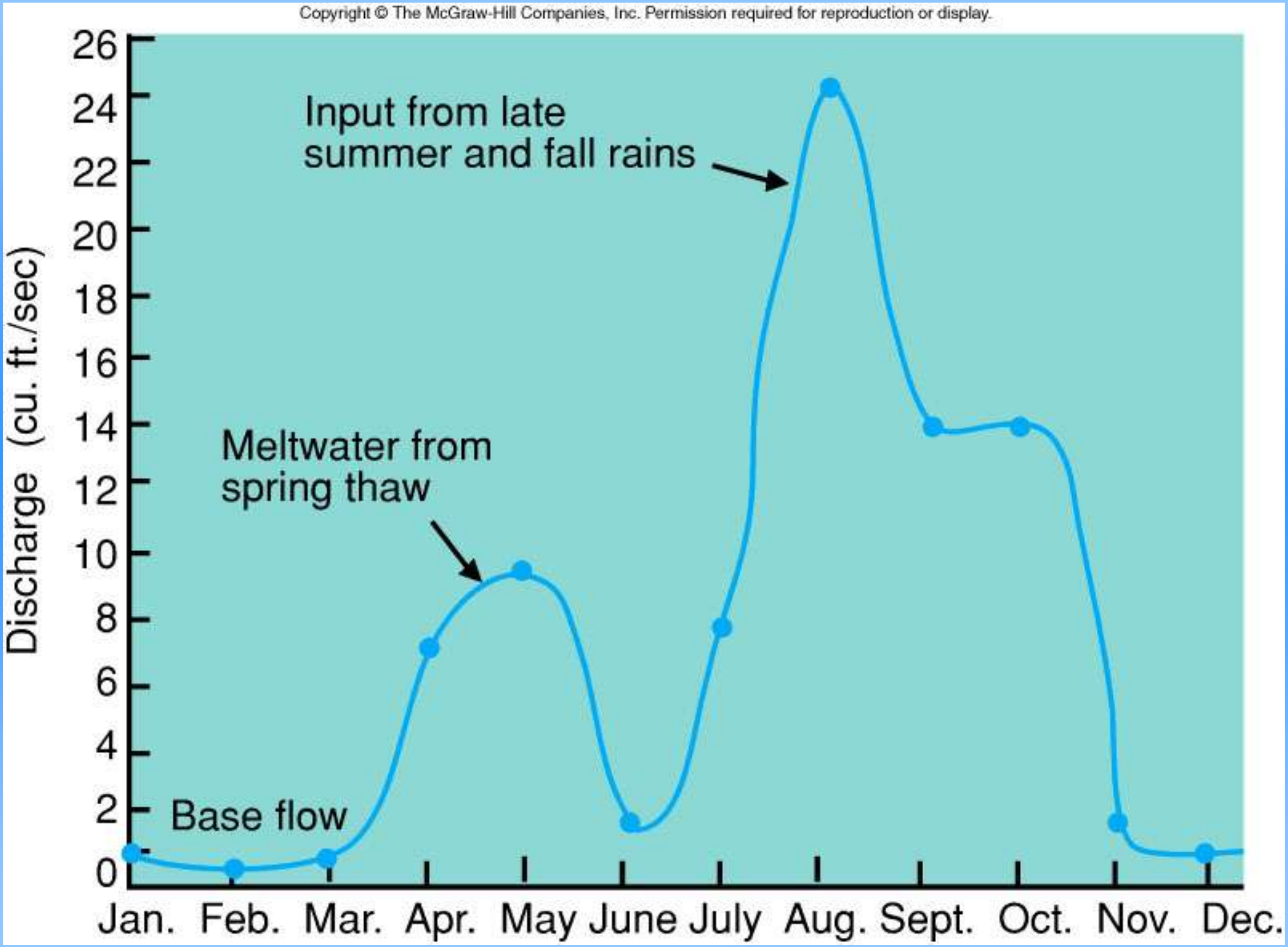
1976 and 1997 Flash Flood Location Map



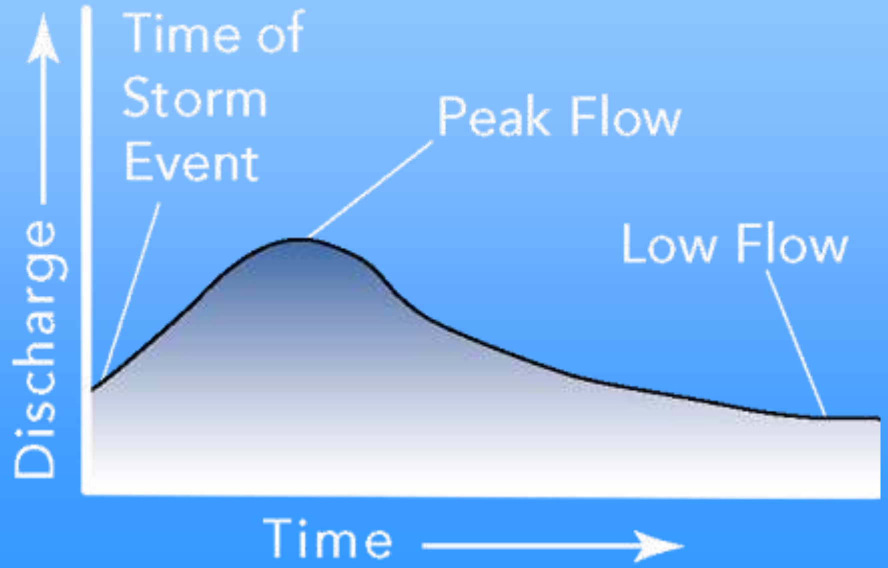
Stream **Hydrograph**

- **Hydrograph** – a plot of stream discharge at a point over time
  - Records fluctuations in discharge or stream height over time
  - Useful tool to monitor stream behavior remotely
- Hydrograph - plot discharge or stage on the vertical axis; plot time on the horizontal axis

Discharge = amount of water flow

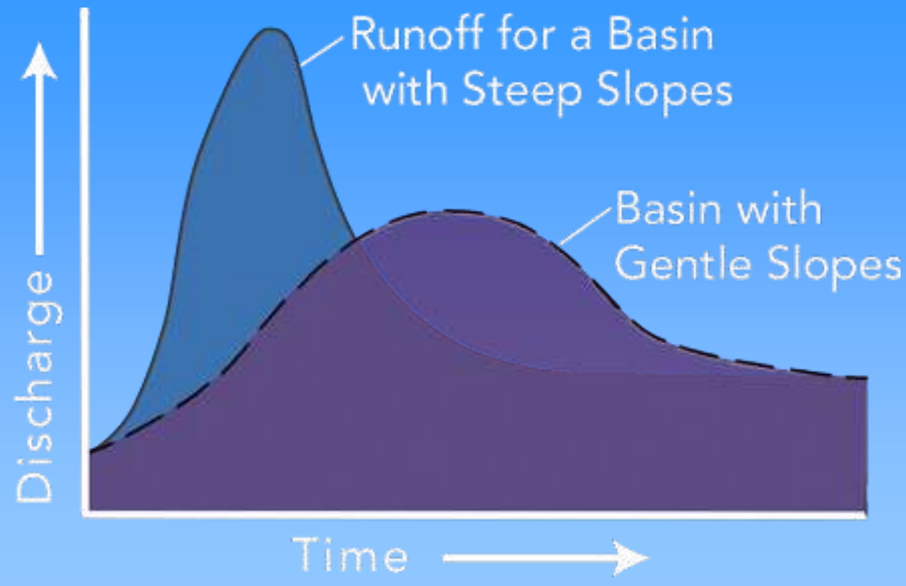


Volume of Flow Versus Time



Plot of discharge versus time is a *hydrograph*

This hydrograph shows discharge (flow) increasing during a flood, then decreasing as flood ends



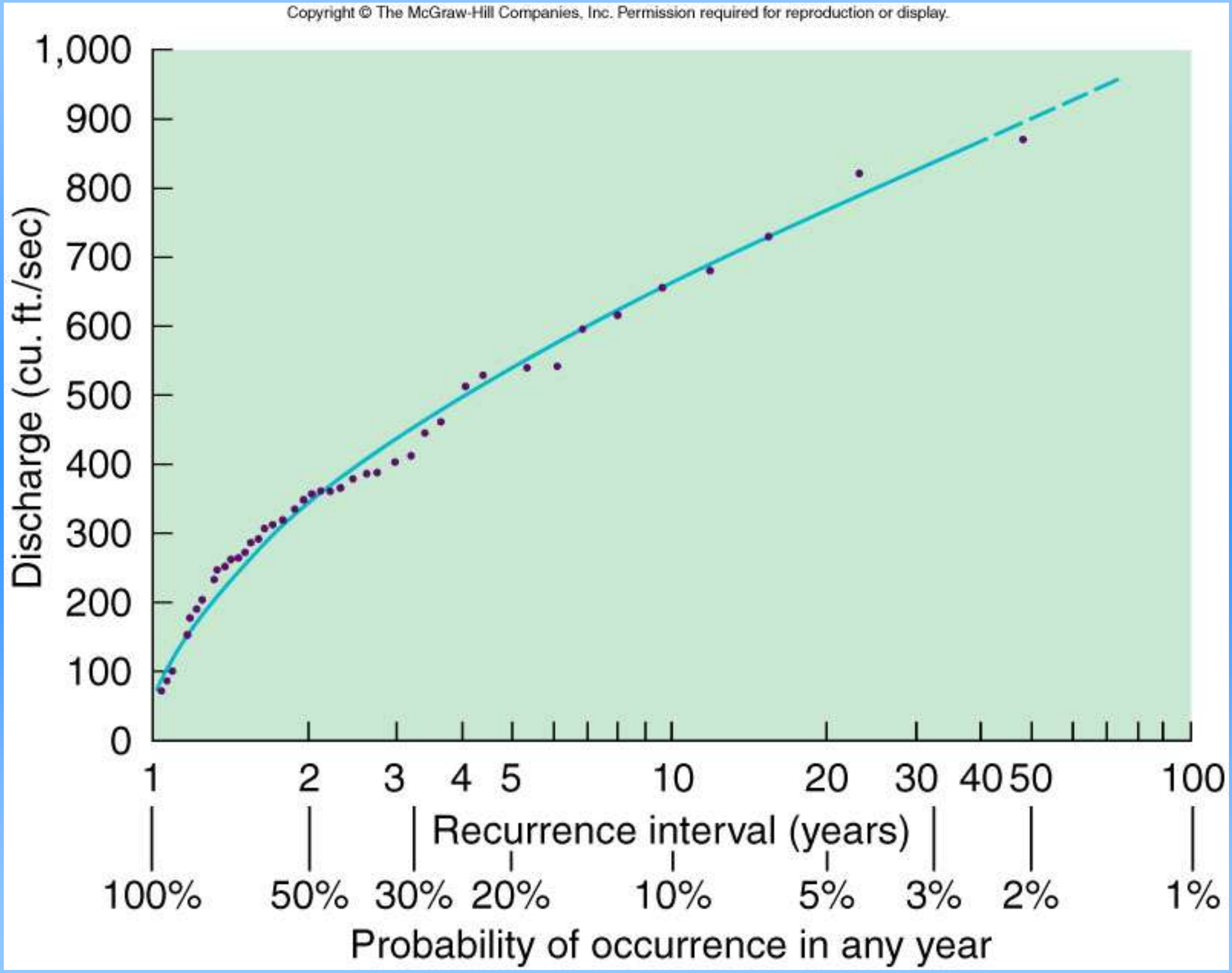
Runoff from steep drainage basin is fast and most water arrives downstream at once

Runoff from basin with gentle slopes is spread out over time; less peak flow

Flood-Frequency Curve

- Useful tool to evaluate frequency of flood events
- Long-term records very important to use of flood frequency curves – few long terms records exist
- Curve is constructed by plotting discharge as a function of **recurrence interval**
- A statistical tool only – probability information is possible
- $R = (N+1)/M$
  - R = recurrence interval
  - N = number of years
  - M = ranking of annual maxima

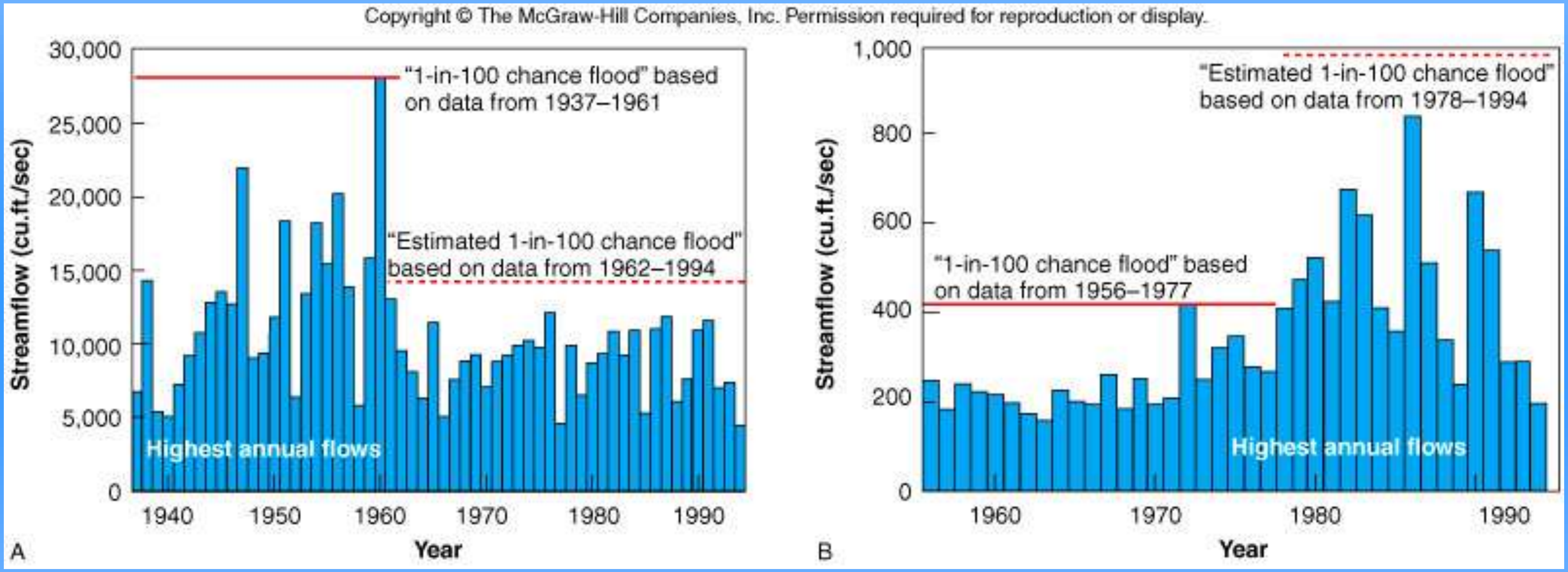
Flood probability



Development in a Floodplain

- Reasons for floodplain occupation
  - Ignorance of flood hazards
  - Inexpensive land and often extremely beautiful
- Effects of development on flood plain
  - Asphalt and concrete - reduce infiltration
  - Buildings - replace water volume, raises stream height
  - Filling in floodplain land - reduces volume
  - Storm drains - rapid delivery of storm water to streams causing increase in stream height
  - Vegetation loss - farm lands and urban areas remove natural vegetation and expose the soil
    - Streams can “silt up”
    - Silt reduces a streams capacity to rapidly carry water away

