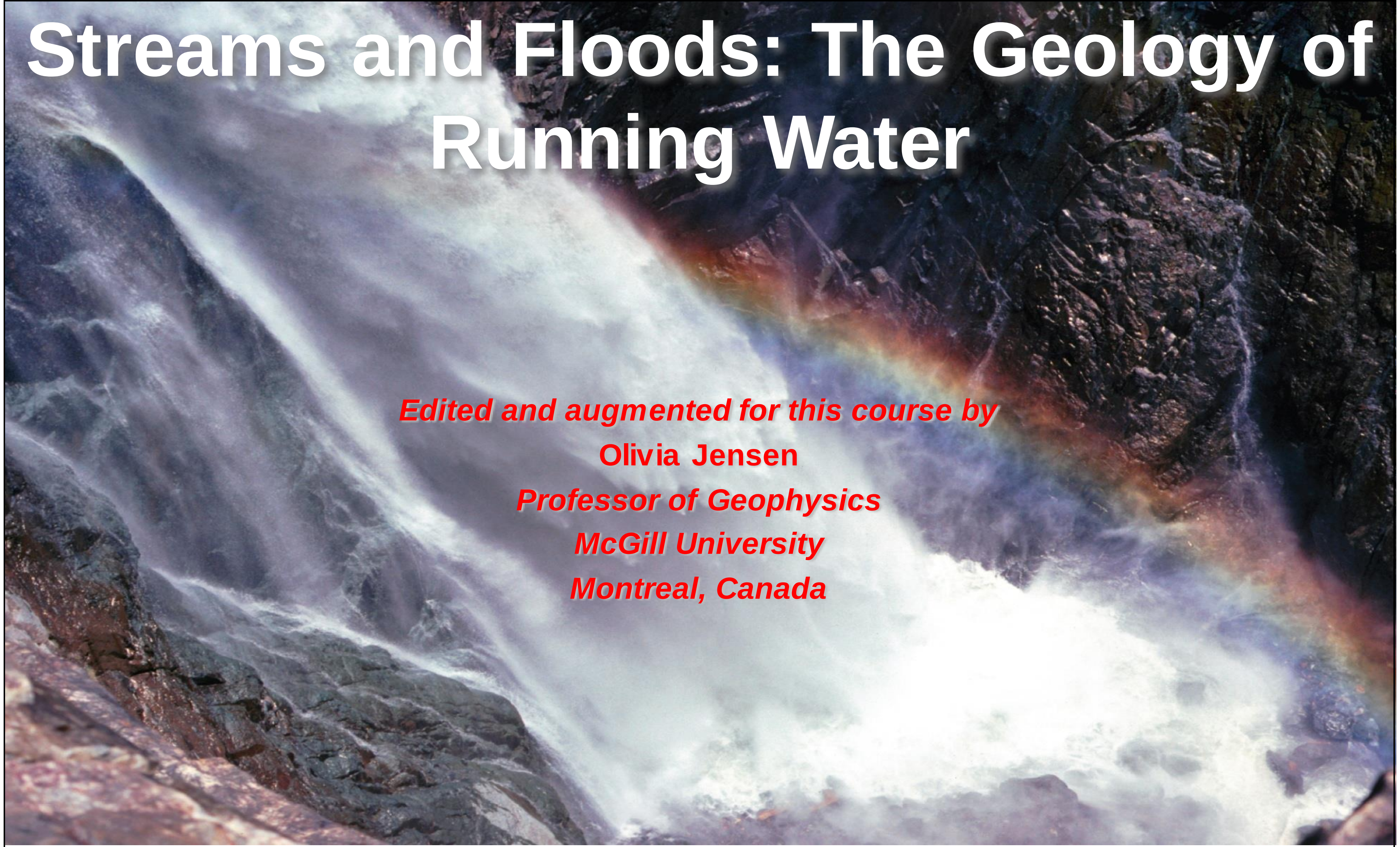
Streams and Floods: The Geology of Running Water



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Stream Flow

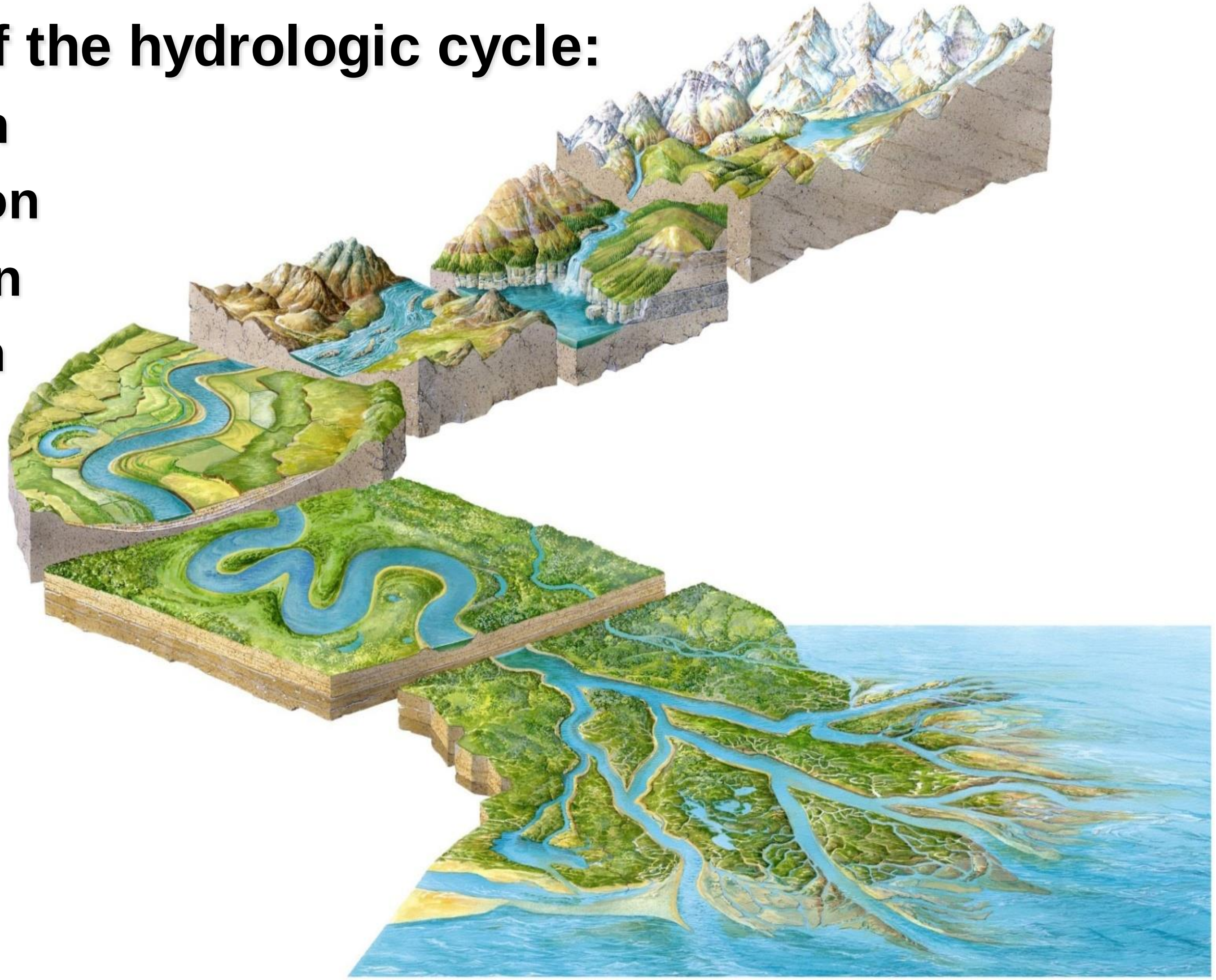
- Streams and rivers—concentrated flows of water in channels.
- A flood occurs when a stream exceeds channel capacity.
  - Flooding can claim lives and destroy property.
- Stream flow is crucial for humans:
  - Drinking
  - Irrigation
  - Industrial use
  - Transportation
  - Recreation
  - Aesthetics
  - Energy

Stream Flow

- Stream runoff is an important geologic agent.
  - Flowing water:
    - Erodes, transports, and deposits ions and sediments.
    - Sculpts landscapes.
    - Transfers mass from continents to ocean basins.

