Chapter 3 Lecture Outline

Foundations of Earth Science
Seventh Edition

Landscapes Fashioned by Water

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Focus Question 3.1

• What are external processes and what role do they play in the rock cycle?
Earth’s External Processes

- **External processes**
  - Occur at or near Earth’s surface
  - Powered by energy from the Sun

- **Internal processes**
  - Powered by energy from Earth’s interior
Earth’s External Processes

- **External processes include:**
  - **Weathering**
    - Disintegration and decomposition of rock
  - **Mass wasting**
    - Transfer of rock and soil downslope under influence of gravity
  - **Erosion**
    - Physical removal of material by a mobile agent (e.g., flowing water, waves, wind, ice)
Focus Question 3.1

• What are external processes and what role do they play in the rock cycle?
  – External processes occur at or near Earth’s surface
    • Derive energy from the Sun
    • Transform rock into sediment
Focus Questions 3.2

• What factors control the initiation and nature of mass wasting?
• How does mass wasting shape a landscape?
Mass Wasting: The Work of Gravity

• Earth’s surface is covered by slopes
• Slopes are unstable
  – Gravity causes material to move downslope
  – This movement is called **mass wasting**
    • May be slow and imperceptible, or catastrophic
    • Does not require a transporting medium
Mass Wasting: The Work of Gravity

A. Slump

B. Rockslide

C. Debris flow

D. Earthflow
Mass Wasting: The Work of Gravity

• Landform evolution:
  – Weathering breaks rocks apart
  – Mass wasting transfers materials downslope
  – Erosion (transportation) carries the materials away

• Mass wasting shapes stream valleys
  – Most common landform
  – Generally much wider than they are deep
    • Mass wasting increases width
  – Eventually transforms steep, rugged landscapes into gentle, subdued terrain
Mass Wasting: The Work of Gravity
Mass Wasting: The Work of Gravity

- Gravity is the controlling force
- Other factors overcome inertia to create downslope motion
  - Slope material is gradually weakened
  - Slope gets closer and closer to being unstable until a trigger initiates downslope movement
    - Saturation with water
    - Oversteepening
    - Removal of vegetation
    - Earthquakes
Mass Wasting: The Work of Gravity

• Triggers of mass wasting:
  – Saturation
    • Water in pore space reduces cohesion and allows particles to slide
    • Water adds weight to sediment
  – Oversteepening
    • Unconsolidated sediment forms a stable slope at a certain angle of repose depending on the size and shape of the particles
    • Stream undercutting a valley
    • Waves undercutting a cliff
    • Human activity
The angle of repose for this granular material is about 30°.

As sand accumulates along a dune crest, the slope gets steeper. Eventually, some sand slides down the oversteepened slope.
Mass Wasting: The Work of Gravity

• Triggers of mass wasting:
  – Removal of vegetation root systems that bind sediment
    • Forest fires, deforestation, development, farming
  – Earthquakes can dislodge rock and unconsolidated material

• Many mass wasting events occur without an identifiable trigger
Mass Wasting: The Work of Gravity
Focus Questions 3.2

• What factors control the initiation and nature of mass wasting?
  – Gravity initiates mass wasting, which can be triggered by saturation with water, oversteepened slopes, removal of vegetation or earthquakes.

• How does mass wasting shape a landscape?
  – Mass wasting widens stream valleys
Focus Question 3.3

• What are the major reservoirs for water on Earth?
The Hydrologic Cycle

• Water moves between the ocean, atmosphere, and land via the **hydrologic cycle**
• Hydrosphere is all of the reservoirs where water is held
  – Oceans
  – Glaciers
  – Rivers
  – Lakes
  – Soil
  – Living tissues
The Hydrologic Cycle

HYDROLOGIC CYCLE

Evaporation 320,000 km³
Evaporation 284,000 km³
Precipitation 96,000 km³
Evaporation/Transpiration 60,000 km³
Runoff 36,000 km³
Infiltration