Figure 6.19



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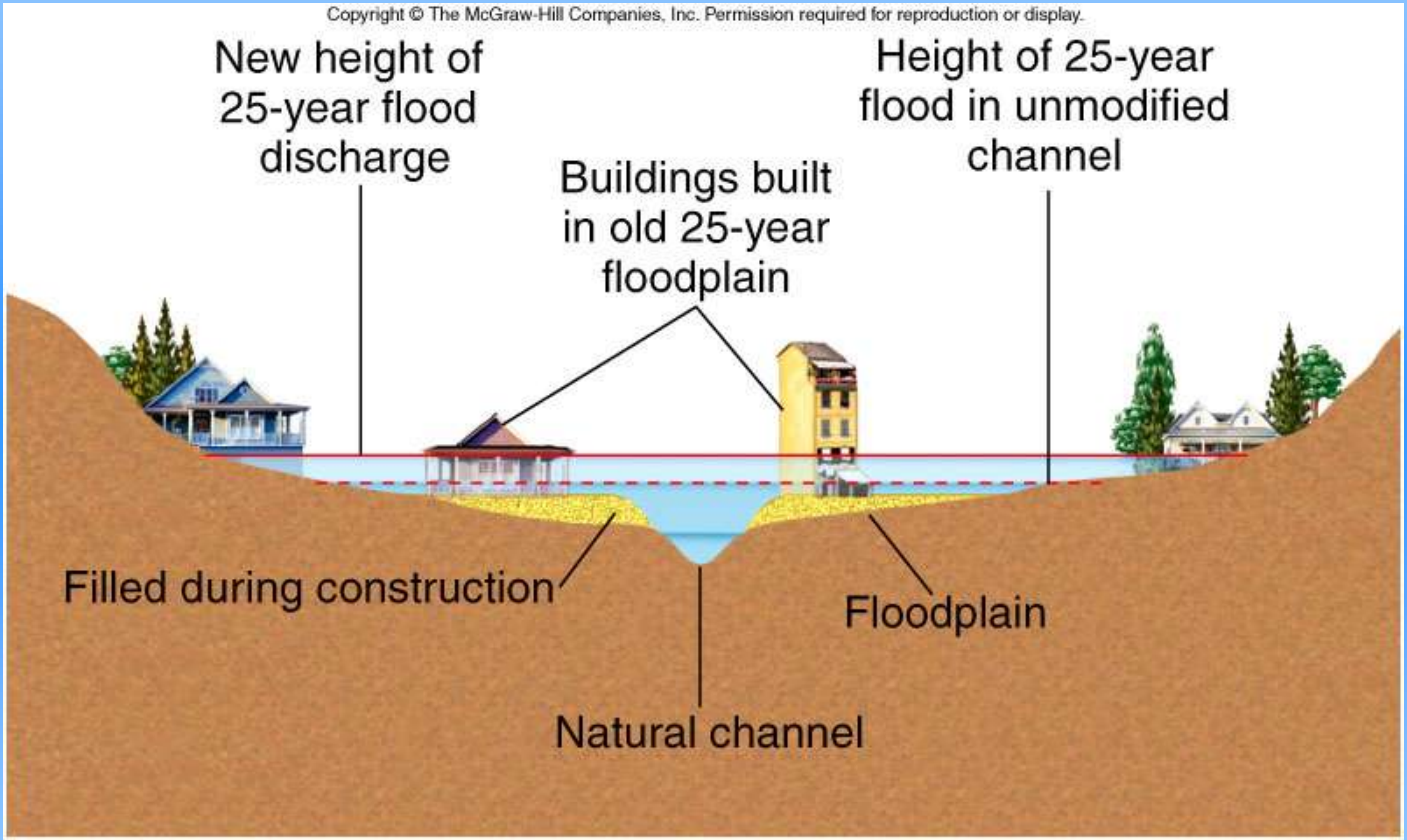
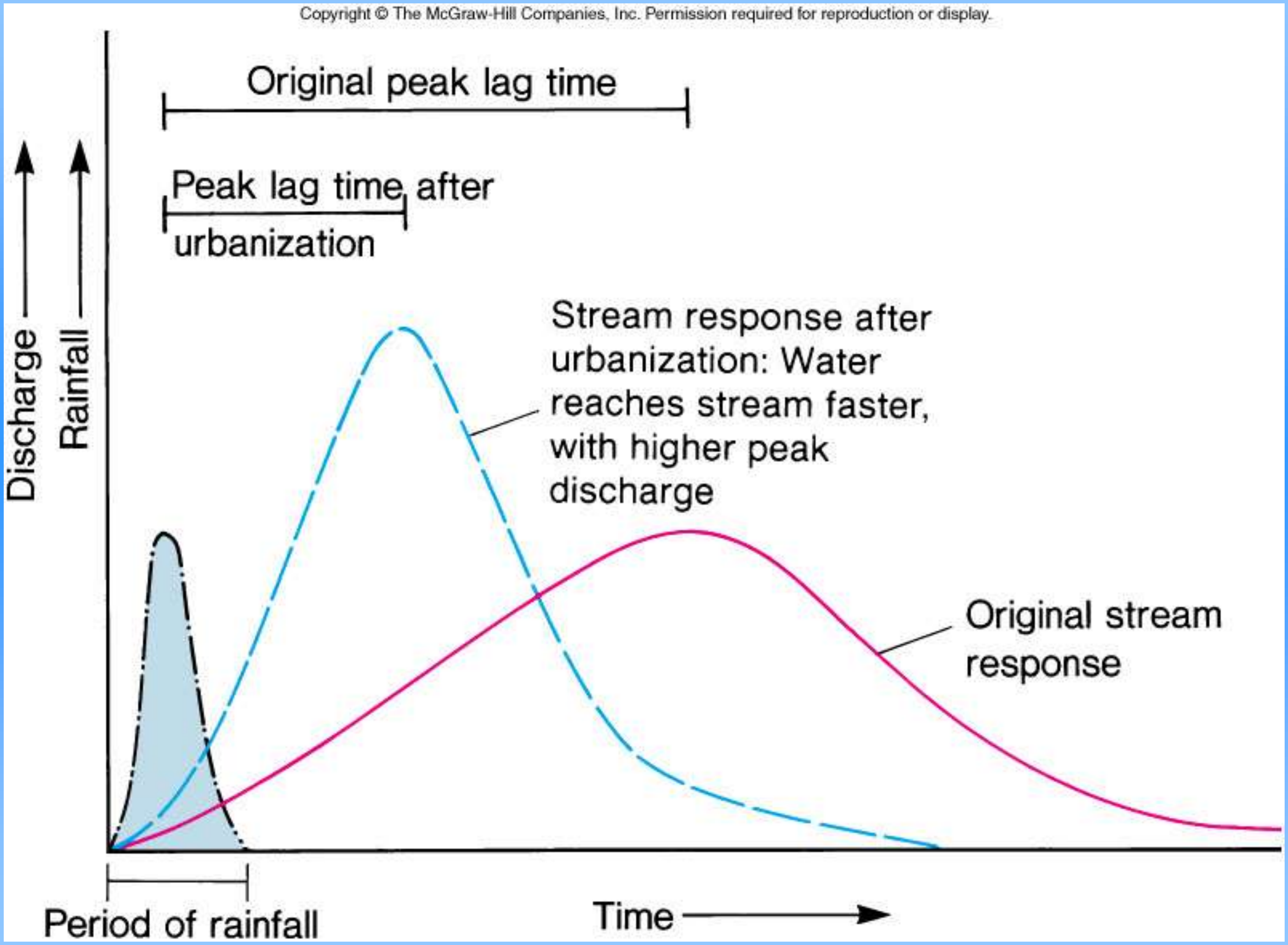
30,000
25,000
20,000
15,000
10,000
5,000
0
Streamflow (cu.ft./sec)
"1-in-100 chance flood" based on data from 1937–1961
"Estimated 1-in-100 chance flood" based on data from 1962–1994
Highest annual flows
1940
1950
1960
1970
1980
1990
Year
A
1,000
800
600
400
200
0
Streamflow (cu.ft./sec)
"Estimated 1-in-100 chance flood" based on data from 1978–1994
"1-in-100 chance flood" based on data from 1956–1977
Highest annual flows
1960
1970
1980
1990
Year
B

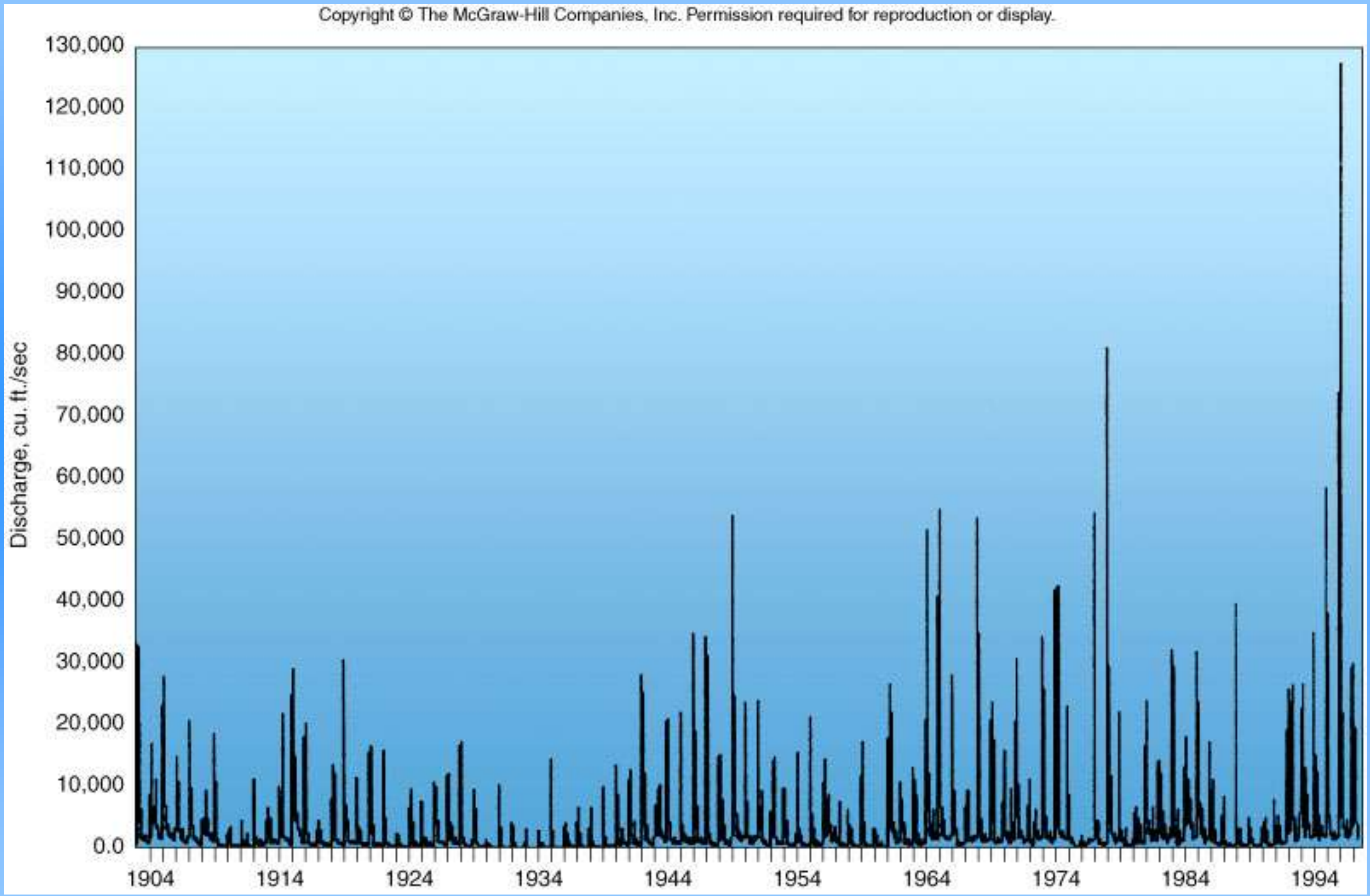
floodplains



Effect of urbanization on flooding



Variation in river discharge by year



Flood Hazard Reduction Strategies

- **Restrictive Zoning**, similar to strategies applicable to reducing damage from seismic and other geologic hazards
- **Retention Pond,** trap some of the surface water runoff
- **Diversion Channel,** comes into play as stream stage rises, and redirects some of the water flow into other safe places
- **Channelization,** various modifications of the stream channel itself to increase the velocity of water flow, the volume of the channel, or both
- **Levees,** raised banks along a stream channel
- Flood Control Dams and Reservoirs

