Running Water: The Geology of Streams and Floods
Stream Flow

- Stream runoff is an important geologic agent.
  - Flowing water…
    - Erodes, transports, and deposits sediments.
    - Sculpts landscapes.
    - Transfers mass from continents to ocean basins.
  - Earth: Only planet in the solar system with flowing water.
  - Without flowing water, Earth might resemble Mars.
The Hydrologic Cycle

- Stream runoff is a component of the hydrologic cycle.
- Hydrologic cycle processes:
  - Evaporation.
  - Transpiration.
  - Precipitation.
  - Infiltration.
  - Runoff.
Streamflow begins as water is added to the surface.
Forming Streams

- Streamflow begins as moving sheetwash.
  - Thin surface layer of water.
  - Moves down the steepest slope.
  - Erodes substrate.
- Sheetwash erosion creates tiny rill channels.
- Rills coalesce, deepen, and downcut into channels.
Forming Streams

- Intense scouring marks entry into the channel.
- Rapid erosion lengthens the channel upslope.
- This process is called headward erosion.
Forming Streams

- Over time, nearby channels merge.
- Smaller tributaries join a larger trunk stream.
- The array of linked channels is a drainage network.
- Drainage networks change over time.
Drainage Networks

- Drainage networks often form geometric patterns.
- These patterns reflect underlying geology.
- Common drainage patterns.
  - Dendritic – Branching, “treelike” due to uniform material.
Drainage Networks

- Common drainage patterns.
  - Radial – From a point uplift (mesa, volcano, etc.)
Drainage Networks

- Common drainage patterns.
  - Rectangular – Controlled by jointed rocks.
Drainage Networks

- Common drainage patterns.
  - Trellis – Alternating resistant and weak rocks.
Drainage Networks

- Common drainage patterns.
  - Parallel – Streams developed on a uniform slope.
Drainage Basins

- Land areas that drain into a specific trunk stream.
- Also known as catchments or watersheds.
- Divides are uplands that separate drainage basins.
Drainage Divides

- Watersheds exist in a variety of scales.
  - Tiny tributaries.
  - Continental rivers.
- Large watersheds...
  - Feed large rivers.
  - Section continents.
- Continental divides separate flow to different oceans.
Permanent vs. Ephemeral

- **Permanent streams**
  - Water flows all year.
  - At or below water table.
  - Humid or temperate.
    - Sufficient rainfall.
    - Lower evaporation.
  - Seasonal discharge

- **Ephemeral Streams**
  - Do not flow all year.
  - Above the water table.
  - Dry climates.
    - Low rainfall.
    - High evaporation.
  - Flow mostly during rare flash floods.
**Discharge**

- The amount water flowing in a channel.
  - Volume of water passing a point per unit time.
    - Cubic feet per second (ft³/s or cfs).
    - Cubic meters per second (m³/s).
  - Given by cross-sectional area times flow velocity.
  - Varies seasonally due to precipitation and runoff.
Discharge

- Velocity is not uniform in all areas of a channel.
  - Friction slows water along channel edges. Friction is...
    - Greater in wider, shallower streams.
    - Lesser in narrower, deeper streams.
  - In straight channels, highest velocity is in the center.
  - Few natural channels are straight.
Discharge

- Velocity is not uniform in all areas of a channel.
  - In curved channels, max. velocity traces the outside curve.
    - The outside curve is preferentially scoured and deepened.
    - The deepest part of the channel is called the thalweg.
    - Flow around curved channels follows a spiral path.
Discharge

- Velocity is not uniform in all areas of a channel.
  - Stream flow is characteristically turbulent.
    - Chaotic and erratic.
    - Abundant mixing.
    - Swirling eddies.
    - High velocity.
- Turbulence caused by...
  - Flow obstructions.
  - Shear in water.
- Turbulent eddies scour the channel bed.
Erosional Processes

- Erosional processes – Streamflow does work.
  - The energy imparted to streamflow is derived from gravity.
  - Streams do work by converting potential to kinetic energy.
- Erosion is maximized during floods.
  - Large water volumes.
  - High water velocities.
  - Abundant sediment.
Erosional Processes

- Streams scour, break, abrade, and dissolve material.
  - Scouring – Running water picks up sediment and moves it.
  - Breaking and lifting – The force of moving water can...
    - Break chunks of rock off of the channel.
    - Lift rocks off of the channel bottom.
Erosional Processes

- Abrasion – Sediment grains in flow “sandblast” rocks.
  - Bedrock exposed in channels is often polished smooth.
  - Gravel swirled by turbulent eddies drills holes in bedrock.
    - These bowl-shaped depressions are called potholes.
    - Potholes are often intricately sculpted.
- Dissolution – Mineral matter dissolves in water.
Sediment Transport

- The material moved by streams is the sediment load.
- There are 3 types of load.
  - Dissolved load – Ions from mineral weathering.
  - Suspended load – Fine particles (silt and clay) in the flow.
  - Bed load – Larger particles roll, slide and bounce along.
Sediment Transport

- Sediment transport changes with discharge.
  - High discharge – Large cobbles and boulders may move.
  - Low discharge – Large clasts are stranded.
- Competence – The maximum size transported.
- Capacity – The maximum load transported.
Sediment Deposition

- When velocity decreases so does competence.
  - Sediment grains drop out; water sorts them by size.
    - Gravel settles in channels.
    - Sands are removed from the gravels; muds from both.
    - Sands drop out in near channel environments.
    - Silts and clays are suspended only to settle in slack water.
Sediment Deposition

- Fluvial sediments are called alluvium.
  - Channels may be decorated with mid-channel bars.
  - Sands build up the point bars inside meander bends.
  - Muds are deposited away from the channel during floods.
  - A stream builds a sediment delta upon entering a lake.
Longitudinal Changes

- The character of a stream changes with flow distance.
- In profile, the gradient describes a concave-up curve.
Longitudinal Changes

- The character of a stream changes with flow distance.
  - Near the headwater source of the stream...
    - Gradient is steep.
    - Discharge is low.
    - Sediments are coarse.
    - Channels are straight and rocky.
Longitudinal Changes

- The character of a stream changes with flow distance.
  - Toward the mouth...
    - Gradient flattens.
    - Discharge increases.
    - Grain-sizes are smaller.
    - Channels describe broad meander belts.
The lowest point to which a stream can erode.