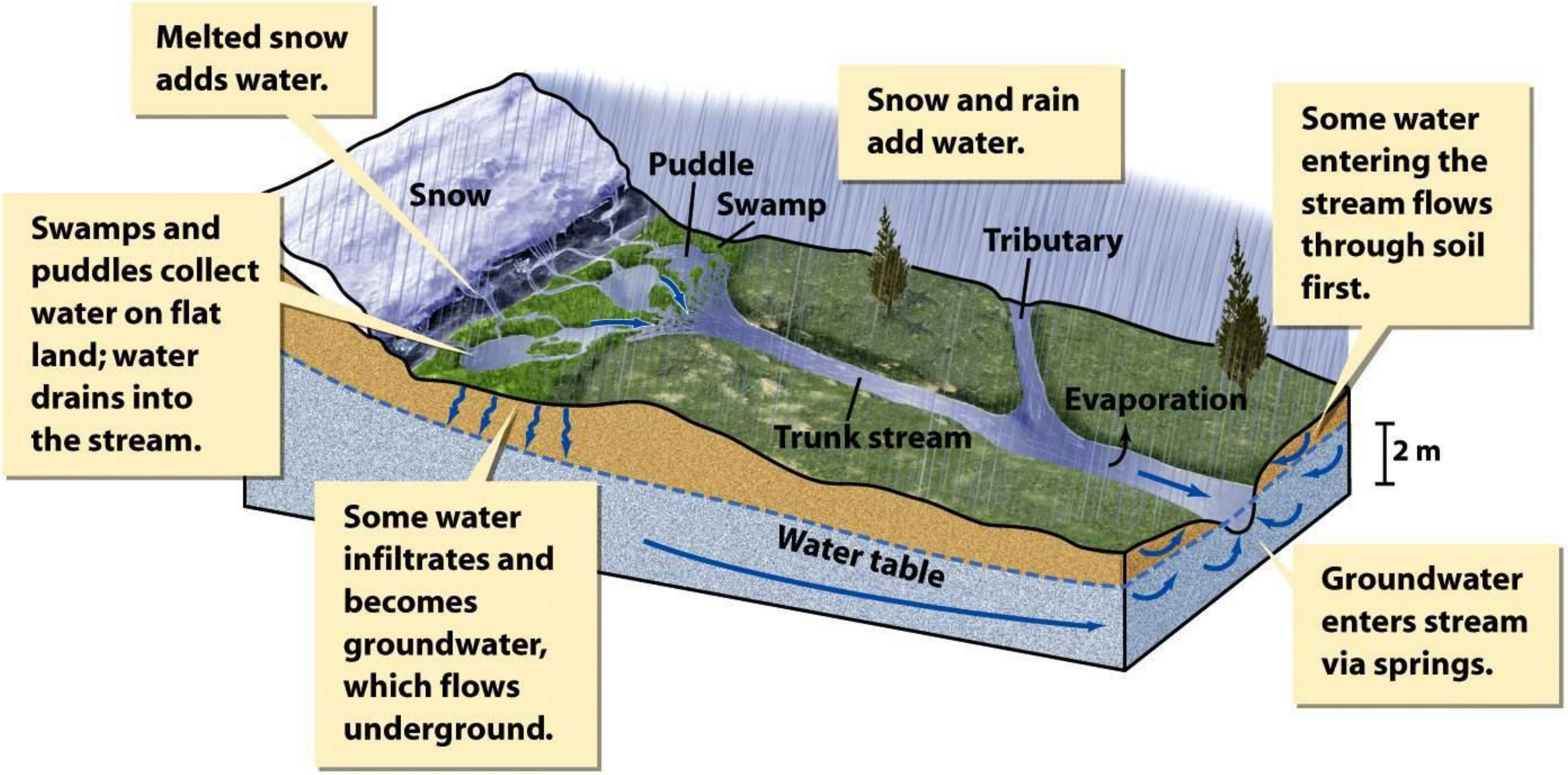
The Hydrologic Cycle

- Stream flow is part of the hydrologic cycle.
- Major parts of the hydrologic cycle:
  - Evaporation
  - Transpiration
  - Precipitation
  - Sublimation
  - Infiltration
  - Melting
  - Runoff



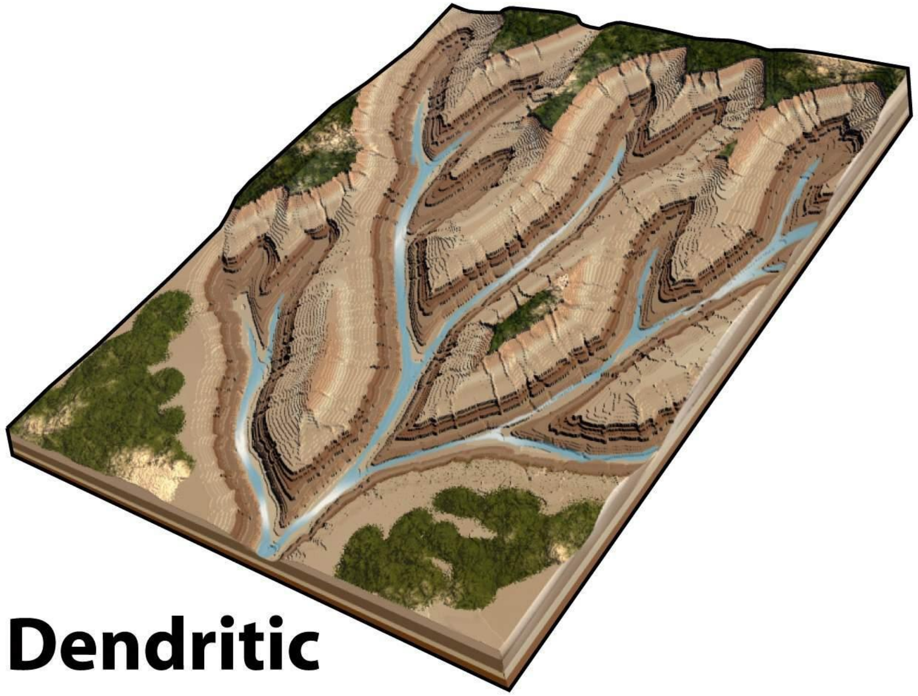
Forming Streams

- **Stream flow begins as scattered *runoff*.**



Drainage Networks

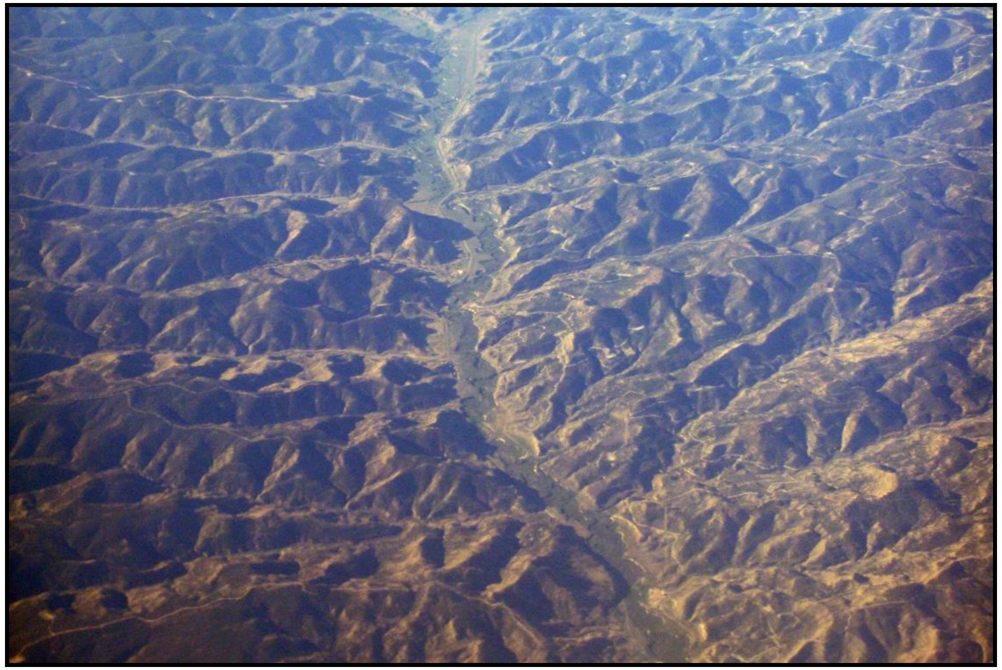
- Common drainage patterns
  - Dendritic—branching or tree-like
  - Common in regions of uniform material