Figures 6.22 a and b

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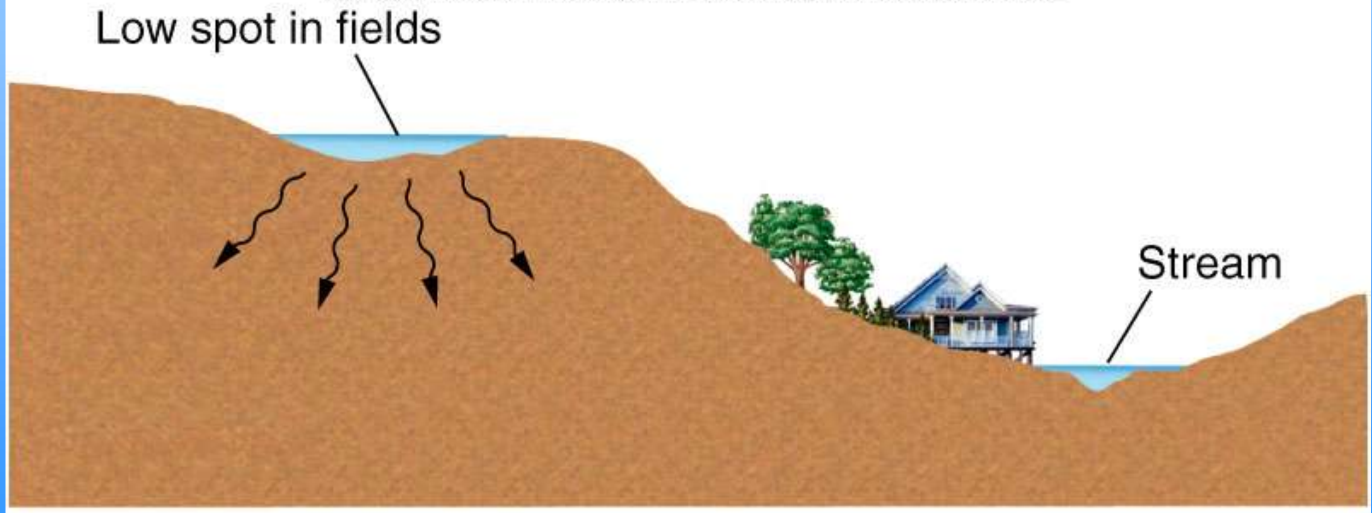
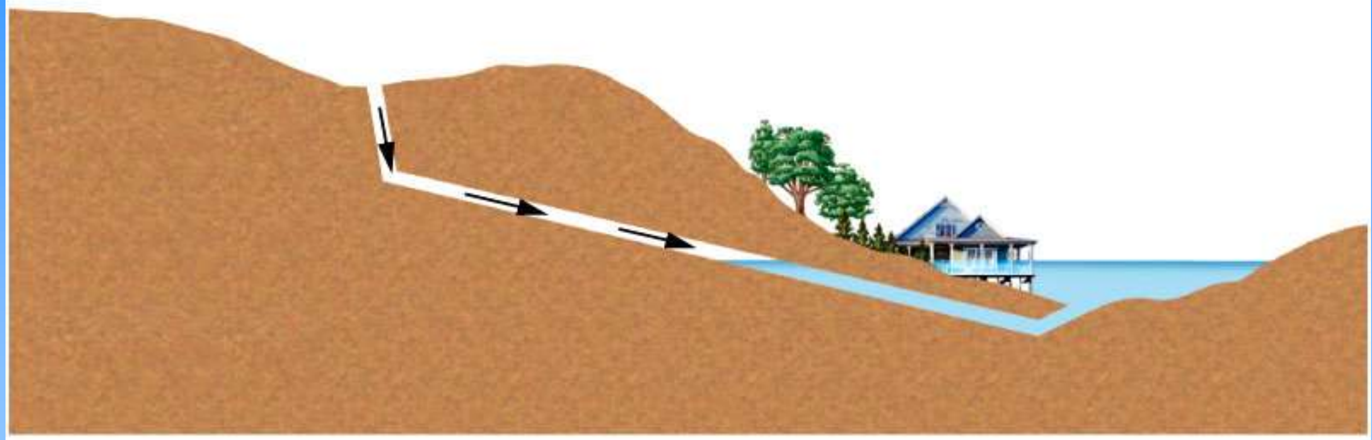


A



B

Figure 6.24

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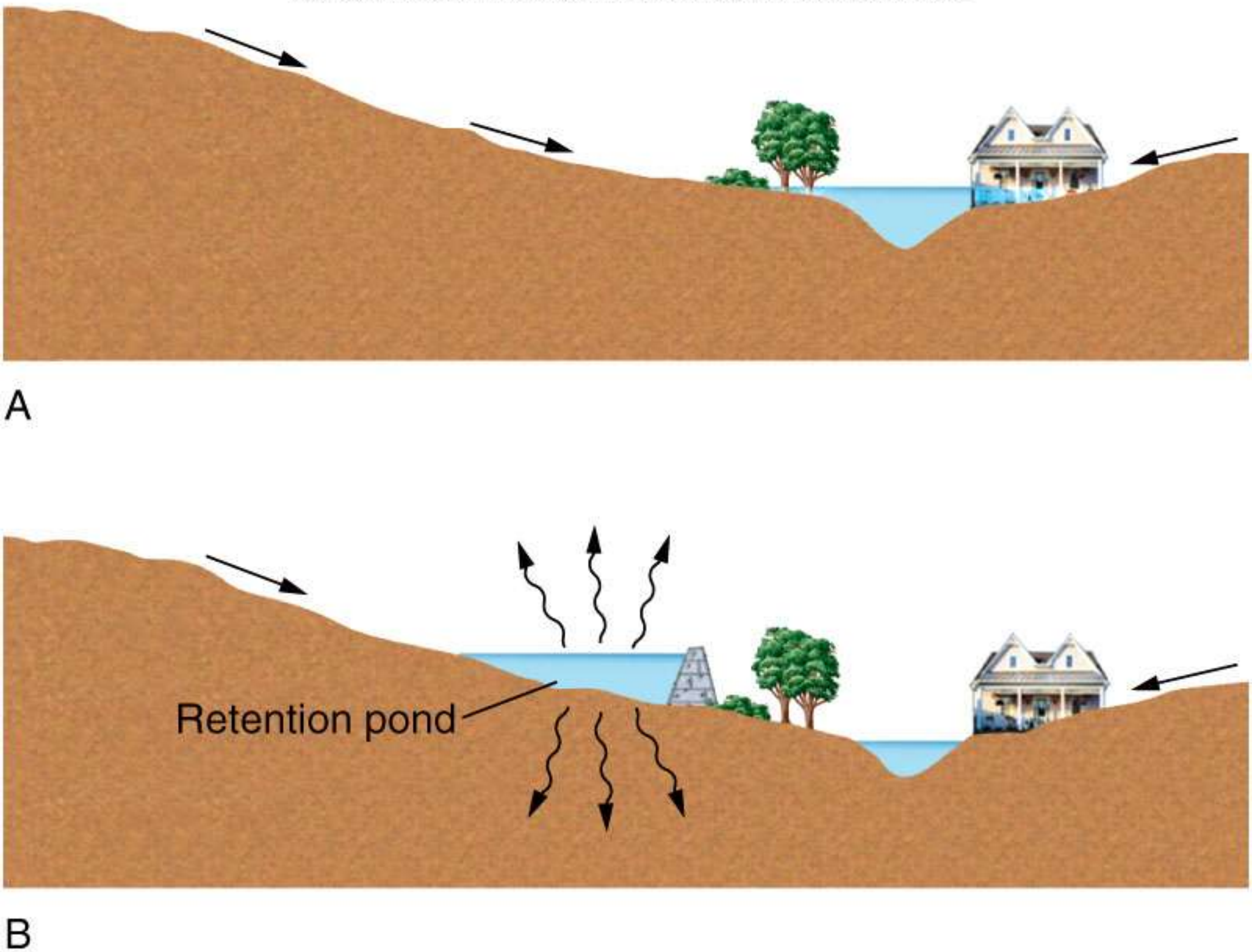
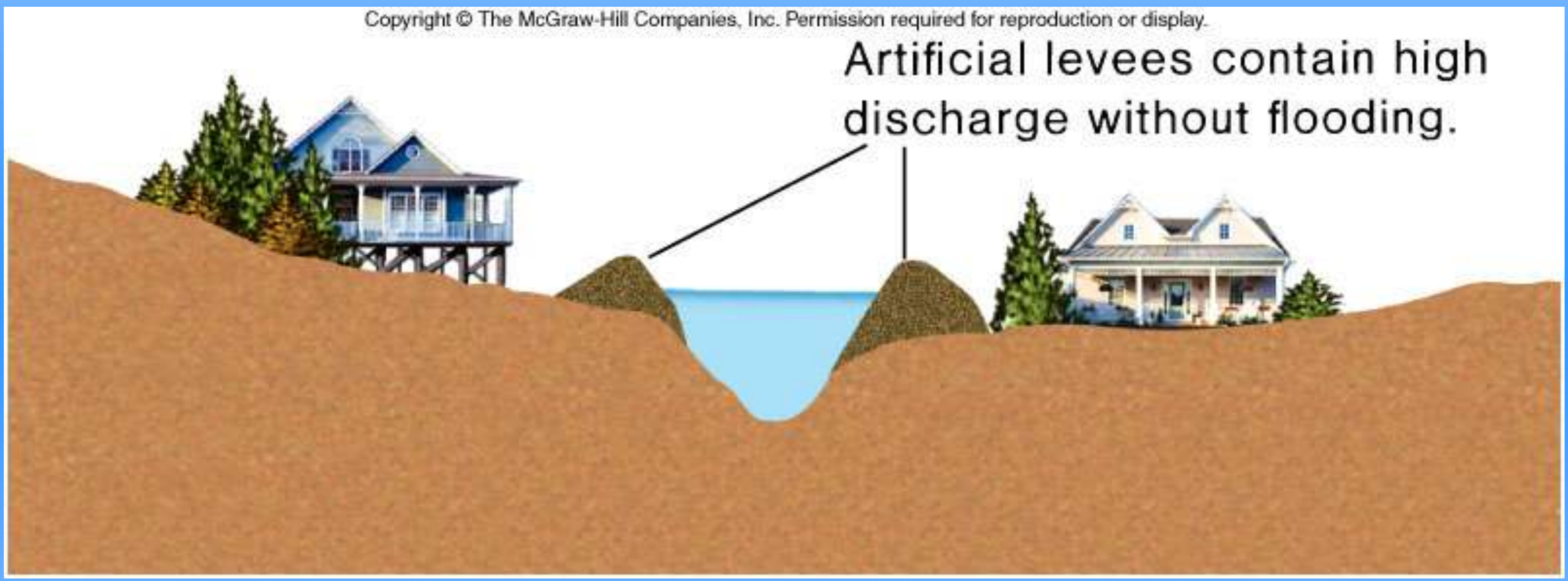


Figure 6.25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Artificial levees contain high discharge without flooding.

Figures 6.26 a and b

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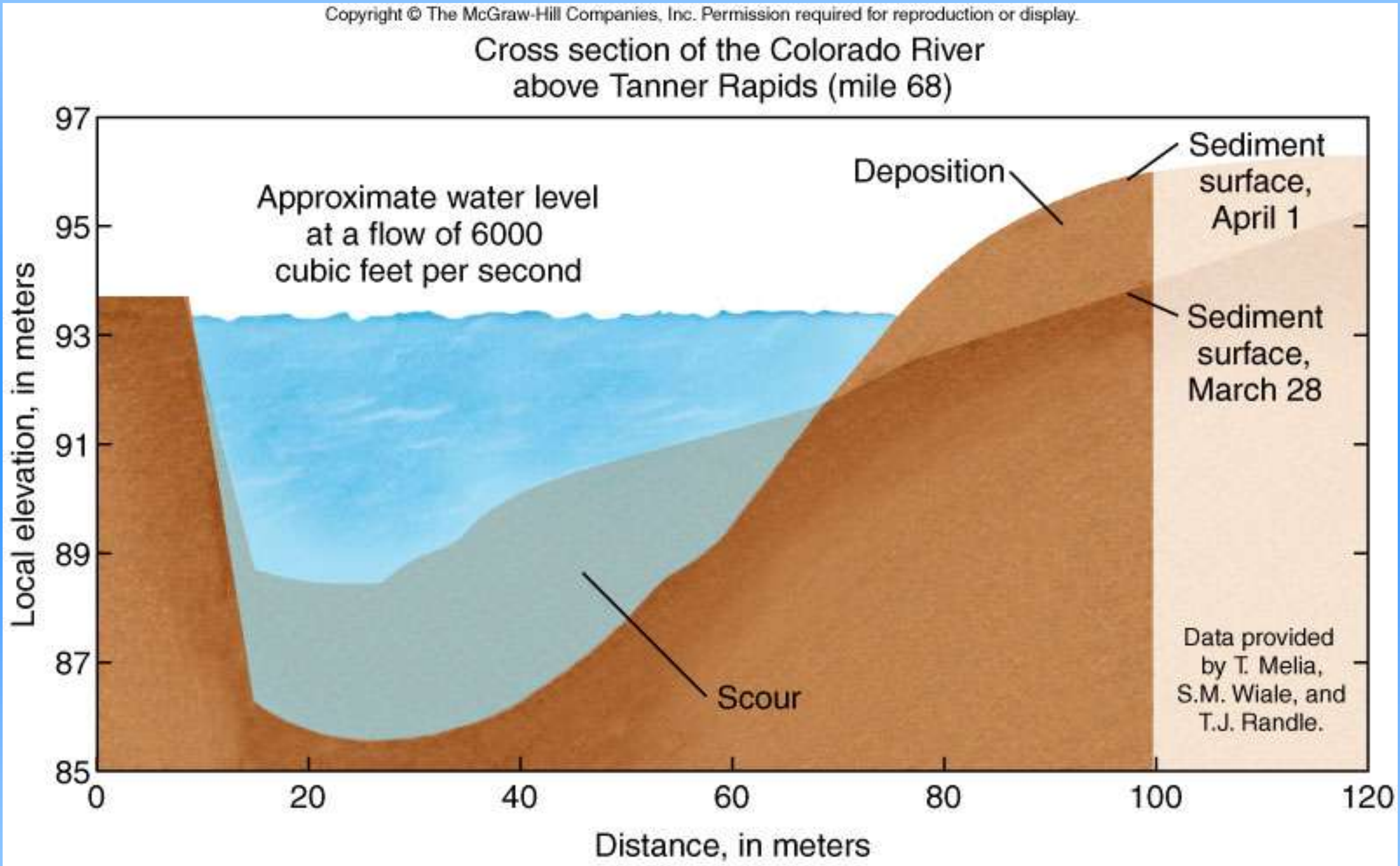
Figure 6.28



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Cross section of the Colorado River
above Tanner Rapids (mile 68)
Approximate water level
at a flow of 6000
cubic feet per second
Deposition
Sediment
surface,
April 1
Sediment
surface,
March 28
Scour
Data provided
by T. Melia,
S.M. Wiale, and
T.J. Randle.
Local elevation, in meters
97
95
93
91
89
87
85
0
20
40
60
80
100
120
Distance, in meters