- Ultimate base level is defined by the position of sea level.
  - Streams cannot erode below sea level.
- A lake serves as a local (or temporary) base level.
- Base level changes cause stream re-adjustments.
  - Raising base level results in an increase in deposition.
  - Lowering base level accelerates erosion.
Base Level

- The lowest point to which a stream can erode.
  - A ledge of resistant rock may define the local base level.
  - Erosive forces act to slowly remove the resistant layer.
    - This acts to restore the longitudinal profile.
Valleys and Canyons

- Land far above base level is subject to downcutting.
- Rapid downcutting creates an eroded trough.
  - Canyon – Steep trough sidewalls form cliffs.
  - Valley – Gently sloping trough sidewalls define a V-shape.
- Determined by rate of erosion vs. strength of rocks.
Valleys and Canyons

- Stratigraphic variation often yields a stair step profile.
  - Strong rocks yield vertical cliffs.
  - Weak rocks produce sloped walls.
- Geologic processes stack strong and weak rocks.
Valleys and Canyons

- Active downcutting flushes sediment out of channels.
- Valleys store sediment when base level is raised.
- Renewed incision creates stream terraces.
  - Terraces mark former floodplains.
Rapids

- Rapids are turbulent water with a rough surface.
- Rapids reflect geologic control.
  - Flow over resistant bedrock steps.
  - Flow over large clasts.
  - Abrupt narrowing of a channel.
  - Sudden increase in gradient.
Waterfalls

- Streams that cascade or free-fall.
  - Waterfall energy scour a plunge pool at the base.
  - Basal erosion initiates collapse of overlying rocks.
  - Waterfalls are temporary base levels.
Waterfalls

- Niagara Falls – Lake Erie drops 55 m to Lake Ontario.
- Dolostone caprock is resistant; underlying shale erodes.
- Blocks of unsupported dolostone collapse and fall.
- Niagara Falls continuously erodes south toward Lake Erie.
- Erosion since deglaciation has formed Niagara Gorge.
Waterfalls

- Niagara Falls.
  - Diversion of American Falls revealed huge blocks of rock.
  - The rate of waterfall retreat is presently 0.5 m/yr.
  - Lake Erie will drain when the Falls reach it.
Alluvial Fans

- Alluvial fans build at the base of a mountain front.
- Sediments rapidly dropped near the stream source.
  - Coarsest material found near the stream source.
  - Sediments are fine and thin away from canyon stream.
- Sediments create a conical, fan-shaped structure.
Braided Streams

- Form where channels are choked by sediment.
- Flow is forced around sediment obstructions.
  - Diverging – converging flow creates sand and gravel bars.
  - Bars are unstable, rapidly forming, and being eroded away.
- Flow occupies multiple channels across a valley.
Meandering Streams

- Channels can form intricately looping curves...
  - Along the lower portion of the profile with a low gradient.
  - Where streams travel over a broad floodplain.
  - When substrates are soft and easily eroded.

- Meanders increase the volume of water in the stream.
- Meanders evolve.
Meandering Streams

- Meanders change from variation in thalweg position.
- Maximum velocity swings back and forth across flow.
  - Fast water erodes one stream bank.
  - The opposite bank collects sediment.
Meandering Streams

- Erosion accentuates the cut bank.
  - High-velocity flow scours the outside of the meander bend.
  - Collapsed cut-bank material is transported away.

- Deposition builds the point bar.
  - Sediment accumulates inside the meander bend.
  - Continued addition expands the point bar laterally.
Meandering Streams

- Meanders become more sinuous with time.
  - The cut bank erodes; the point bar accretes.
  - Meander curves become more pronounced.
  - Meanders elongate.
Meandering Streams

- Meander sinuosity increases until the meander is cut off.
  - Cut banks converge and a meander neck thins.
  - During flooding, high-velocity flow saws through the neck.
  - The meander cut-off forms an oxbow lake.
  - The oxbow fills with sediment, leaving an arcuate scar.
Meandering Streams

- Occupy only a small part of the floodplain.
- Floodplains are typically bounded by eroded bluffs.
- During floods, the floodplain may be immersed.
- Natural levees form ridges parallel to the channel.
  - Made of sand dropped as floodwaters jump from channel.
Deltas form when a stream enters standing water.
- Current slows and loses competence; sediments drop out.
- Stream divides into a fan of small distributaries.
- Shape due to the interplay of flow, waves, and tides.
Drainage Evolution

- Landscapes evolve over time.
- Streamflow is the cause of most landscape changes.
- Example:
  - Uplift sets a new base level.
  - Stream cuts into former surface.
  - Valleys widen; hills erode.
  - Landscape eroded to base level.
Drainage Evolution

- Stream rejuvenation is initiated by base level drop.
  - Meanders initially develop on a gentle gradient.
  - Uplift raises the landscape or base level falls.
  - The river chainsaws downward creating incised meanders.
Stream Piracy.

- A stream captures another’s flow.
- One stream, with more vigorous headward erosion (a steeper gradient), intercepts a neighbor.
- The captured stream flows into the new stream.
- Below the point of capture, the old stream dries up.