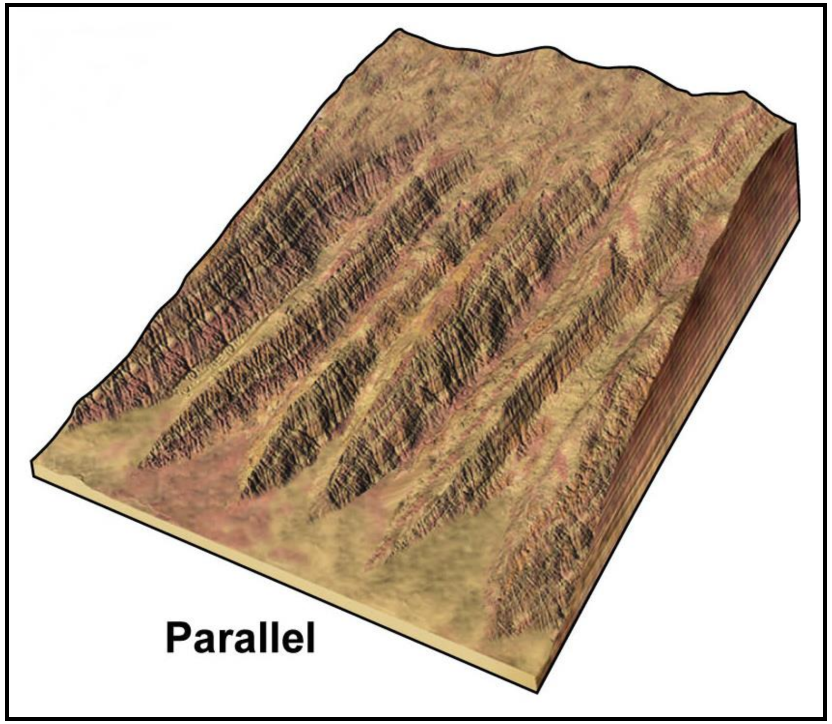


Dendritic

Drainage Networks

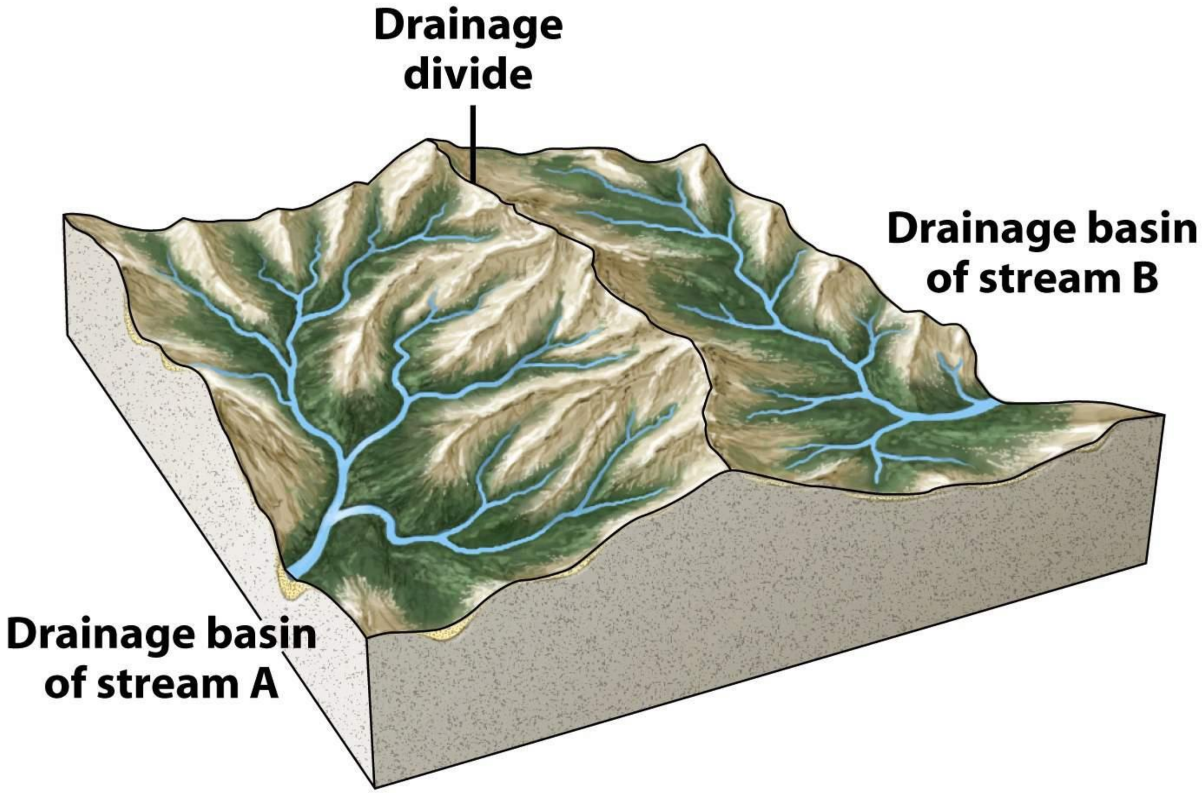
- Common drainage patterns
  - Parallel—several streams with parallel courses
  - Common in surface with uniform slope





Drainage Basins

- Land areas drain into a trunk stream or body of water.
- A watershed is the area of land that drains into a stream.
- Ridges and peaks separate *drainage basins*.

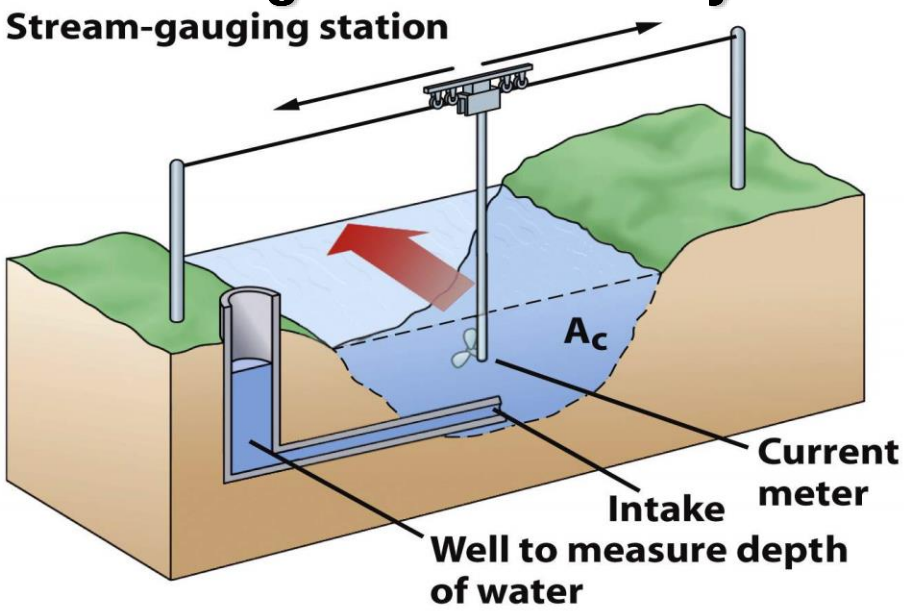


Drainage Divides

- Watersheds exist at multiple scales.
- Large watersheds contain many smaller watersheds.
- Continental divides separate drainages that flow to different water bodies (e.g., to Gulf of Mexico versus Atlantic Ocean).

Describing flow in streams

- ***Discharge*** = the amount of water flowing in a channel.
  - Volume of water passing a point per unit of time
    - Cubic meters per second (m^3/s)
    - St. Lawrence: ~17 000 (m^3/s) average
    - Amazon: ~209 000 (m^3/s) average
  - Multiply cross-sectional area x average water velocity.
    - $D = A_c \times v_a$
  - Varies due to season, climate, and other factors.
- Velocity is not uniform in a channel.
  - Friction with banks, bottom, and submerged objects slows the flow of water.

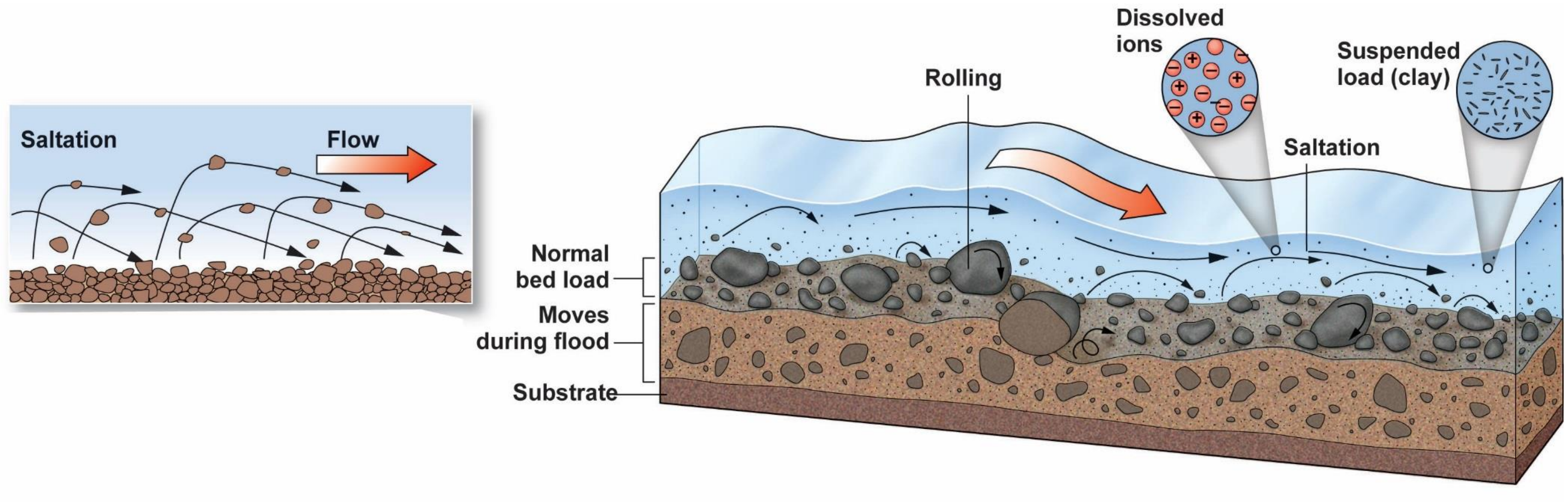


The Work of Running Water

- River erosion and sediment transport
  - The energy of flowing water is from mass and gravity.
  - Streams convert potential energy (PE) to kinetic energy (KE). KE (e.g., fast water flow) lifts and moves solids.
- Erosion is greatest during a flood because KE is higher:
  - Erodes more
  - Transports more

How Do Streams Transport Sediment?

- Sediment load = material moved by running water load.
- Three types of load:
  - Dissolved load—ions from chemical weathering
  - Suspended load—fine particles (silt and clay) in the water.
  - Bed load—larger particles roll, slide, and bounce along the bottom
    - Bed load moves by saltation.