Major Floods

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TABLE 6.2

Significant Floods of the Twentieth Century

Flood Type	Map No.	Date	Area or Stream with Flooding	Reported Deaths	Approximate Cost (uninflated)*	Comments
Regional flood	1	Mar.–Apr. 1913	Ohio, statewide	467	$143M	Excessive regional rain.
	2	Apr.–May 1927	Mississippi River from Missouri to Louisiana	unknown	$230M	Record discharge downstream from Cairo, Illinois.
	3	Mar. 1936	New England	150+	$300M	Excessive rainfall on snow.
	4	July 1951	Kansas and Neosho River Basins in Kansas	15	$800M	Excessive regional rain.
	5	Dec. 1964–Jan. 1965	Pacific Northwest	47	$430M	Excessive rainfall on snow.
	6	June 1965	South Platte and Arkansas Rivers in Colorado	24	$570M	14 inches of rain in a few hours in eastern Colorado.
	7	June 1972	Northeastern United States	117	$3.2B	Extratropical remnants of Hurricane Agnes.
	8	Apr.–June 1983 June 1983–1986	Shoreline of Great Salt Lake, Utah	unknown	$621M	In June 1986, the Great Salt Lake reached its highest elevation and caused $268M more in property damage.
	9	May 1983	Central and northeast Mississippi	1	$500M	Excessive regional rain.
	10	Nov. 1985	Shenandoah, James, and Roanoke Rivers in Virginia and West Virginia	69	$1.25B	Excessive regional rain.
	11	Apr. 1990	Trinity, Arkansas, and Red Rivers in Texas, Arkansas, and Oklahoma	17	$1B	Recurring intense thunderstorms.
	12	Jan. 1993	Gila, Salt, and Santa Cruz Rivers in Arizona	unknown	$400M	Persistent winter precipitation.
	13	May–Sept. 1993	Mississippi River Basin in central United States	48	$20B	Long period of excessive rainfall.
	14	May 1995	South-central United States	32	$5–6B	Rain from recurring thunderstorms.
	15	Jan.–Mar. 1995	California	27	$3B	Frequent winter storms.
	16	Feb. 1996	Pacific Northwest and western Montana	9	$1B	Torrential rains and snowmelt.
	17	Dec. 1996–Jan. 1997	Pacific Northwest and Montana	36	$2–3B	Torrential rains and snowmelt.
	18	Mar. 1997	Ohio River and tributaries	50+	$500M	Slow moving frontal system.
	19	Apr.–May 1997	Red River of the North in North Dakota and Minnesota	8	$2B	Very rapid snowmelt.
	20	Sept. 1999	Eastern North Carolina	42	$6B	Slow-moving Hurricane Floyd.
Flash flood	21	June 14, 1903	Willow Creek in Oregon	225	unknown	City of Heppner, Oregon, destroyed.
	22	June 9–10, 1972	Rapid City, South Dakota	237	$160M	15 inches of rain in 5 hours.
	23	July 31, 1976	Big Thompson and Cache la Poudre Rivers in Colorado	144	$39M	Flash flood in canyon after excessive rainfall.
	24	July 19–20, 1977	Conemaugh River in Pennsylvania	78	$300M	12 inches of rain in 6–8 hours.
Ice-jam flood	25	May 1992	Yukon River in Alaska	0	unknown	100-year flood on Yukon River.
Storm-surge flood	26	Sept. 1900	Galveston, Texas	6,000+	unknown	Hurricane.
	27	Sept. 1938	Northeast United States	494	$306M	Hurricane.
	28	Aug. 1969	Gulf Coast, Mississippi and Louisiana	259	$1.4B	Hurricane Camille.
Dam-failure flood	29	Feb. 2, 1972	Buffalo Creek in West Virginia	125	$60M	Dam failure after excessive rainfall.
	30	June 5, 1976	Teton River in Idaho	11	$400M	Earthen dam breached.
	31	Nov. 8, 1977	Toccoa Creek in Georgia	39	$2.8M	Dam failure after excessive rainfall.
Mudflow flood	32	May 18, 1980	Toutle and lower Cowlitz Rivers in Washington	60	unknown	Result of eruption of Mt. St. Helens.

After U.S. Geological Survey Fact Sheet 024-00.

*[M, million; B, billion]

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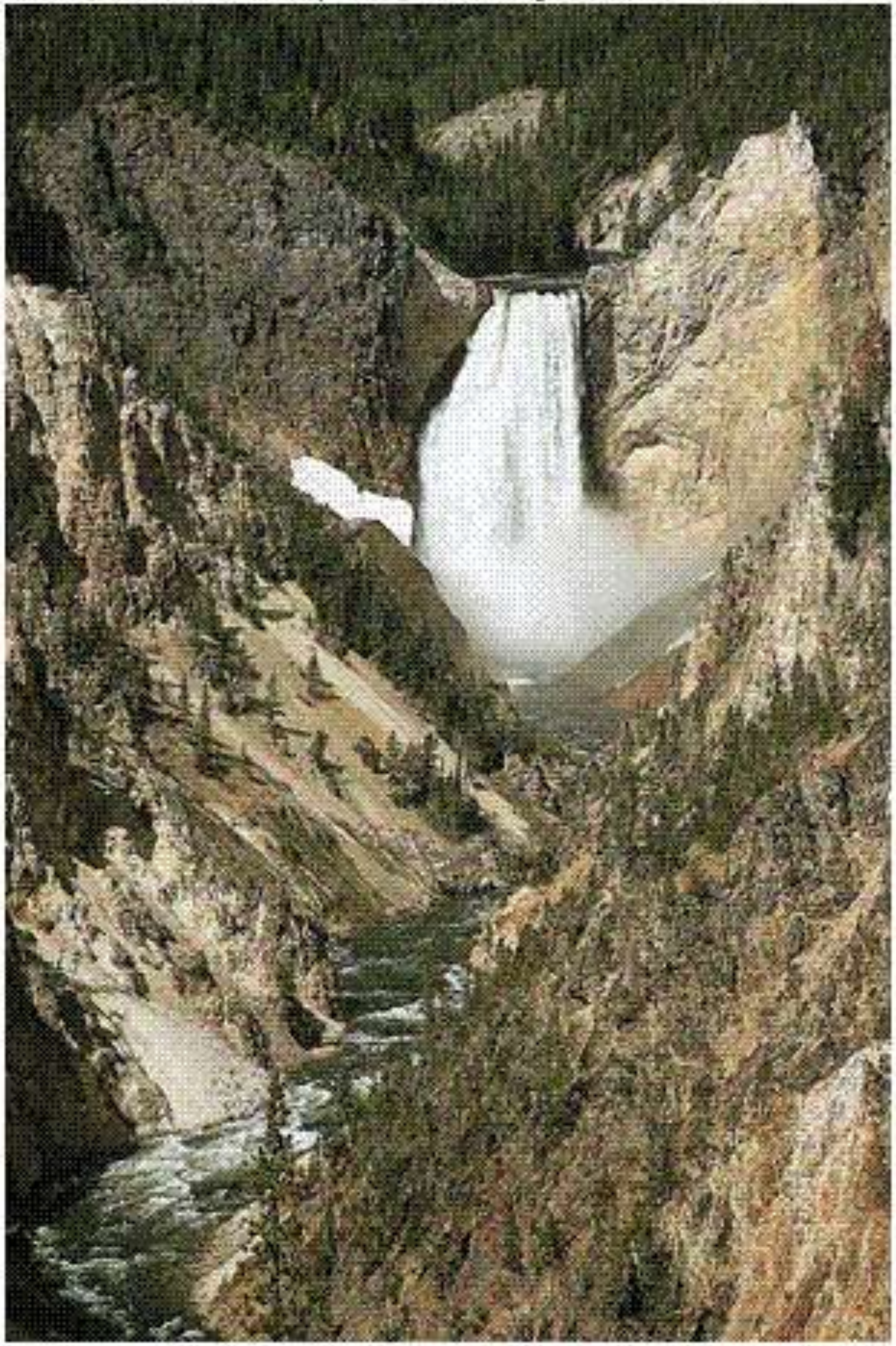
Yellowstone Waterfall and Rapids



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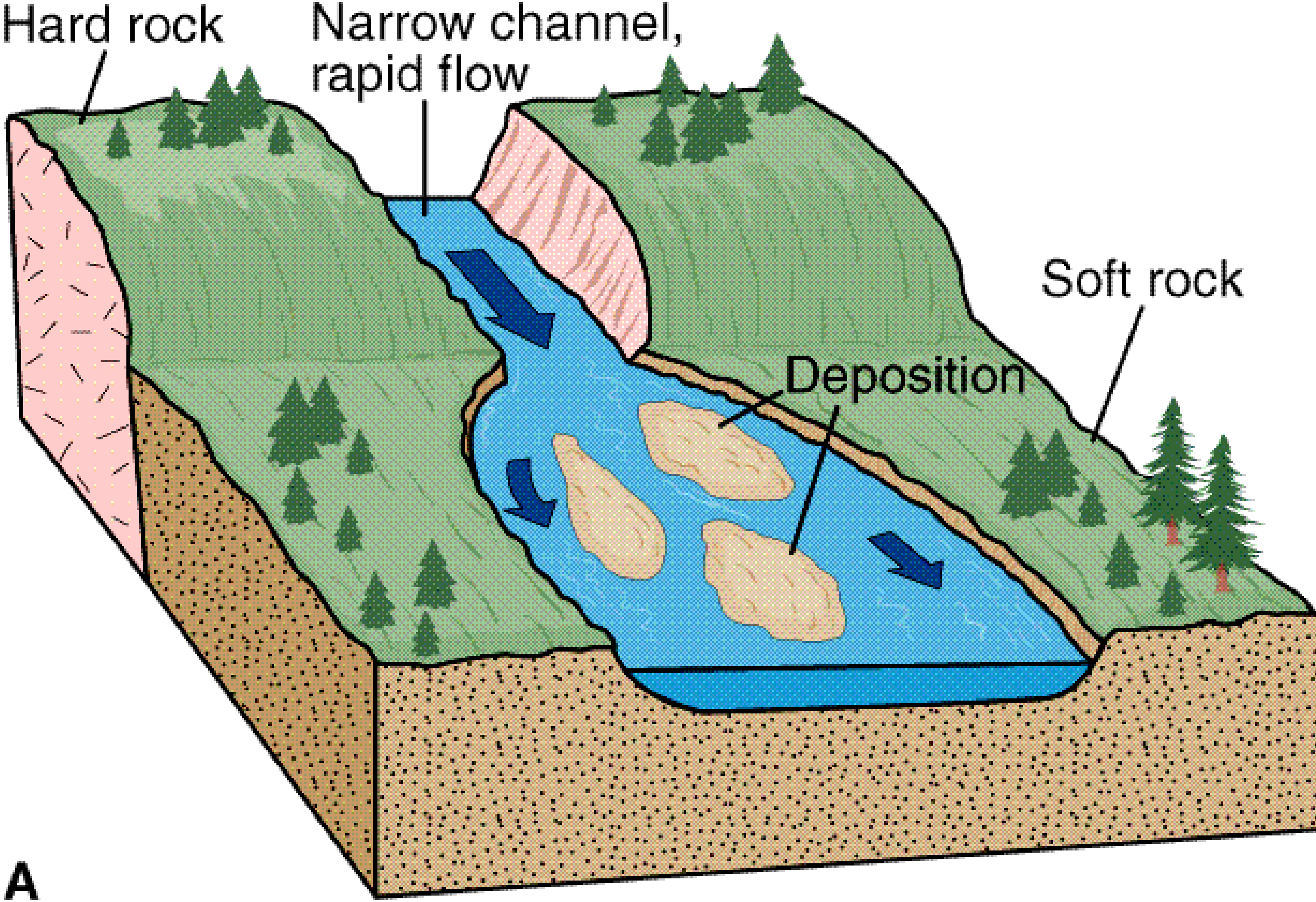
Channel Widens in Soft Rock



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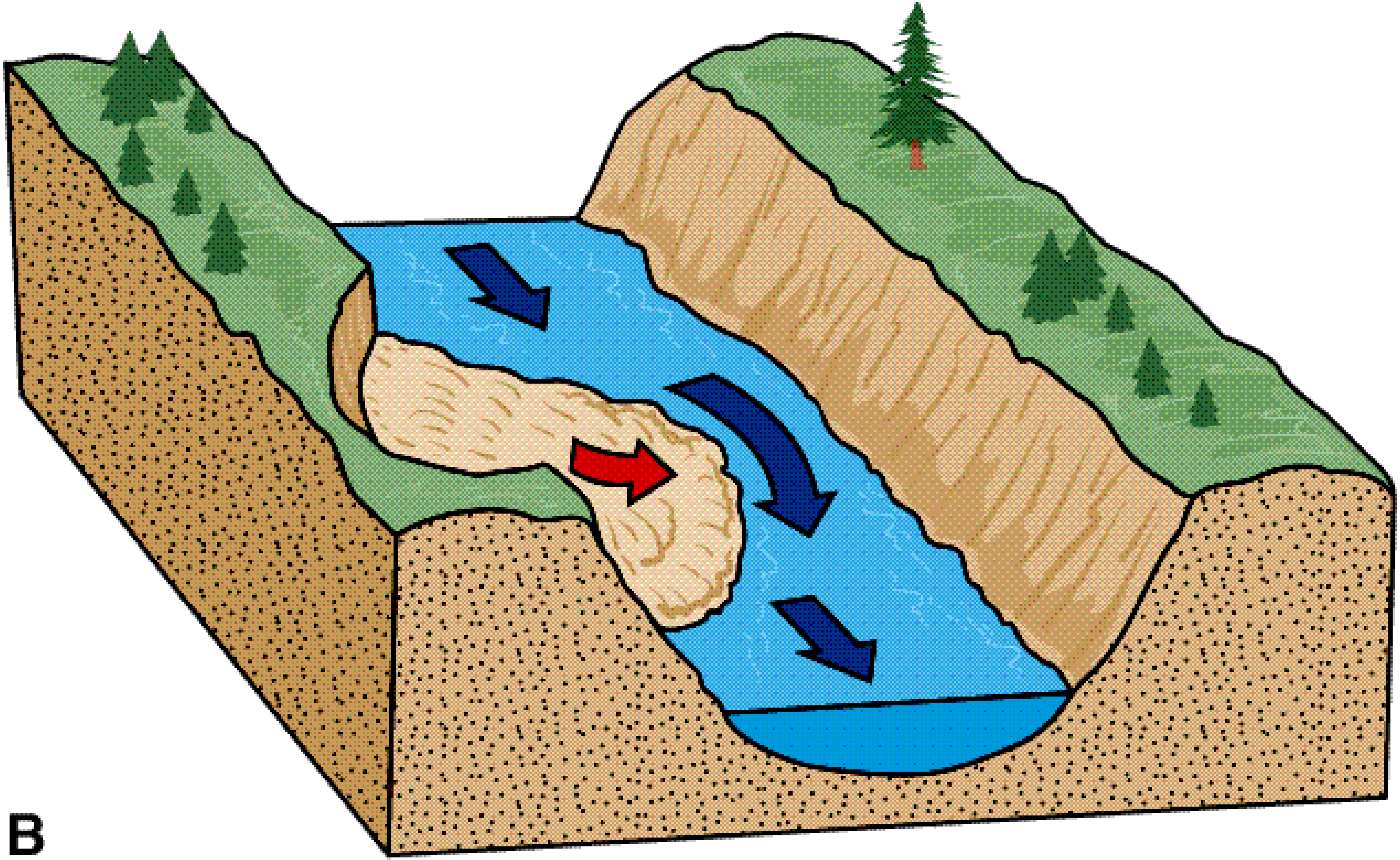
Landslide Narrows Channel