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The Hydrologic Cycle

- 96.5% of hydrosphere is the global ocean
- 1.76% is ice sheets and glaciers
- ~2% is lakes, streams, groundwater, and atmosphere
The Hydrologic Cycle

- Hydrologic cycle is powered by the Sun
- Water enters atmosphere from the oceans via evaporation
- Winds transport water through the atmosphere
- Precipitation either falls to the ocean or continents
  - Precipitation to the oceans completes the hydrologic cycle
  - Precipitation to the continents must return to the ocean
The Hydrologic Cycle

• Some water soaks into the ground (infiltration)
• Surplus water flows over the surface (runoff)
• Water absorbed by plants is eventually released via transpiration
• Evapotranspiration is the combined effects of evaporation and transpiration
• Precipitation in cold regions becomes part of glaciers
  – Significant reservoirs: melting all glaciers would cause sea level rise of dozens of meters
Focus Question 3.3

• What are the major reservoirs for water on Earth?
  – Oceans
  – Glaciers and ice sheets
  – Lakes, streams, groundwater, plants
Focus Questions 3.4

- What happens to water as it runs off Earth’s surface?
- What are the four basic drainage patterns?
Running Water

• Precipitation that forms runoff depends on:
  – Intensity and duration of rainfall
  – Amount of water already in the soil
  – Nature of the surface material
  – Slope of the land
  – Extent and type of vegetation
Running Water

- Runoff starts as unconfined thin sheets across hillslopes
- Flow develops threads of current in tiny channels called rills
- Rills converge to form gullies
- Gullies converge to form streams and rivers that carry water from broad areas
  - **Drainage basins** (separated by **divides**) are the land area that contribute water to a river system
Running Water
A river system carries water from an entire drainage basin

- Includes three zones:
  - Sediment production (erosion dominant)
  - Sediment transport
  - Sediment deposition
Running Water

- Zone of sediment production
  - Where most water and sediment is derived
  - Headwater regions

- Transportation through the channel network occurs via trunk streams

- Rivers slow when they enter a body of water; sediment accumulates forming a delta
Running Water

• Networks of streams form drainage systems with distinctive patterns:
  – **Dendritic** (irregularly branching) patterns
    • Uniform material, slope of land determines pattern
  – **Radial** patterns
    • Diverge from a central point on volcanic cones and domes
  – **Rectangular** patterns
    • Right-angle bends formed when bedrock is crosscut by joints or faults
  – A **trellis** pattern
    • Rock layers are variably resistant and tributary streams are parallel
Running Water

Dendritic pattern develops on relatively uniform surface materials.

Rectangular pattern develops on highly jointed bedrock.

Radial pattern develops on isolated volcanic cones or domes.

Trellis pattern develops in areas of alternating weak and resistant bedrock.

Volcano

Ridges of resistant rock.

Valleys cut in less-resistant rock.
Focus Questions 3.4

• What happens to water as it runs off Earth’s surface?
  – Unconfined sheets concentrate into rills, converging into gullies and eventually streams and rivers

• What are the four basic drainage patterns?
  – Dendritic
  – Radial
  – Rectangular
  – Trellis
Focus Question 3.5

• What factors cause streamflow to change?
Streamflow

• Water flow in slow-moving streams can be **laminar**
  – Moves in roughly straight-line paths parallel to stream channel

• Most stream flow is **turbulent**
  – Water moves erratically in a swirling motion
  – Lifts sediment from streambed

• Increasing flow velocity increases turbidity
Streamflow

This water is not standing still. It is moving slowly toward the bottom of the image. The flow in the foreground is primarily laminar.