Sediment Transport

- Flowing water moves sediments
  - Slow water can only transport fine sediments and solutes
  - Fast-flowing water can move boulders and clasts
  - Competence: a measure of ability to move large clasts

Sediment Deposition

- Decrease in water velocity affects sediment transport.
  - Competence reduced, sediment drops out.
  - Boulders, then gravels, then sands fill channel bottoms.
  - Sands form inside banks (point bars).
  - Silts and clays drape floodplains.

Sediment Deposition

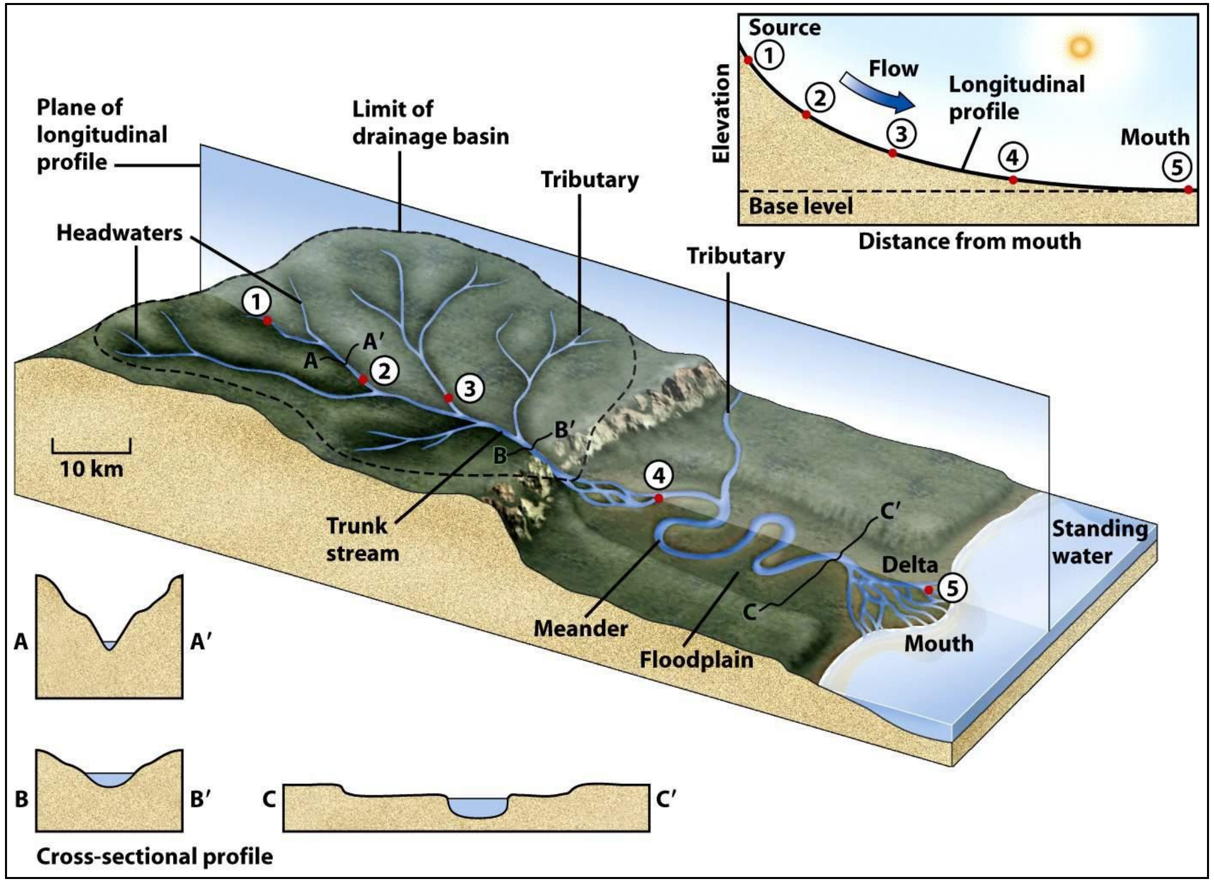
- Deposition in stream and river systems
  - Fluvial deposits are sediments transported by streams.
  - Alluvium—another commonly used term for stream sediments
- Sediment accumulates in channel bars and point bars.
- During a flood, sediment accumulates on the floodplain.

Stream Changes along Their Length

- The longitudinal profile describes changes in a stream channel's elevation from its mouth to its headwaters.
- In profile, the gradient describes a concave-up curve.

Stream Gradient = change in elevation per distance flowed.

Common units: (ft/mi) = feet of elevation change per mile of channel.



Longitudinal Changes

- The character of a stream changes along its length.
- Near the headwaters (source) of the stream:
  - Gradient is usually steep.
  - Discharge is low.
  - Competence is high (sediments are coarse).
  - Channels are straight.

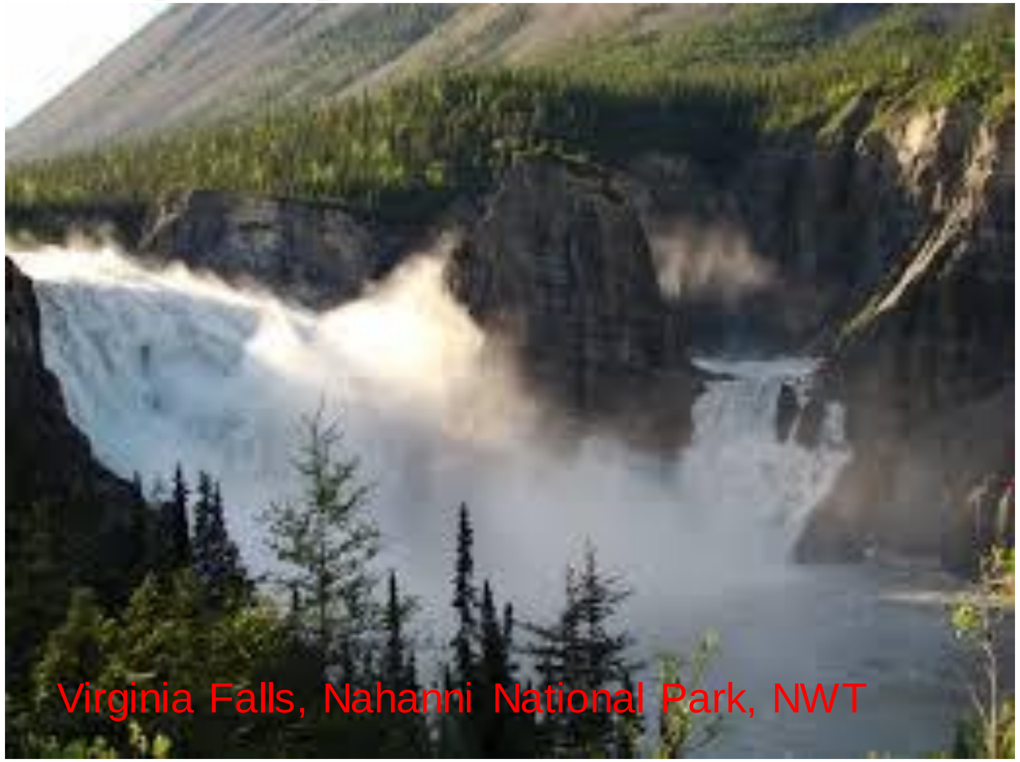
Valleys and Canyons

- Variations in resistance to erosion may result in a stair-step profile along canyon walls.
  - Strong rocks yield steep slopes and cliffs.
  - Weak rocks yield gentle slopes.

Fig. 14.11c

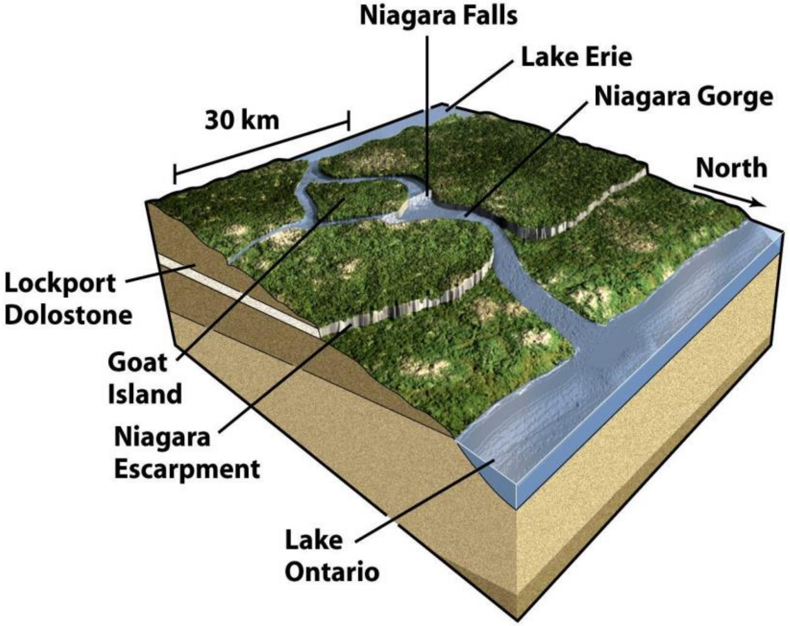
Waterfalls

- Gradient is so steep that water cascades or free falls.
- Waterfalls scours a deep plunge pool.
- Basal erosion leads to collapse of overlying rocks.
- Waterfalls are temporary base levels.