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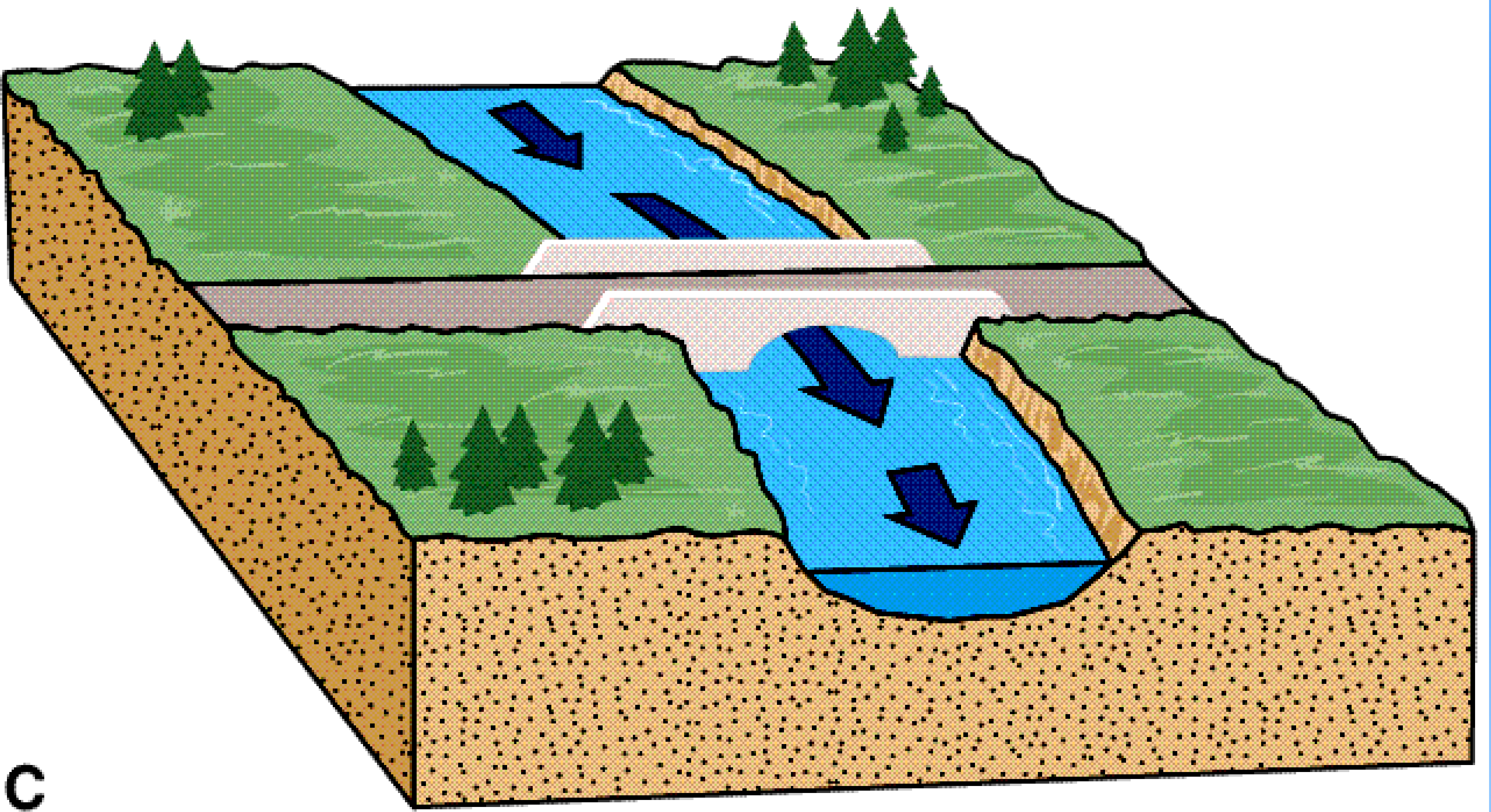
Bridge Piers Increase Velocity



C

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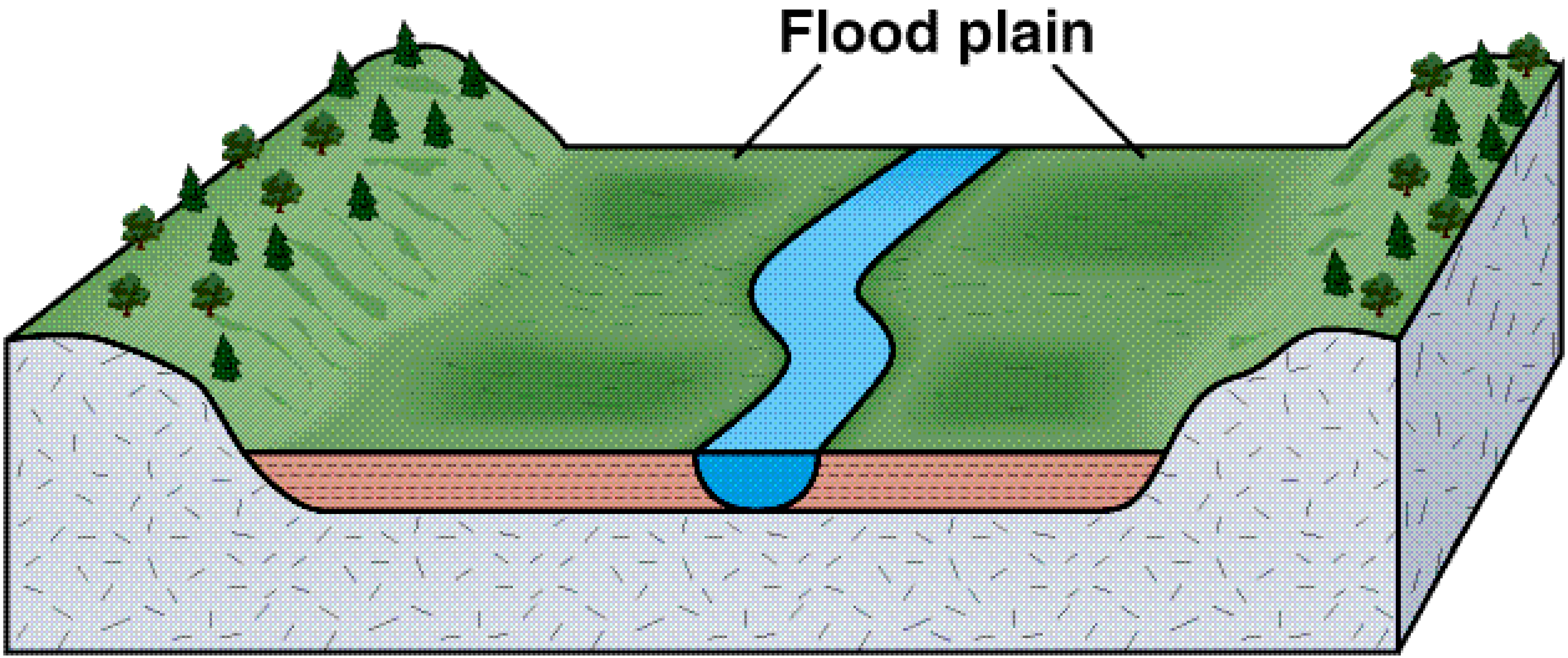
Natural Levee Deposition, Normal Flow



A

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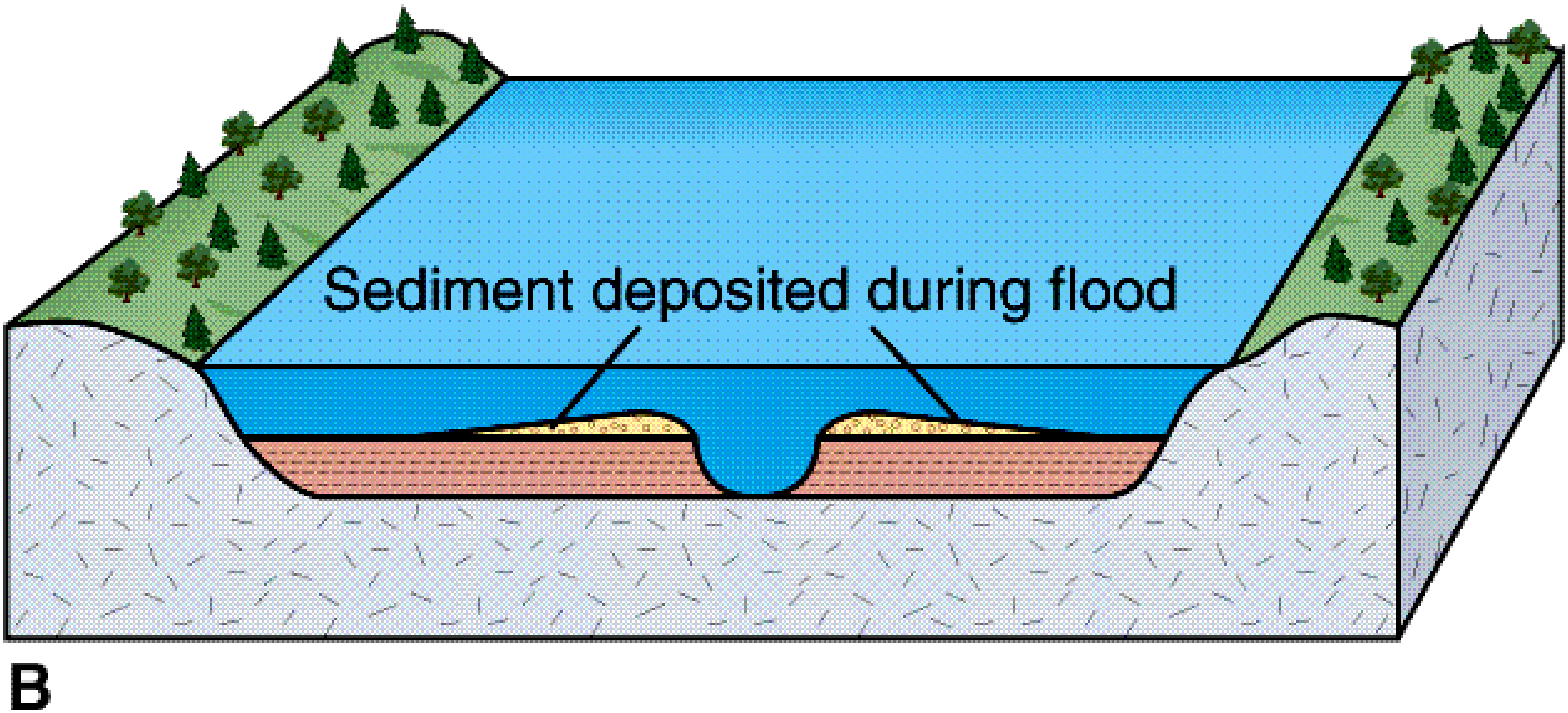
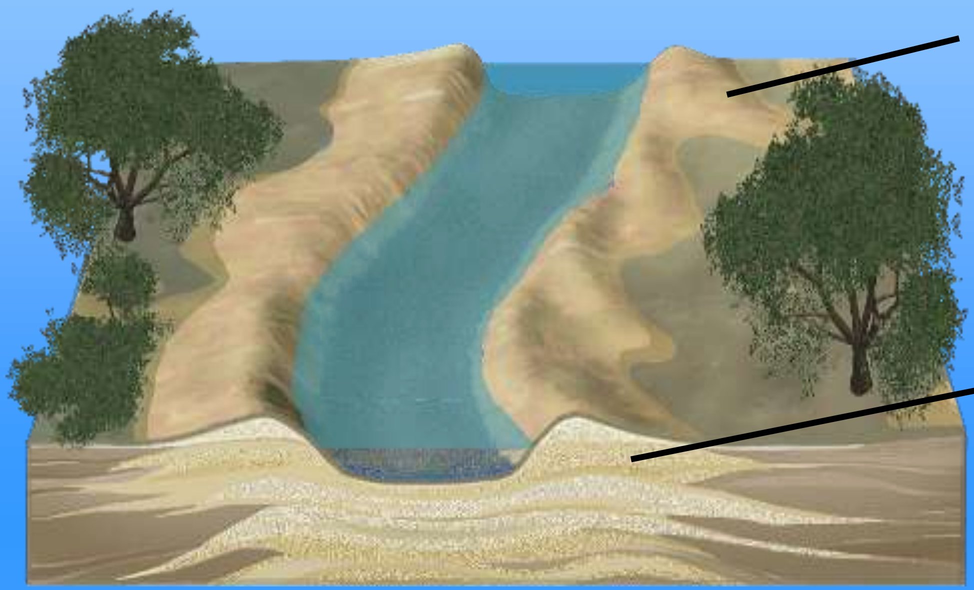
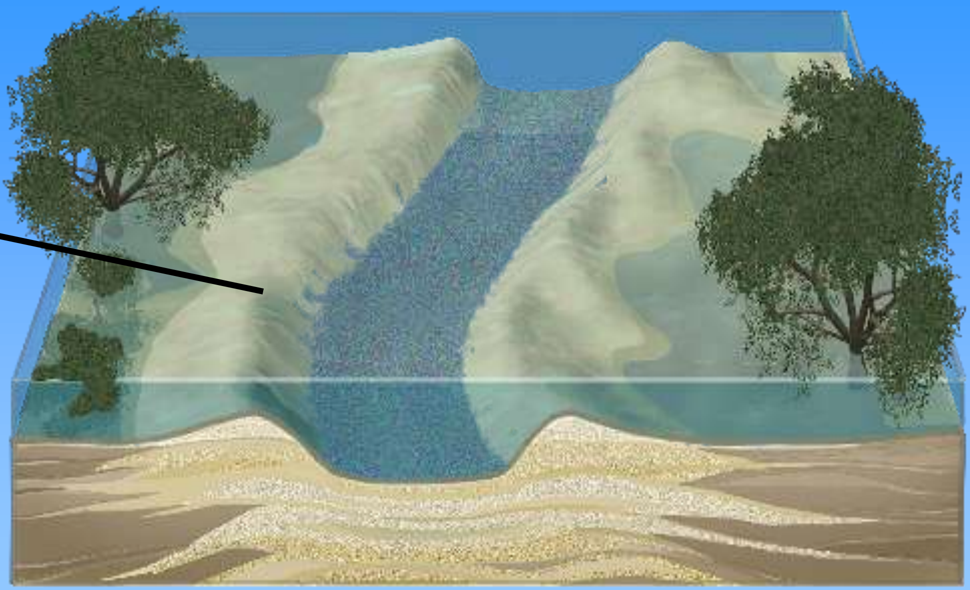
Natural Levee Deposition, Flood



How Do Levees Form?