Running the rapids in the Grand Canyon—a extreme example of turbulent flow.
Streamflow

• Flow velocity varies along a stream and through time

• Flow velocity depends on:
  – Channel slope or gradient
  – Channel size and cross-sectional shape
  – Channel roughness
  – Amount of water flowing in the channel
Streamflow

• **Gradient** is the vertical drop over a specified distance
  – Varies from stream to stream and over a single stream’s length
  – Steeper gradient provides more energy for flow

• Shape, size, and roughness of channel affect the amount of friction between channel and water
  – Higher friction creates turbulence and slower flow

• **Discharge** is the volume of water flowing past a certain point in a given unit of time (m$^3$/s)
  – Intermittent streams only flow during wet periods
  – Ephemeral streams carry water after heavy rainfall
Streamflow

• The cross-sectional view of a stream from headwaters to mouth is called **longitudinal profile**
  – Gradient decreases from head to mouth
    • Also increase in discharge and channel size
    • Reduction in sediment size
  – Overall shape is concave curve with local irregularities
Streamflow

A longitudinal profile is a cross-section along the length of a stream.

- Head
- Steeper gradient
- Mouth
- Gentler gradient

Mount Whitney
Sierra Nevada
Fresno, CA
Kings River
Streamflow

• How would the flow velocity in the Mississippi River compare to the flow velocity of a rocky mountain stream? Why?
Focus Question 3.5

• What factors cause streamflow to change?
  – Gradient
  – Channel size and shape
  – Roughness
  – Discharge
Focus Question 3.6

• How do streams erode, transport, and deposit sediment?
The Work of Running Water

• Flow of water in a stream can dislodge and lift particles from the channel
  – Erodes poorly consolidated material quickly
  – Can undercut banks

• Hydraulic force can also cut bedrock
  – Enhanced by particles carried in water
  – Swirling pebbles can carve potholes in channel floors
The Work of Running Water

Abrasion by long-lived whirlpools armed with sand and pebbles creates bowl-shaped bedrock depressions called potholes.
The Work of Running Water

- Streams transport sediment in three ways:
  - **Dissolved load** is material in solution
    - Delivered by groundwater
    - Not effected by velocity
  - **Suspended load** is material suspended in the water
    - Clay and silt particles
    - Largest component of load
  - **Bed load** is material moving along the channel bed
    - Sand, gravel, large boulders
    - Only in motion intermittently
    - Smaller particles move via saltation
    - Larger particles roll or slip
This river's muddy appearance is a result of suspended sediment.
• **Capacity** is the maximum load of solid particles a stream can transport per unit time
  – Increases with discharge
• **Competence** is a stream’s ability to transport particles based on size
  – Increases with flow velocity
• As flow decreases competence is reduced
  – Particles settle when flow reaches critical settling velocity for that particle size
  – **Sorting** separates particles of various sizes
• **Alluvium** is material deposited by a stream
Focus Question 3.6

• How do streams erode, transport, and deposit sediment?
  – Streams erode by dislodging and lifting material from the channel or by abrasion
  – Streams transport sediment as dissolved load, suspended load, or bedload
  – Streams deposit sorted sediment when they reach critical settling velocity
Focus Questions 3.7

• What characterizes bedrock channels?
• What characterizes alluvial channels?
Stream Channels

- Streamflow is confined to a channel
- Two types of stream channels:
  - Bedrock channels are actively cut into solid rock
  - Alluvial channels are composed of unconsolidated sediment
Stream Channels

• Bedrock channels are cut into rock
  – Common in headwaters with steep gradient
  – Transport coarse particles
  – Alternate between gentle gradients (alluvium accumulates) and steep segments (bedrock is cut)
  – Rapids and waterfalls common
  – Channel pattern is controlled by underlying geologic structure
    • Often winding and irregular
Stream Channels

• Turbulent flow in the Little River in northeastern Alabama
Stream Channels

• Alluvial channels are composed of loosely consolidated sediment
• Shape is controlled by average sediment size (can change)
• Two common types
  – Meandering channels
  – Braided channels
Stream Channels

• Meandering channels have sweeping bends called **meanders**
  – High suspended load
  – Deep, smooth channels
  – Banks are resistant to erosion
    • Most erosion occurs on the outside of the meander, or the cut bank, where velocity is highest
    • Sediment is deposited along the inside of the meander where turbulence and velocity are low, forming point bars
  – Meanders migrate laterally and downstream
    • May form a **cutoff** and **oxbow lake** through narrow neck of land
Stream Channels

- Maximum velocity
- Deposition of point bar
- Erosion of cut bank
- Erosion of a cut bank along the Nez Perce River in southwestern Washington State.