Virginia Falls, Nahanni National Park, NWT

Waterfalls

- Niagara Falls
  - Lake Erie drops 55 m at the falls, to reach Lake Ontario.
  - Dolostone cap resists erosion; underlying shale erodes.
  - Blocks of unsupported dolostone collapse and fall.
  - Niagara Falls erodes upriver toward Lake Erie.
  - Erosion since deglaciation has formed Niagara Gorge.

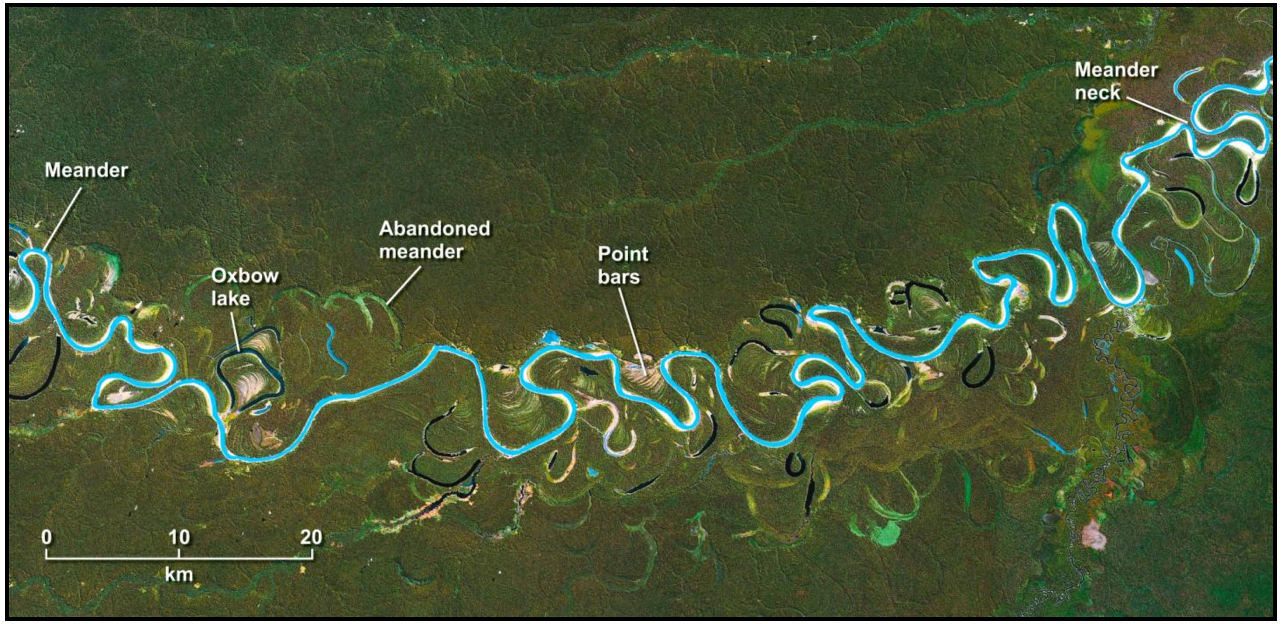


Alluvial Fans

- Alluvial fans build at canyon mouths.
- Sediment drops out as water spreads out from mouth.
  - Coarsest material is dropped first, close to mouth.
  - Finer material is carried further, to distal edge of fan.
- Sediment creates a conical, fan-shaped structure.
- During strong flood, debris flow spreads across, smoothing fan surface.

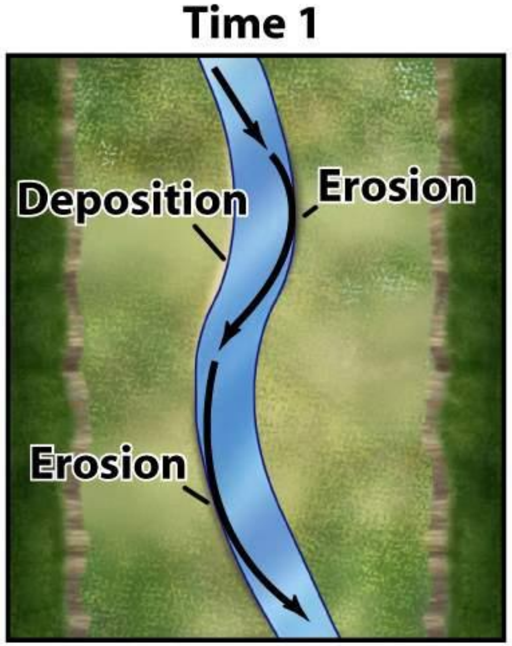
Meandering Streams

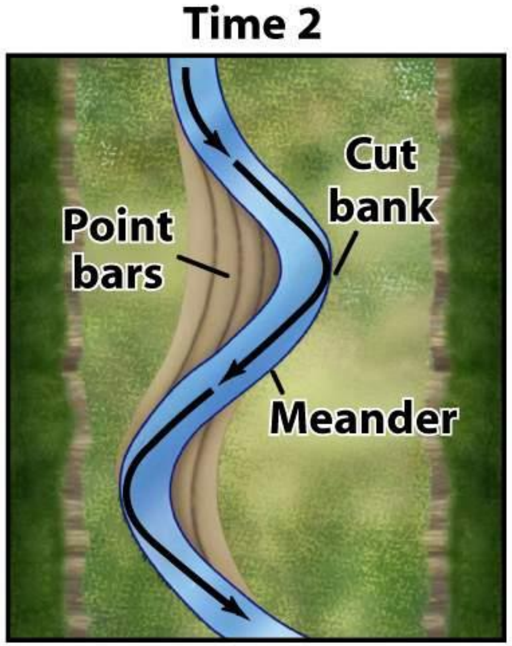
- Have sinuous, looping curves (meanders). They form where:
  - the stream gradient is low.
  - the substrate is soft and easily eroded.
  - the stream exists within a broad floodplain.
- Meanders evolve during times of flood.



Meandering Streams

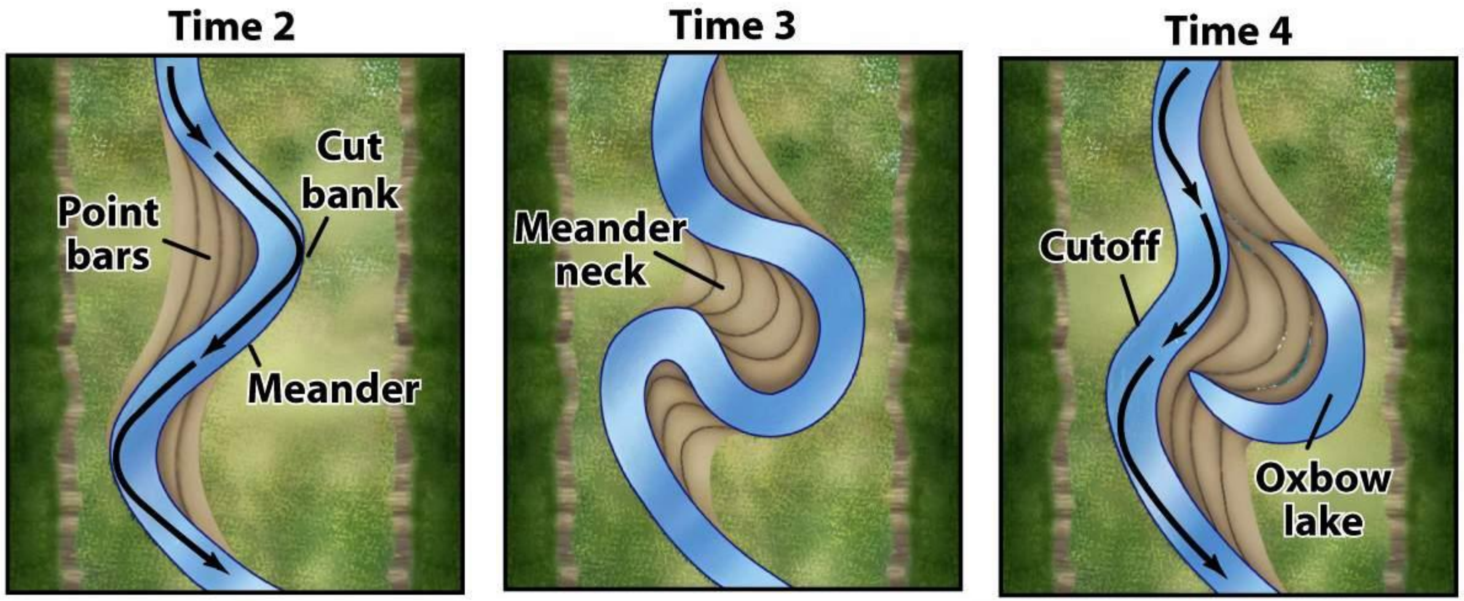
- The channel is modified during periods of flood.
  - Fast part of current swings back and forth.
  - Momentum increases during flood, erodes outside bank.
    - Curves migrate downstream with time.
    - Fast water erodes the outside stream bank.
    - Slower water deposits point bars on inner part of curve.





Meandering Streams

- Curves migrate downstream during flood events.
  - Sinuosity increases.
  - Floodwaters may overtop or cut an outside bank to create a shorter pathway downstream, cutting off meander neck.
  - Oxbow lake is formed from cutoff meander.