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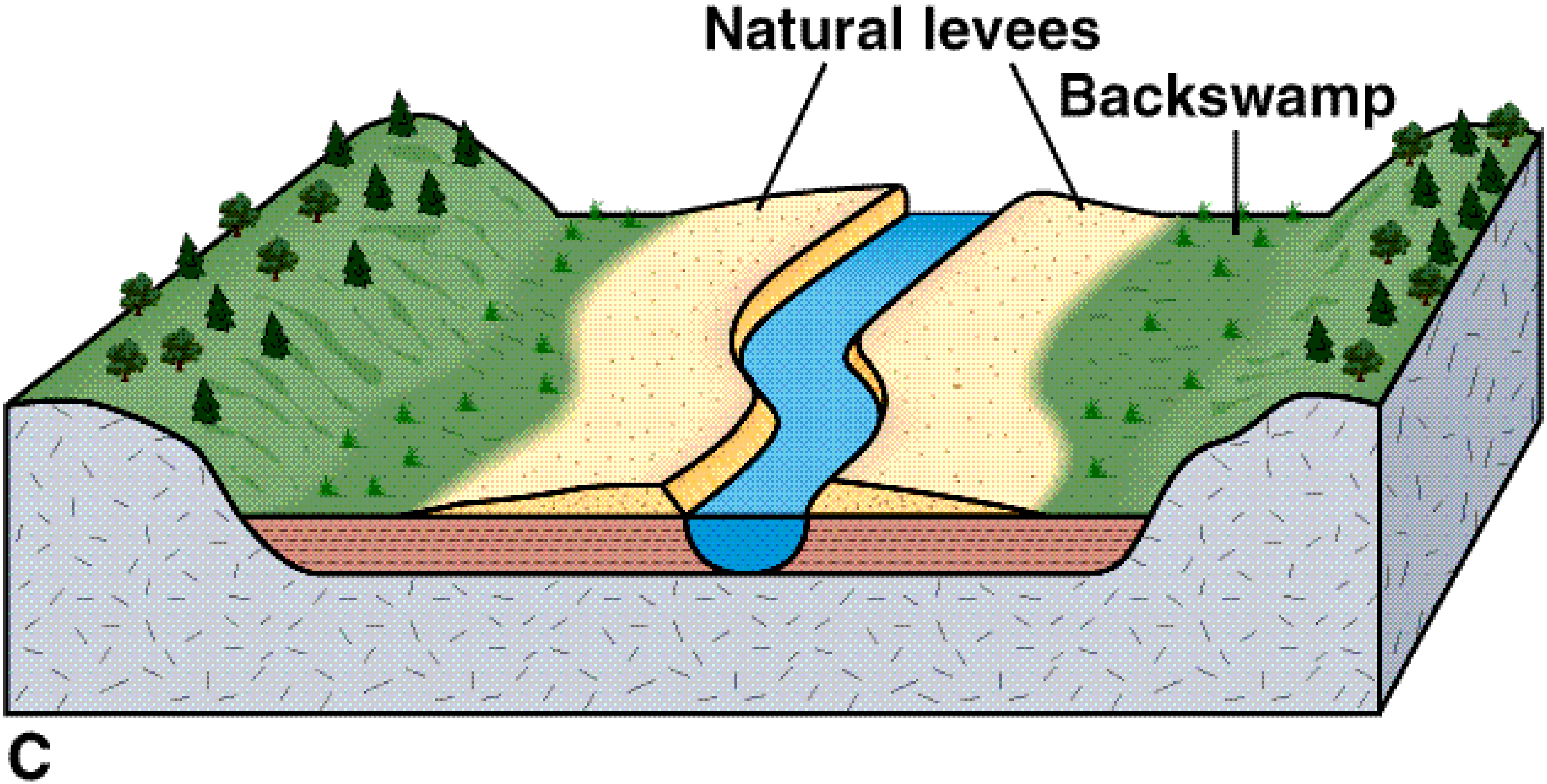
Natural Levee Deposition, after Flood



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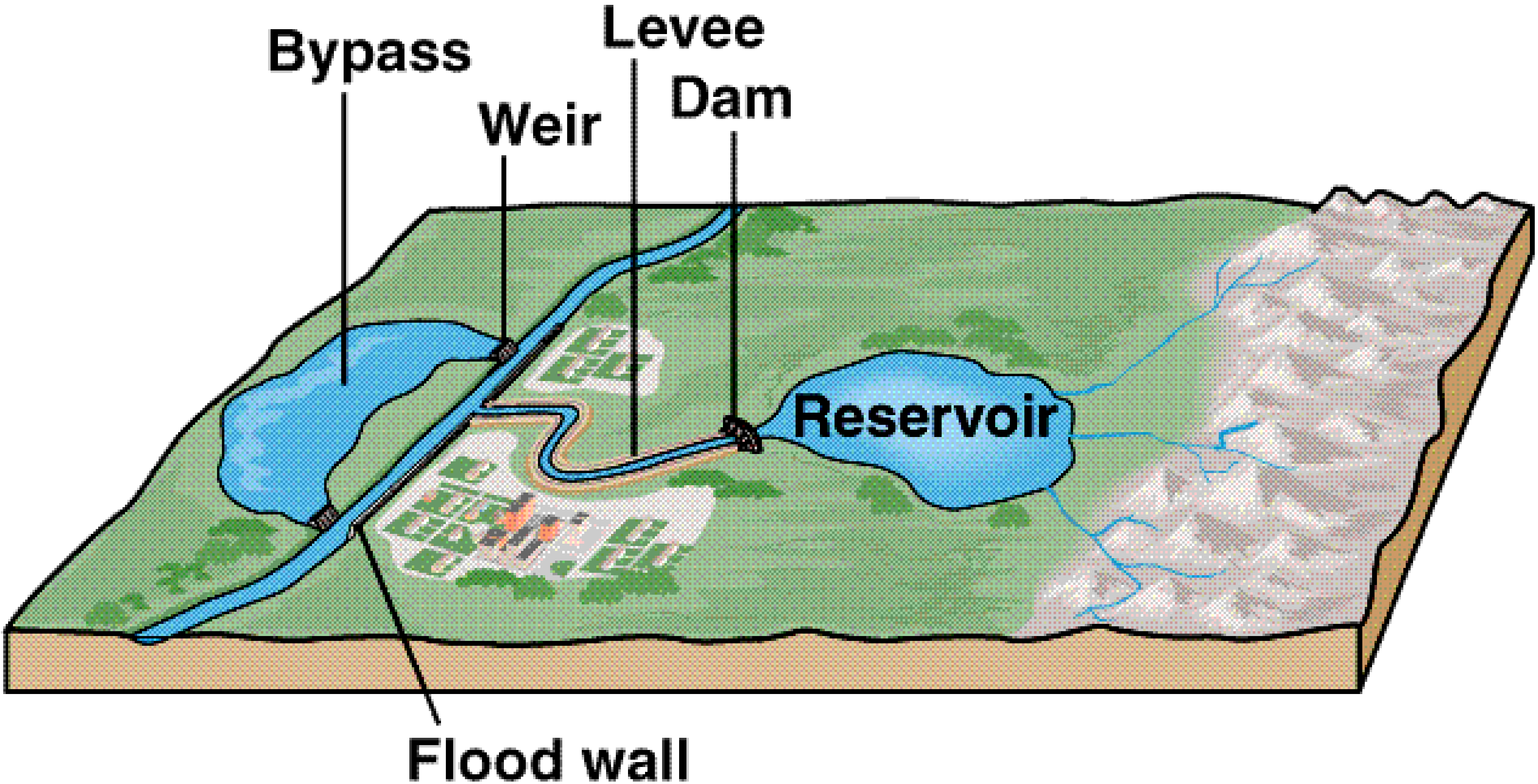
Flood Control Structures



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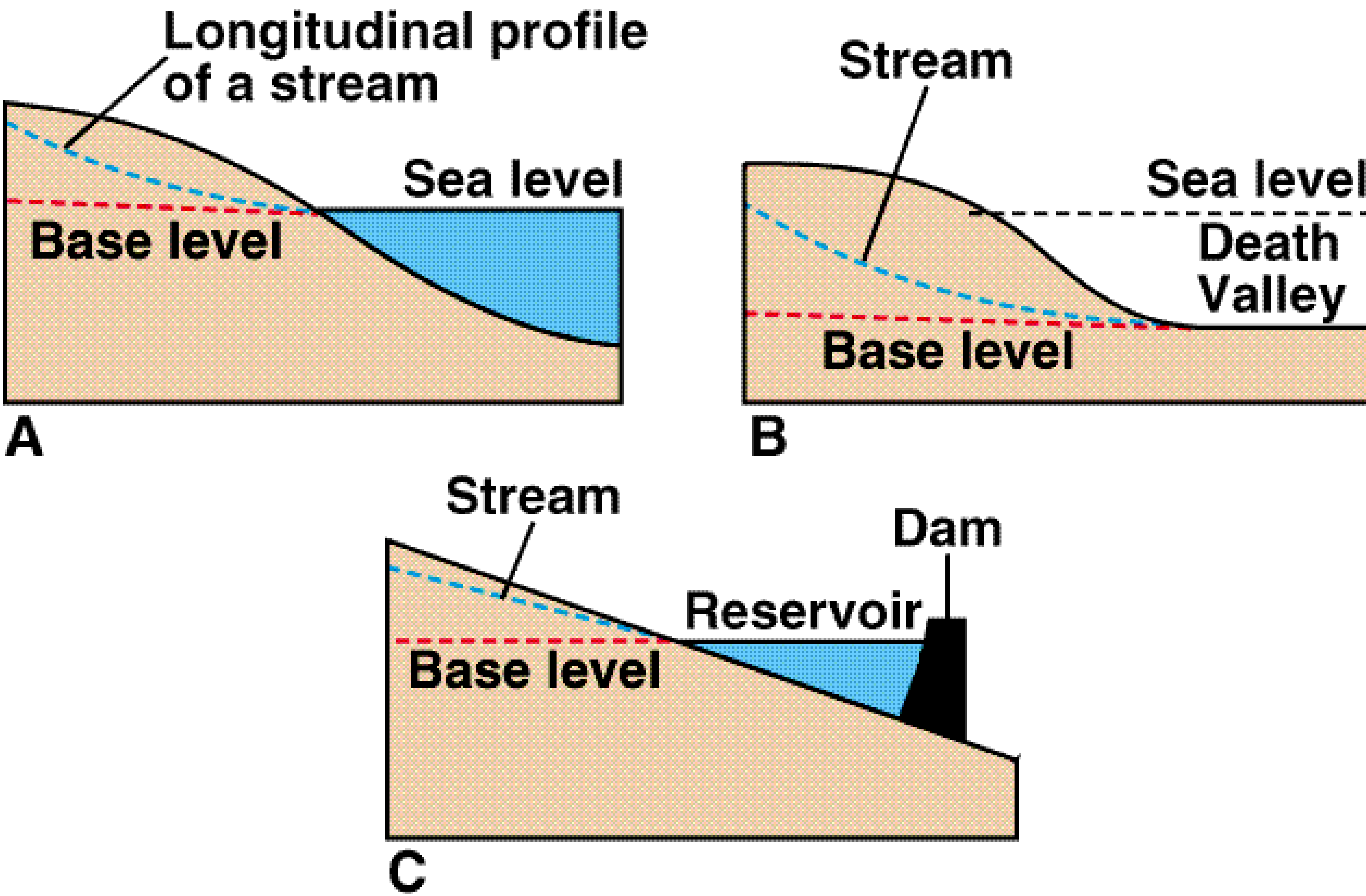
Downcutting