Green River, WY

Meanders
Neck
Cutoff
Oxbow lake

Before the formation of a cutoff
After the formation of a cutoff

Geologist's Sketch
Stream Channels

• **Braided Channels** are a complex network of converging and diverging channels
  – Form where most of stream load is coarse (sand and gravel) and discharge is variable
  – Wide and shallow (bank material erodes easily)
  – Common at the end of glaciers
Stream Channels

• Think about a river or stream nearby. How would you classify this stream (bedrock, meandering, or braided)? What characteristics are you basing your classification on?
Focus Questions 3.7

• What characterizes bedrock channels?
  – Cut into solid rock
  – Steep gradients

• What characterizes alluvial channels?
  – Composed of sediment
  – Meandering or braided
Focus Question 3.8

• What controls the shape of a stream valley?
Shaping Stream Valleys

• A **stream valley** is the channel and surrounding terrain that contributes water to the stream
  – Includes valley bottom and sloping walls
  – Top is generally broader than channel width because of mass wasting
  – Divided into two general types:
    • Narrow, V-shaped valleys
    • Wide valleys with flat floors
Shaping Stream Valleys

• **Base level** is the lower limit to how deep a stream can erode
  – Usually occurs where a stream enters another body of water
    • Velocity and ability to erode are greatly reduced
  – Sea level is the ultimate base level
  – Temporary or local base level includes lakes, resistant rock layers, main streams, etc.

• Change in base level causes readjustment of stream
Shaping Stream Valleys

A. Stream prior to faulting

B. Ultimate base level

C. Profile of stream if resistant rock did not exist

D. Profile of stream adjusted to ultimate base level

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Shaping Stream Valleys

• How would construction of a dam change the temporary base level of a stream? How would the longitudinal profile of the stream change as a result?
Shaping Stream Valleys

• Downcutting is dominant when gradient is steep and channel is above base level
  – Abrasion and hydraulic power
  – Produces V-shaped valley with steep sides
    • Rapids and waterfalls common
Shaping Stream Valleys

• Downward erosion becomes less dominant as channel reaches base level
  – Channel becomes meandering
  – Lateral erosion creates a broad, flat valley floor called a floodplain

• Incised meanders flow in steep, narrow valleys
  – Meanders develop when stream is near base level, but base level falls and stream starts downcutting again
    • Sea level fall
    • Uplift
Shaping Stream Valleys

• The Colorado River developed meanders but is not downcutting because of uplift of the Colorado Plateau
Focus Question 3.8

• What controls the shape of a stream valley?
  – Base level
    • Downcutting if far from base level
    • Becomes meandering close to base level
    • Incised meanders form when base level falls and a stream with developed meanders starts downcutting
Focus Question 3.9

- How do deltas and levees form?
Depositional Landforms

• Streams transport sediment and deposit it downstream
  – **Bars** are deposits of sand and gravel
  – **Deltas** form where streams enter still bodies of water
    • Flow decreases and sediment falls
    • Delta grows outward and gradient lessens
    • Channel chokes with sediment, divides, and moves to higher-gradient areas
    • **Distributaries** carry water and sediment away from main channel
Depositional Landforms

Topset beds are deposited atop the foreset beds during floods.

Distributaries

Foreset beds consist of coarse particles that drop soon after entering the water body. As the delta grows, these beds cover the bottomset beds.

Bottomset beds consist of fine silt and clay particles that settled beyond the mouth of the river.