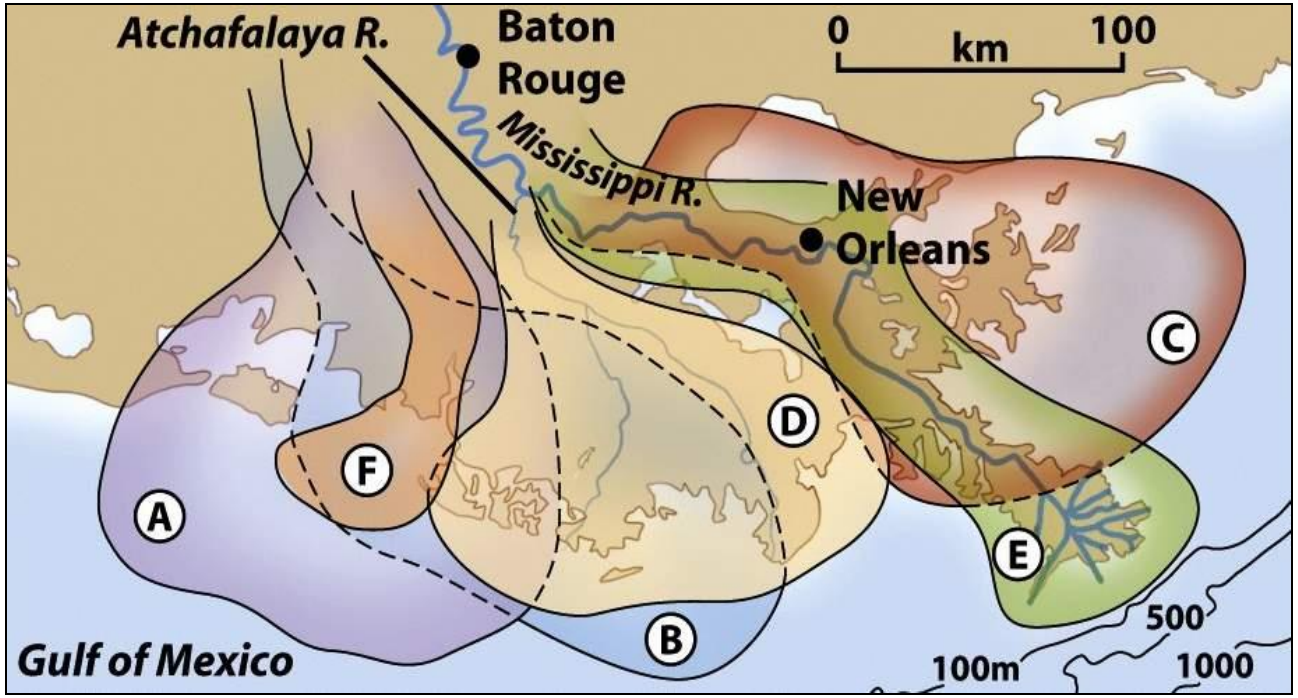
Deltas

- A delta forms when a stream enters standing water.
  - Stream divides into a fan of distributaries.
  - Velocity slows; sediment drops out.
- Delta morphology is a dynamic balance of sediment load, waves and storms, tides and slumping.
  - Bird's-foot
  - Arc-like
  - Δ-shaped

Deltas

- The Mississippi is a sediment-dominated delta.
  - Lobes indicate long-lasting distributaries.
  - Active lobes grow in size and elevation.
- In flood the river may break through a levee—avulsion.
  - Flow jumps to a more direct path to the Gulf of Mexico.

Delta deposit	Age (years)
Ⓕ	400 b.p. – present
Ⓔ	1,000 b.p. – present
Ⓓ	2,500 b.p. – 800 b.p.
Ⓒ	4,000 b.p. – 2,000 b.p.
Ⓑ	5,500 b.p. – 3,800 b.p.
Ⓐ	7,500 b.p. – 5,000 b.p.



Floods

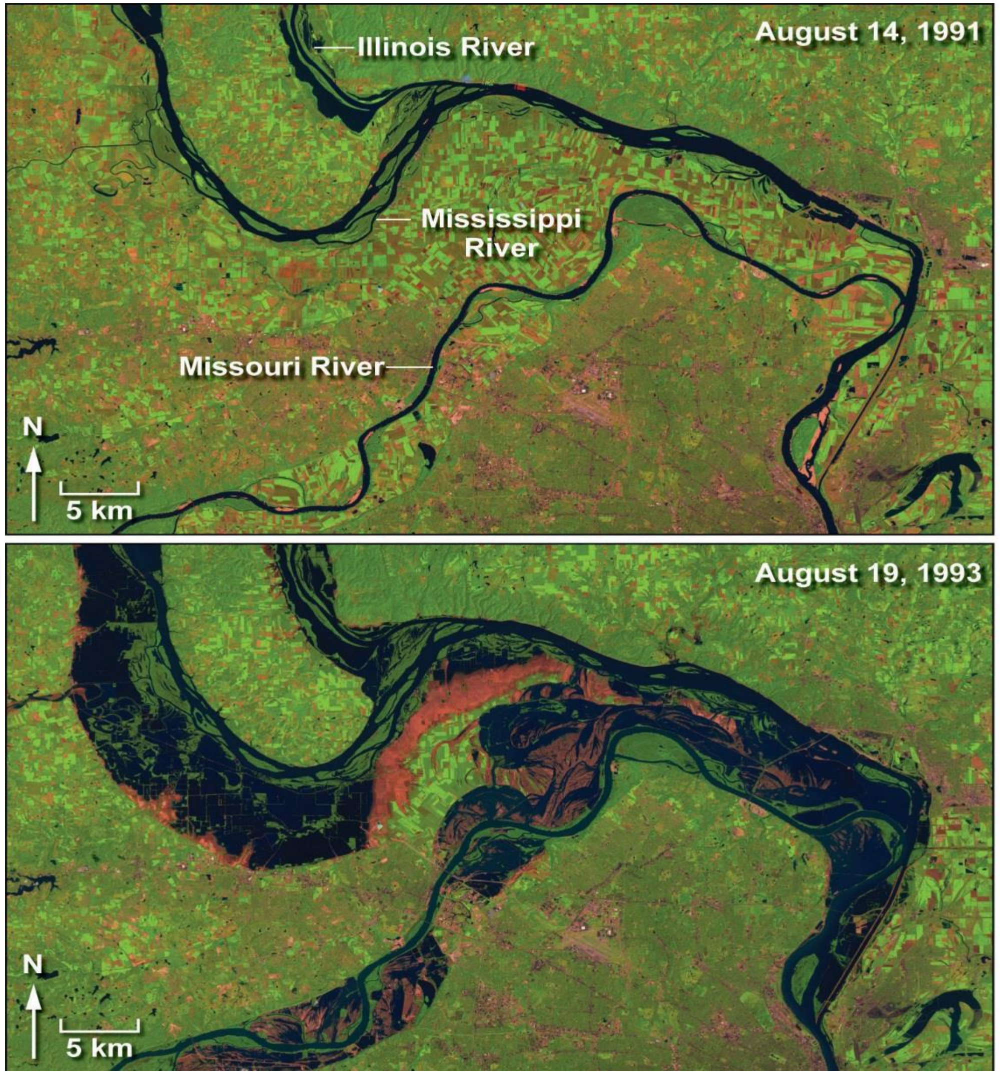
- Floodwaters devastate property and ruin buildings.
  - Floods occur when flow exceeds channel capacity.
  - Water overflows the channel onto adjacent land.
  - Fast-moving water from channel flows onto floodplain, slows down and drops sediments, sometimes forming natural levees.

Raging Waters

- Seasonal floods occur during a “wet season.”
  - Rainfall is heavy or snow begins to melt.
  - Tropical regions during monsoon season
  - Temperate regions when heavy winter snowpack melts
  - Cause floodplain floods or delta-plain floods.

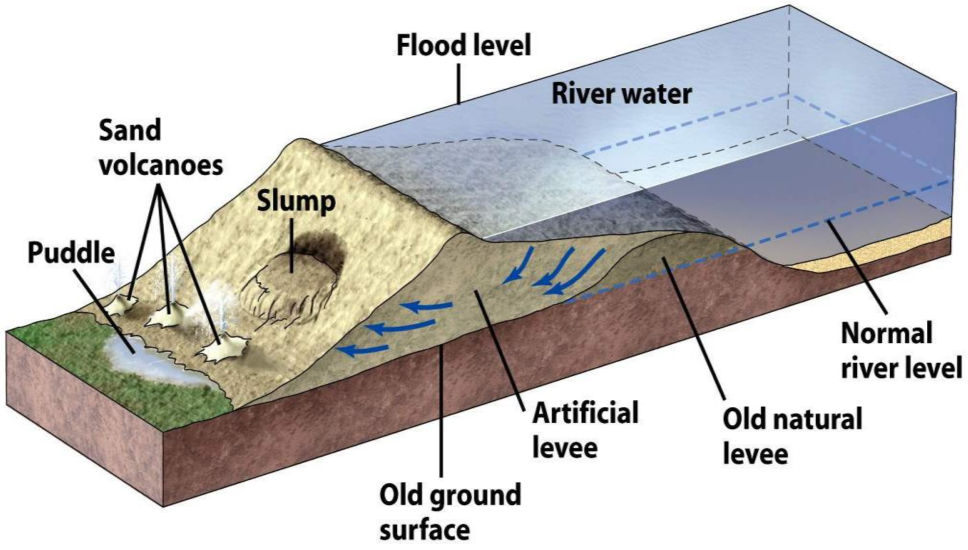
Raging Waters

- Case history: Mississippi and Missouri Rivers, 1993
  - Excess rainfall and snowmelt across region
  - Summer floodwaters invaded huge areas.
    - Covered 40,000 mi^2
    - Flooding lasted 79 days
    - 50 people died
    - 55,000 homes destroyed
  - $12 billion in damage