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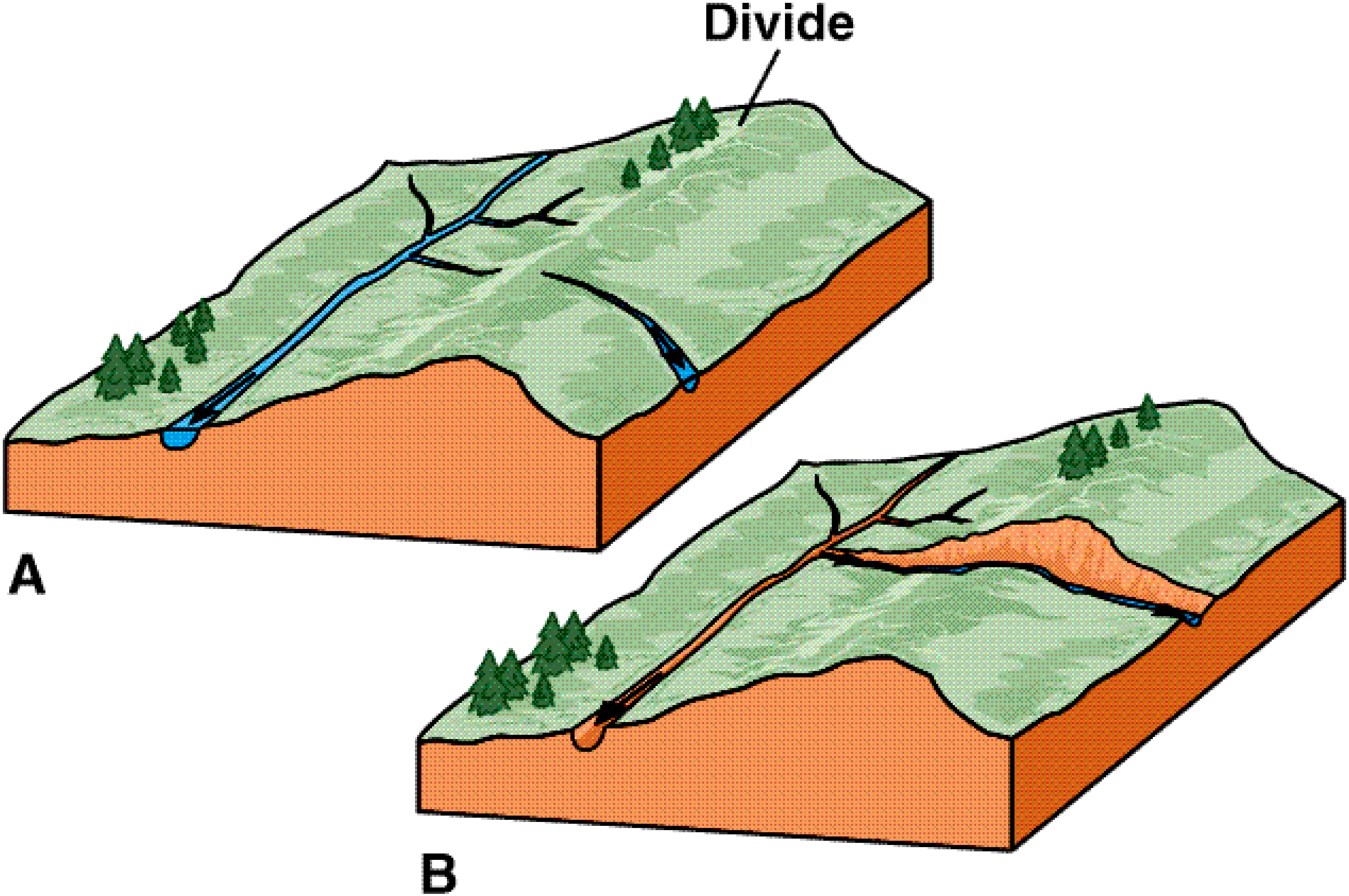
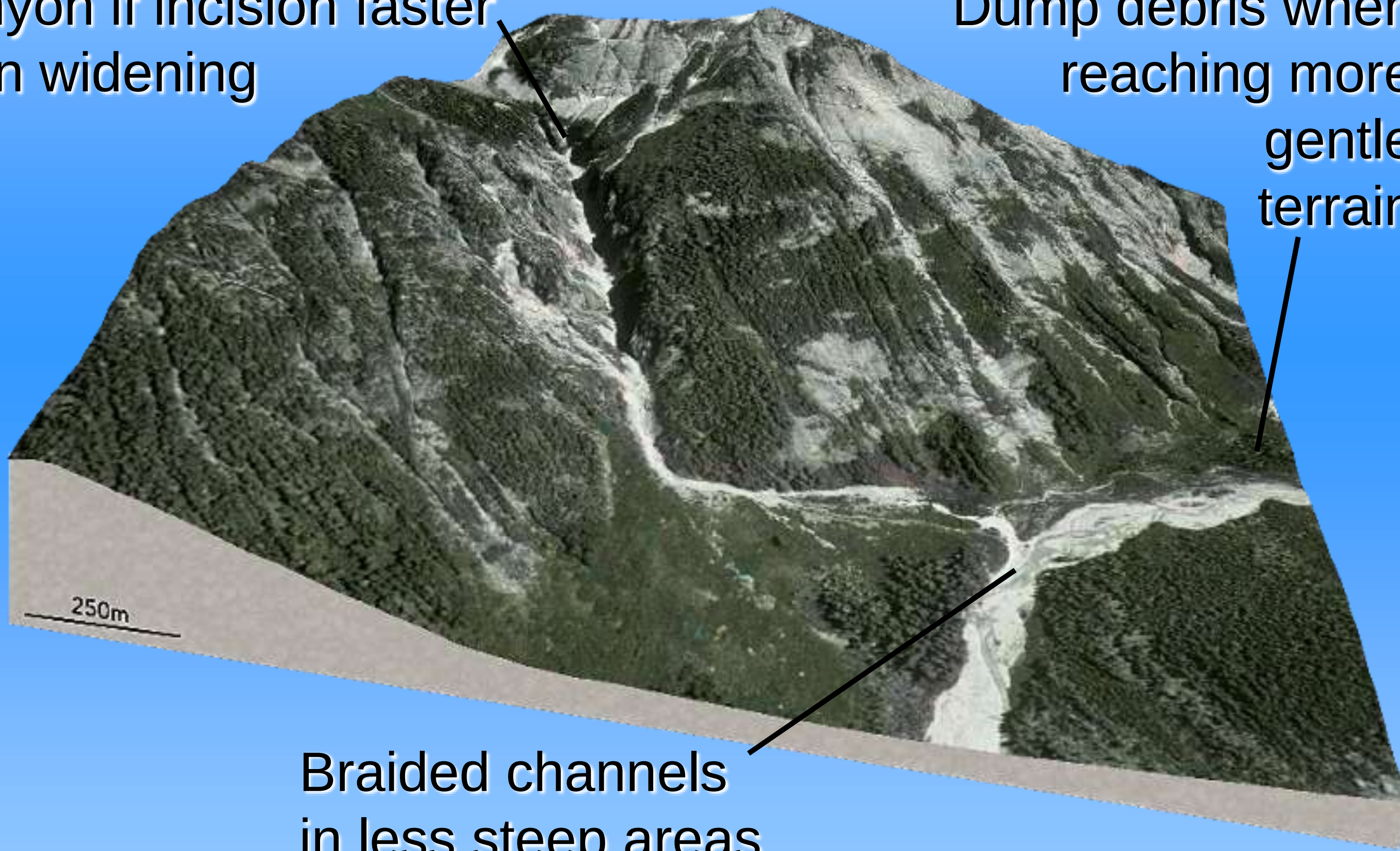
Stream Piracy

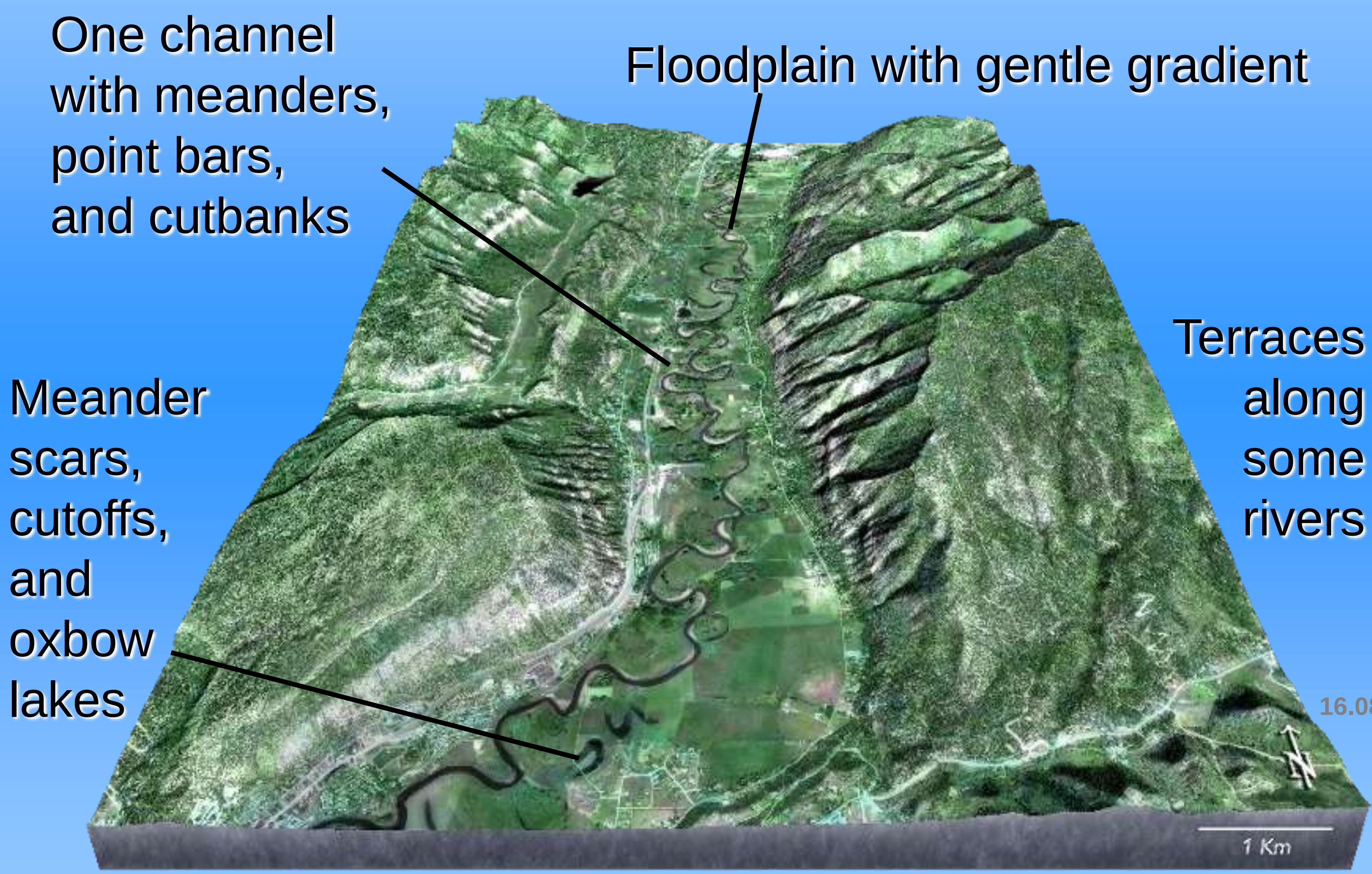


Landforms of Mountain Streams and Rivers



3D

Observe the features of a low-gradient river



16.08.a1

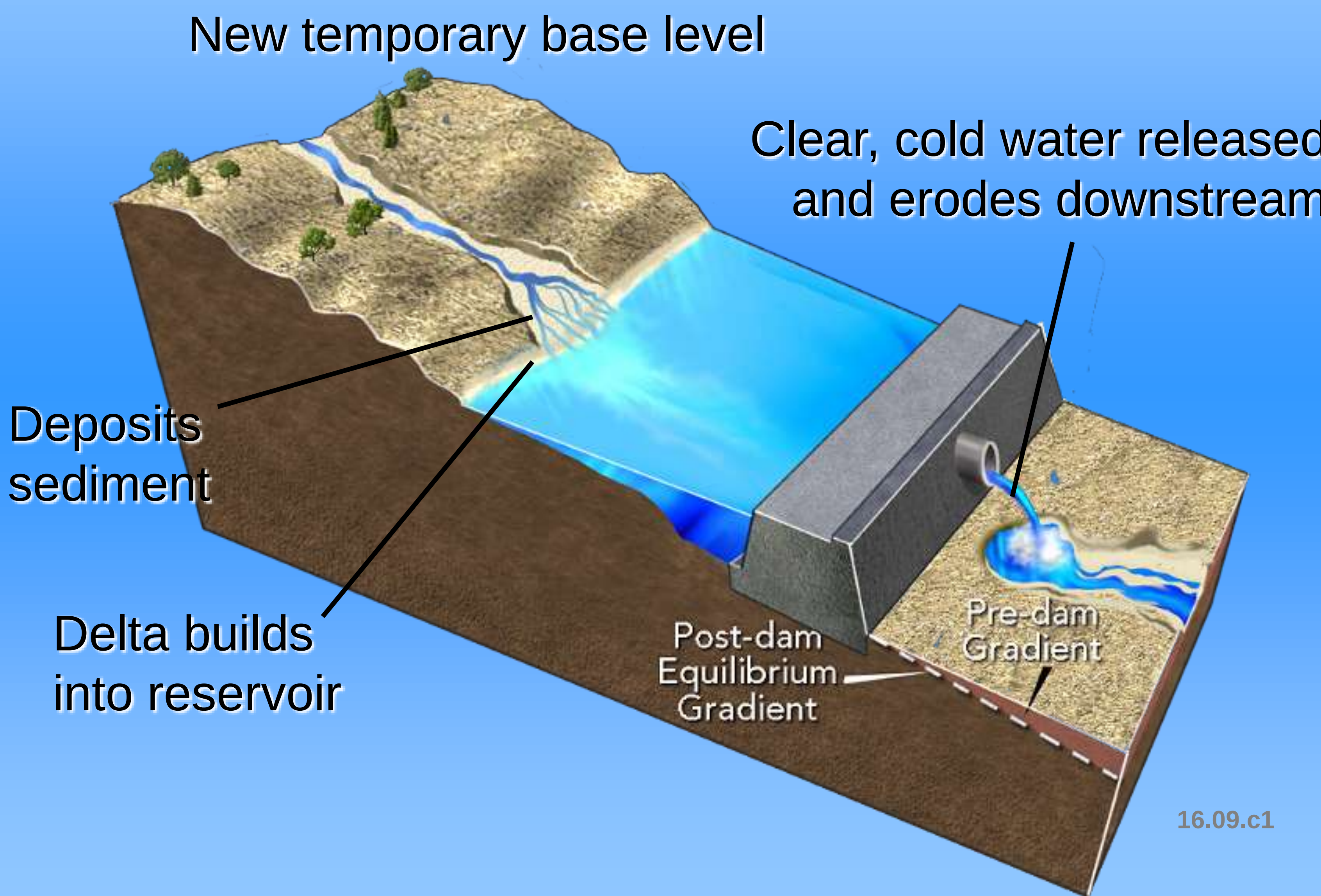
3D

Observe this stretch of the Mississippi River for features typical of low-gradient rivers

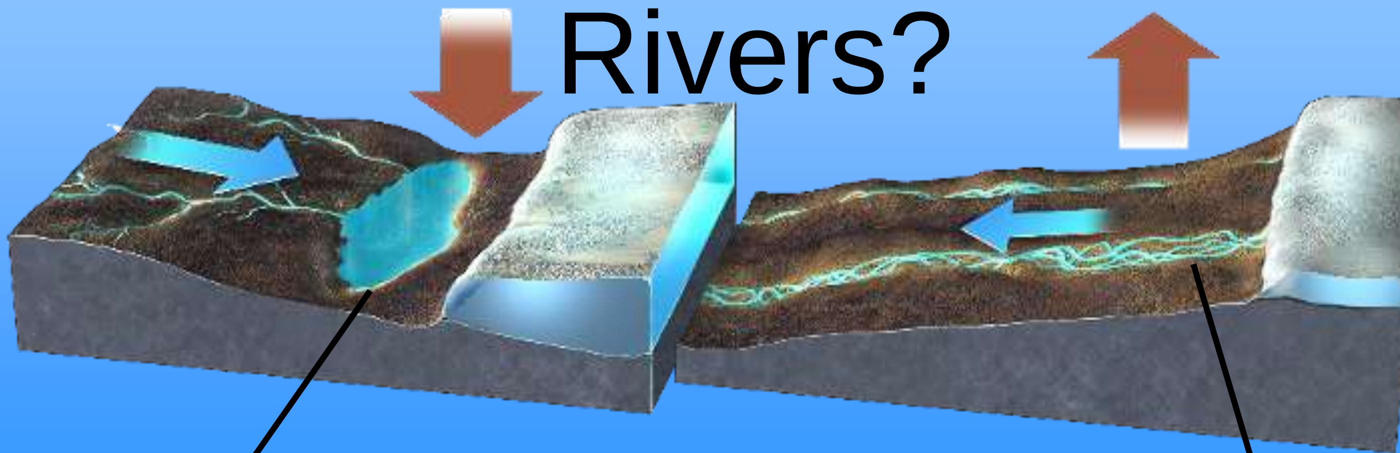
16.08.b2

3D

What do you think are the consequences of a dam?