As the stream extends its channel, the gradient is reduced. During flood stage some of the flow is diverted to a shorter, higher-gradient route forming a new distributary.
Depositional Landforms

- **Natural levees** are built by successive floods on rivers in broad floodplains
  - Flow decreases when streams overflow
  - Coarse sediment deposited in thin strips parallel to channels
  - Fine sediment distributed across floodplain
  - **Back swamps** form because drainage is poor behind levees
    - **Yazoo tributaries** parallel the river until they can breach the levee
Depositional Landforms
Focus Question 3.9

• How do deltas and levees form?
  – Deltas form when streams enter a standing body of water
    • Flow decreases and sediment is deposited
  – Levees form when coarse sediment is deposited in thin strips parallel to channels during flooding
Focus Question 3.10

• What causes floods and how can they be controlled?
Floods and Flood Control

- Floods occur when stream discharge exceeds channel capacity.
- Most floods occur because of weather:
  - Snowmelt, heavy rains over large regions
  - Flash floods:
    - Limited geographic extent
    - Influenced by rainfall intensity, surface conditions, and topography
    - Common in urban areas (rapid runoff)
  - Failure of dams or artificial levees
Floods and Flood Control

• Floods can be controlled by:
  – Artificial levees
  – Flood control dams
  – Channelization
    • Artificial cutoffs shorten the stream and increase gradient and velocity

• Nonstructural approaches may be more efficient
Floods and Flood Control

River

Break in levee
• Do you think this region is prone to flooding events? Why or why not? What could be done to control floods in this area?
Focus Question 3.10

• What causes floods and how can they be controlled?
  – Floods happen because of weather, alteration of surface conditions (urbanization), and failure of dams or artificial levees
  – Floods can be controlled by artificial levees, dams, channellization, or other nonstructural approaches
Focus Questions 3.11

• What is the importance of groundwater?
• Where is groundwater distributed and how does it move through the subsurface?
Groundwater: Water Beneath the Surface

- Groundwater is the largest reservoir of freshwater readily available to humans
  - Source of 40% of water
  - Drinking water for >50% of population
  - 40% of irrigation water
  - 25% of water used in industry
- Overuse can cause streamflow depletion, land subsidence, and increased pumping cost
- Important geologic agent
  - Forms sinkholes and caves
  - Stabilizes streamflow
Groundwater: Water Beneath the Surface

Total global water
- Freshwater 2.5%
- Saline lakes and groundwater 1%
- Oceans 96.5%

Freshwater
- Surface water and other freshwater 1.3%
- Groundwater 30.1%
- Glaciers and ice sheets 68.6%
Groundwater: Water Beneath the Surface

• Comes from infiltration of rainfall into the ground
  – Amount is influenced by slope, surface material, intensity of rainfall, vegetation

• Belt of soil moisture
  – Film of water on soil particles near the surface

• Zone of saturation
  – All pore space is filled with water: groundwater
  – Upper limit is water table

• Area above the water table is called the unsaturated zone
Groundwater: Water Beneath the Surface

• Water table is irregular
  – Groundwater moves slowly
  – Water “piles up” between stream valleys
  – Variations in rainfall
  – Changes in permeability of sediment

• Water table falls during droughts
Groundwater: Water Beneath the Surface

• **Porosity**
  - Total volume of rock or sediment that consists of open pore space
  - Spaces between particles, joints, faults, dissolution cavities, vesicles
  - Depends on size and shape, packing, and sorting of grains
  - 10 – 50% in sediment
  - Quantity of groundwater depends on porosity
• **Permeability**
  – A material’s ability to transmit fluid
  – If spaces are too small, water can’t move through

• **Aquitards**
  • Impermeable layers that prevent water movement
  • Clay

• **Aquifers**
  • Rock or sediment that water moves through easily
  • Sand or gravel
Groundwater moves slowly from pore to pore
  - Typical rate is a few cm/day
  - Moves from high water table to low water table because of gravity
    - Usually towards a stream channel, lake, or spring
  - Pressure increases with depth in zone of saturation
Focus Questions 3.11