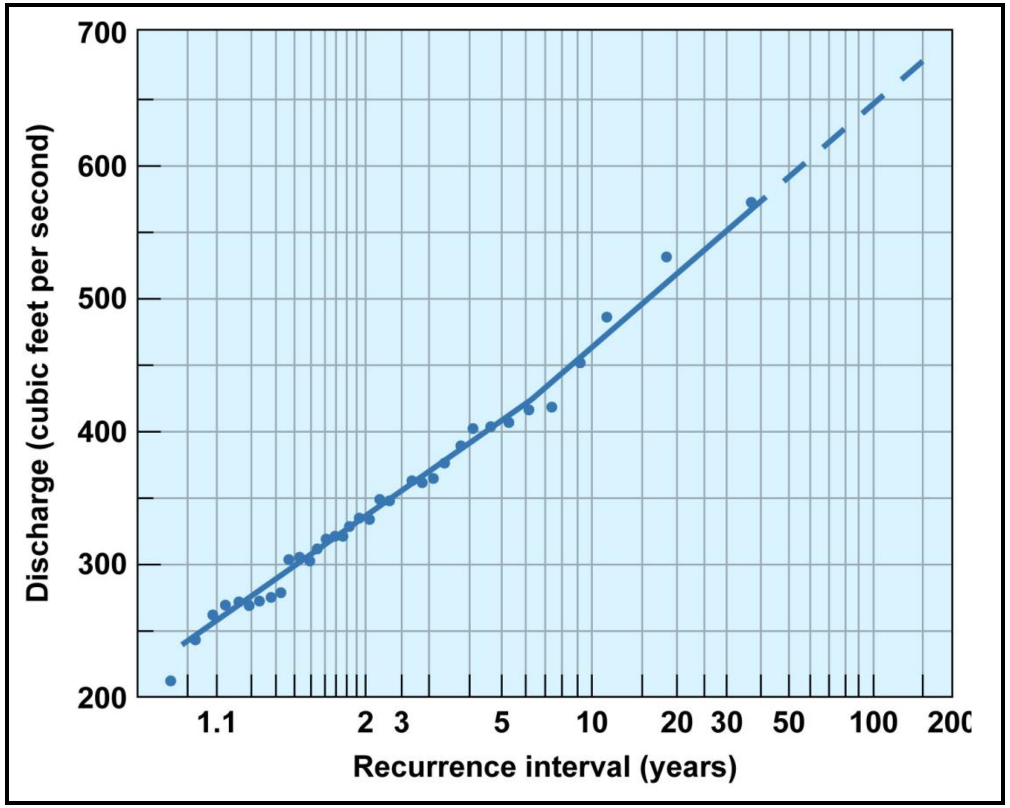
Living with Floods

- Flood control is expensive and ultimately futile.
- Levees and flood walls prevent overflow to floodplains.
  - Artificial levees transmit flood problems downstream.
  - Levees may be overtopped or undermined.
  - 1993, Mississippi River
  - 2005, New Orleans



Evaluating Flood Hazard

- Flood risks are calculated as annual probabilities.
  - Recurrence interval is the average number of years between floods of a particular size.
  - A 100-year flood means 1% risk of such a flood in 1 year.



Evaluating Flood Hazard

- Collect hydrologic data and make flood-hazard maps
  - 1% annual probability (100-year floods)
  - 0.2% annual probability (500-year floods)
- Maintain flood-control structures

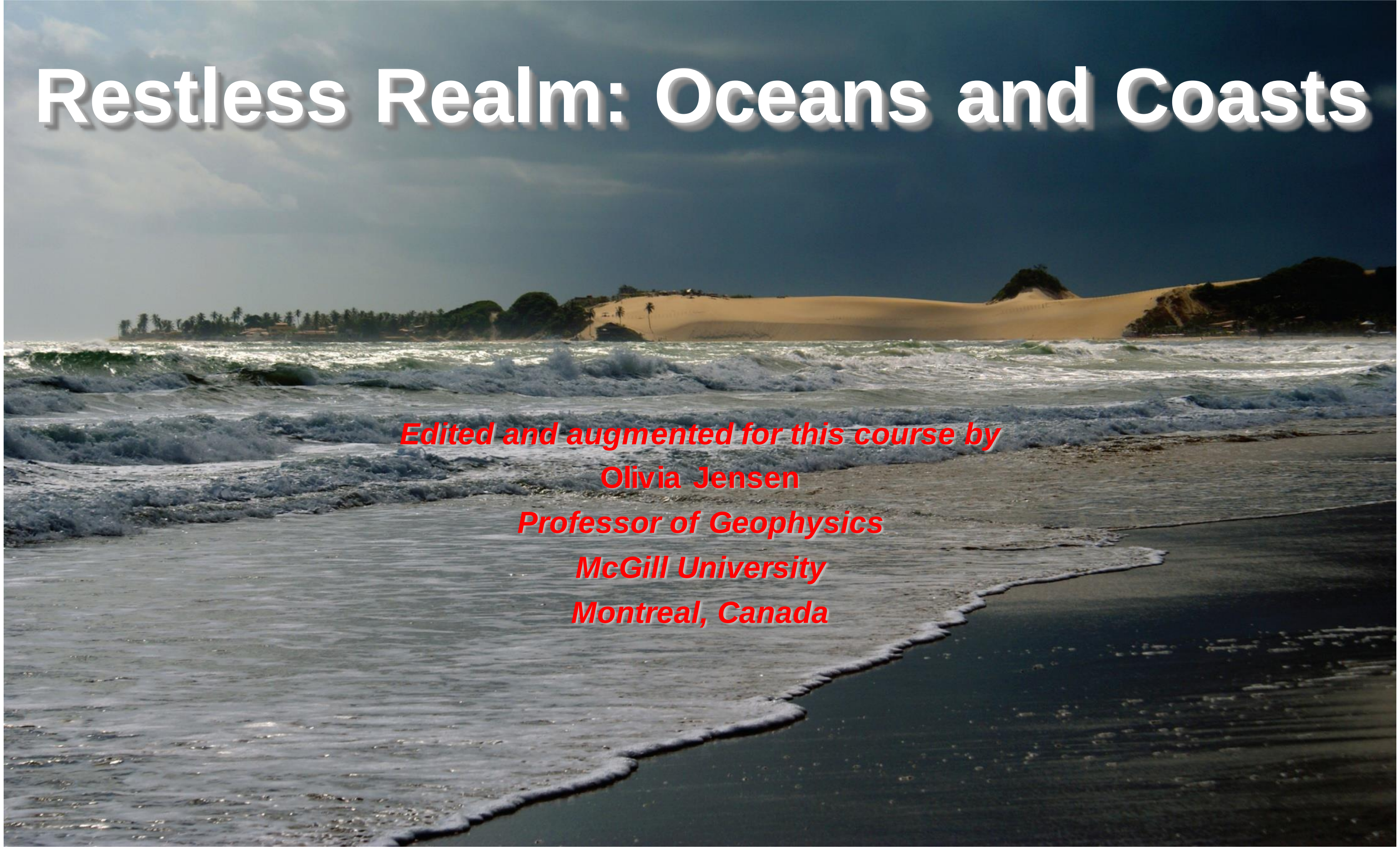
Calgary 2013

Since 1892, there have been two larger floods in Calgary

Vanishing Rivers

- Over time, humans have been overusing/abusing rivers:
  - Pollution
  - Dam construction
  - Overuse of water
  - Urbanization & agriculture