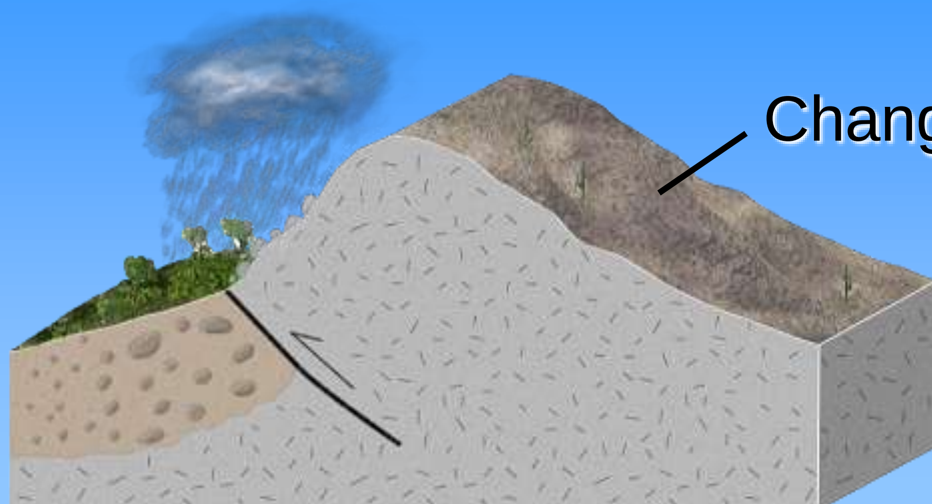


What Conditions Change Rivers?



Ice depresses crust; rivers flow toward ice

Melting ice releases water and weight, causing uplift



Uplifted mountains increase sediment

Change precipitation patterns (rain shadow)

16.10.b

How Does Climate Affect Rivers?

Before 1880 - Streams on Floodplain

Early streams flowing on broad valleys

About 1880 - Incision of Channels

Climate caused streams to incise, forming dry terraces

About 1940 - Channel Filling Begins

Channels deposited sediment and built up

Upper Mississippi River

Before 15,000 years ago, ice covered region (river did not exist)

16.10.a

Ice sheets melted and formed upper part of river

Rivers that Cut Across Structures

Green River flows across fold. Why?

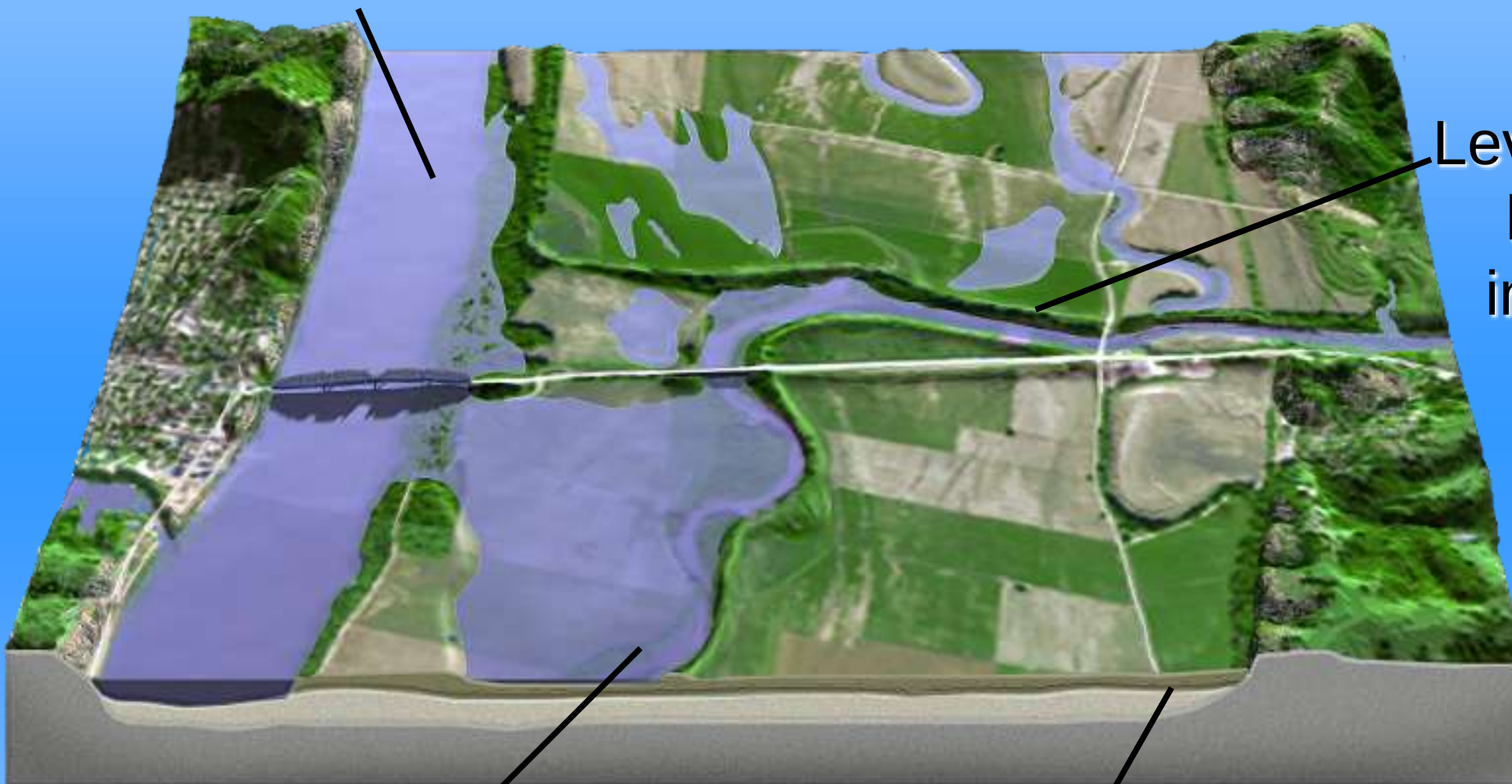
Either fold grew after river or hard rocks were not exposed when river downcut

Interpretation: fold formed first, but was covered by soft sediment

3D

What Is and Is Not a Flood?

Not a flood if stays within channel, unless lots erosion



Levees help keep flow in channel

16.12.a1

Flood if overflows channel and spills onto floodplain

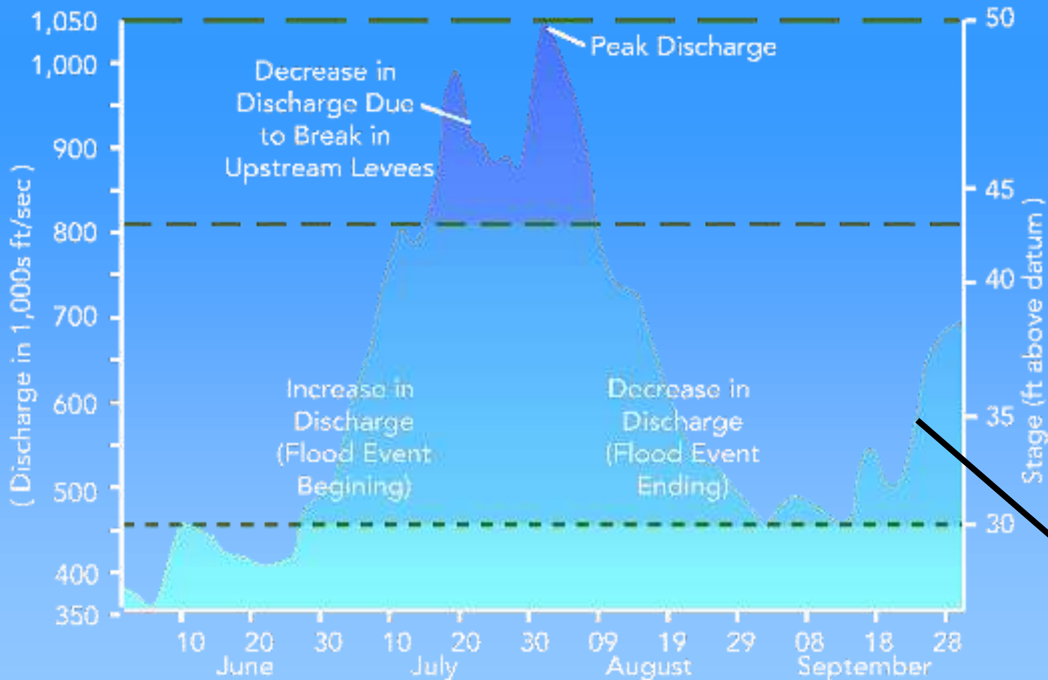
Floodplain built by floods

The 1993 Mississippi Flood

Cold air and warm air collide, causing persistent thunderstorms

Before flooding

During flooding

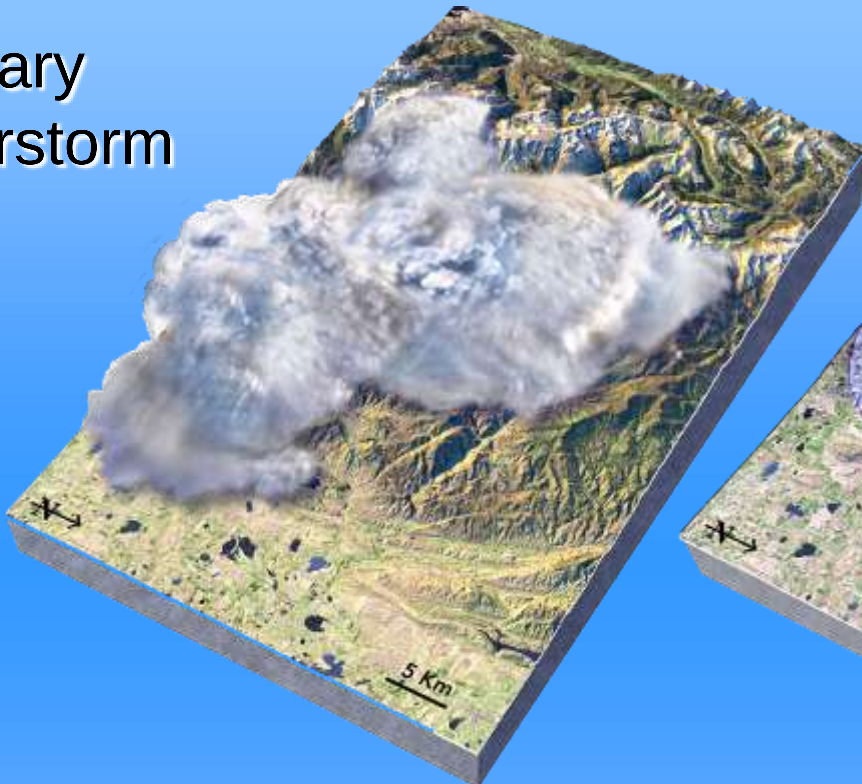


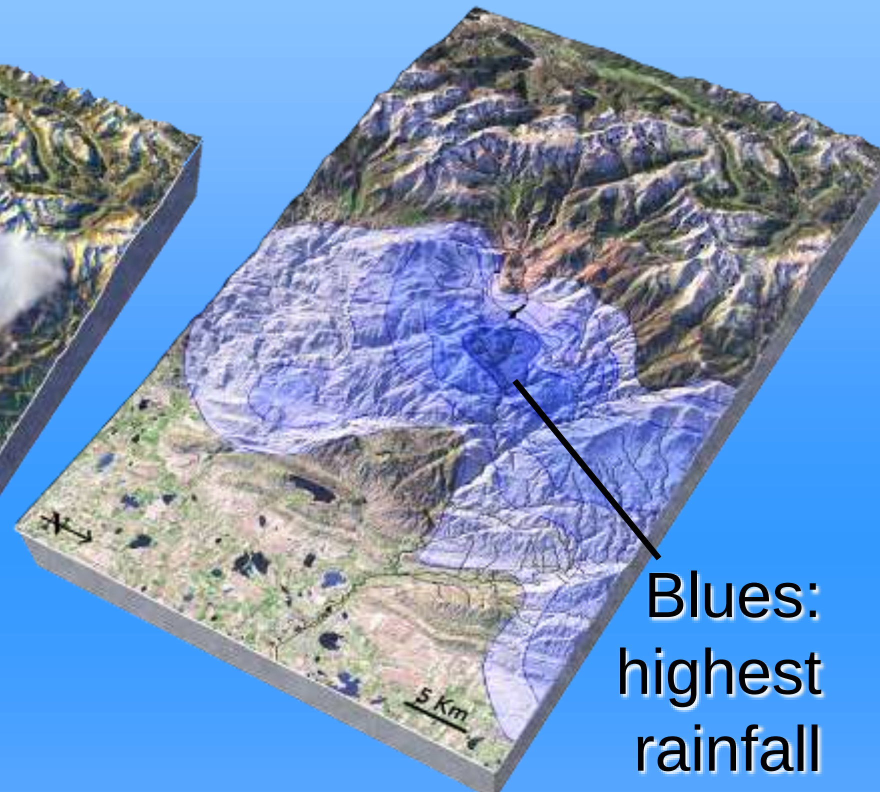
Discharge higher than normal for months

16.13.a

The 1976 Big Thompson Flood

Stationary thunderstorm





Blues: highest rainfall over Big Thompson River

Flash flood killed campers and destroyed buildings

16.13.b