• What is the importance of groundwater?
  – Largest accessible reservoir of fresh water

• Where is groundwater distributed and how does it move through the subsurface?
  – Surrounds grains in the belt of soil moisture and fills pore space in the zone of saturation
  – Moves slowly from pore to pore because of gravity
Focus Questions 3.12

- What are some features that result when groundwater reaches the surface?
- How else does water reach the surface?
• A **spring** is a natural outflow of groundwater
  – Occurs where the water table intersects Earth’s surface
  – Aquitard prevents downward movement of water

• A **perched water table** is a localized zone of saturation above an aquitard
Hot springs are warm because groundwater circulates at depth
- Temperature increases about 2°C every 100 meters
- Generally water is at least 6°C warmer than average annual air temperature

Geysers are columns of hot water and steam ejected with great force
- Underground chambers full of water are heated and expand
Springs, Wells, and Artesian Systems

• **A well** is a hole drilled into the *zone of saturation* to remove groundwater

• **Drawdown** is the lowering of a water table when water is withdrawn
  – Decreases with increasing distance from the well
  – Creates a **cone of depression**
Springs, Wells, and Artesian Systems

• An **artesian system**
  – Free flowing groundwater from an outlet far above the water table

• A **confined water table**
  – The aquifer is inclined
  – Aquitards border above and below an aquifer

• Increased pressure in a confined water table causes water to rise and create an artesian system
Focus Questions 3.12

• What are some features that result when groundwater reaches the surface?
  – Springs, perched water table, hot springs

• How else does water reach the surface?
  – Geysers, wells, artesian systems
Focus Question 3.13

• What are some environmental problems associated with groundwater?
Environmental Problems of Groundwater

• Groundwater is a natural system in equilibrium
  – Not a renewable resource
• Ground subsidence occurs when water is removed faster than it is replenished
• Contamination
Although the contaminated water has traveled more than 100 meters before reaching Well 1, the water moves too rapidly through the cavernous limestone to be purified.

As the discharge from the septic tank percolates through the permeable sandstone, it moves more slowly and is purified in a relatively short distance.
Focus Question 3.13

• What are some environmental problems associated with groundwater?
  – Nonrenewable resource
  – Ground subsidence
  – Contamination
Focus Question 3.14

• How do caverns and karst topography form?
• Most groundwater contains carbonic acid
  – $\text{CO}_2$ dissolved from air and decaying plants
  – Dissolves limestone
  – Forms caverns, sinkholes, and karst landscapes
The Geologic Work of Groundwater

• **Caverns** form due to the erosional work of groundwater
  – Created in the zone of saturation
  – Dissolved load is discharged into streams

• Decorated by calcium carbonate deposits
  – Form when cavern is above water table
  – **Stalactites** hang from the ceiling
  – **Stalagmites** develop upward from the floor
The Geologic Work of Groundwater
• **Karst topography** results from groundwater dissolution

• Common in Kentucky, Tennessee, Alabama, Indiana, and Florida
  – Not enough groundwater in arid or semiarid regions
During early stages, groundwater percolates through limestone along joints and bedding planes. Solution activity creates and enlarges caverns at and below the water table.

With time, caverns grow larger and the number and size of sinkholes increase. Surface drainage is frequently funneled below ground.

Collapse of caverns and coalescence of sinkholes form larger, flat-floored depressions. Eventually solution activity may remove most of the limestone from the area, leaving isolated remnants as in Figure 17.36.
The Geologic Work of Groundwater

- **Sinkholes** are depressions where limestone has been dissolved
- **Tower karst landscapes** have isolated, steep-sided hills
Focus Question 3.14

• How do caverns and karst topography form?
  – Groundwater contains carbonic acid which dissolves limestone