The Colorado River doesn't reach the sea



Restless Realm: Oceans and Coasts

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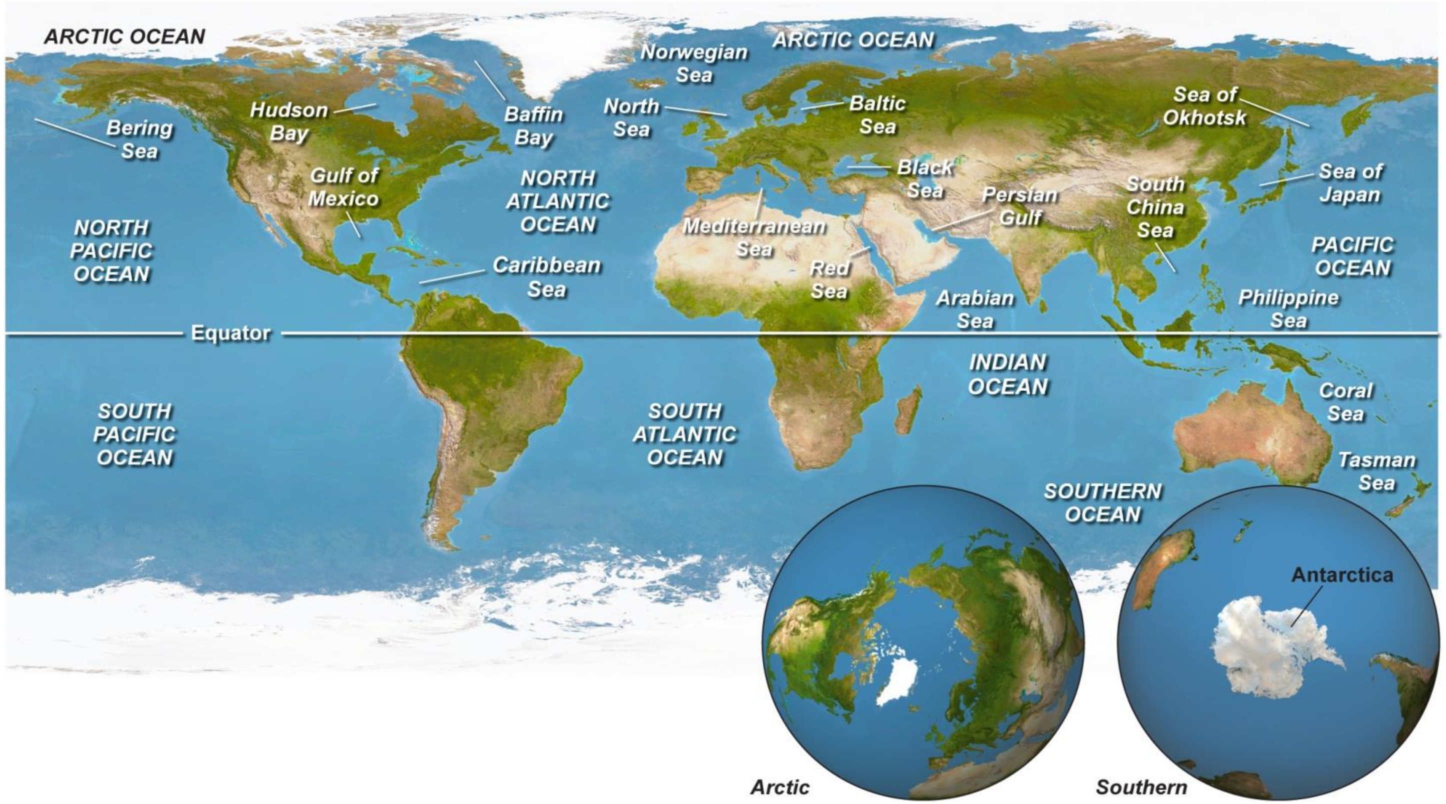
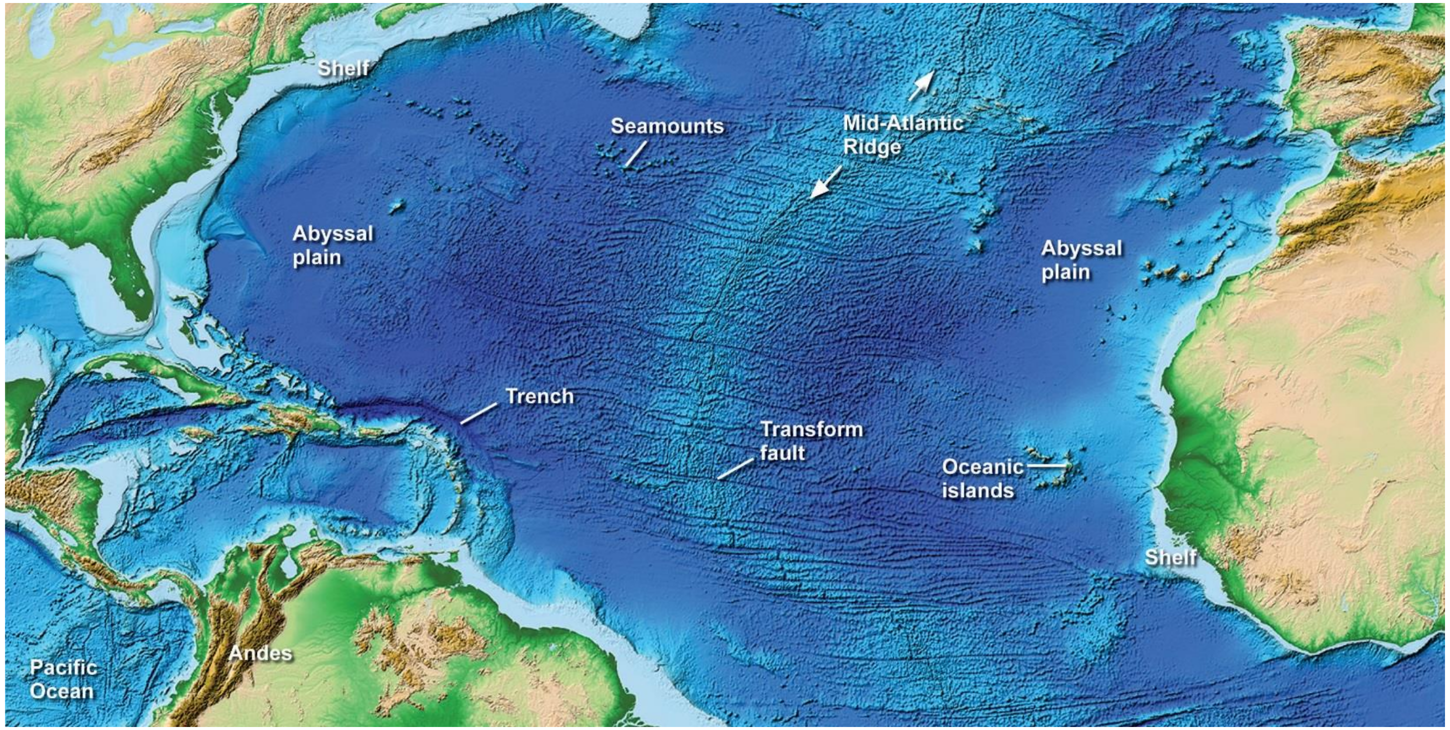
Introduction

- Oceans cover 70.8% of the planet. Oceans:
  - Essential for both marine and terrestrial life
  - Regulate weather and climate
  - Play a key role in geochemical cycles (including CO_2)



Undersea Landscapes

- **Bathymetry = depth variations and bottom topography of the sea floor.**
  - **Plumb line (pre-20th century)**
  - **Sonar measurements (mid-20th century)**
  - **Satellite surveys (recent decades)**

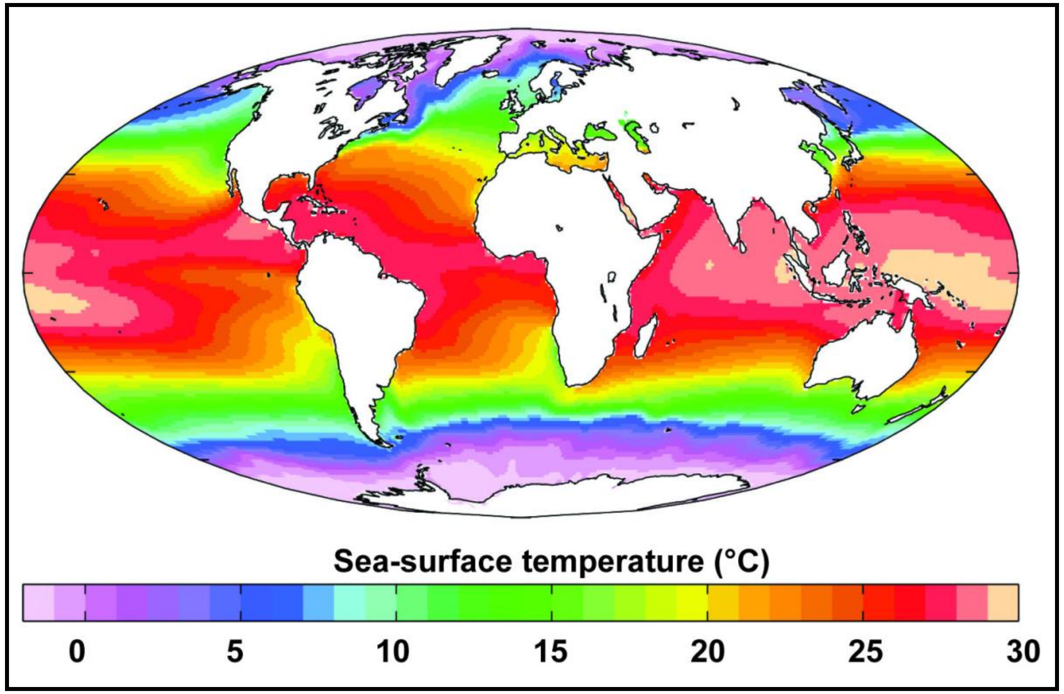


Ocean Water Composition

- Normal marine salinity averages 3.5% by mass.
  - Salinity varies with location; ranges about 1.0–4.1%.
  - Salinity reflects balance between addition of freshwater by rivers and removal by evaporation.
  - Evaporating all water would result in 60m thick salt layer:
    - Halite (NaCl)
    - Gypsum ($CaSO_4 \cdot 2H_2O$)
    - Anhydrite ($CaSO_4$)

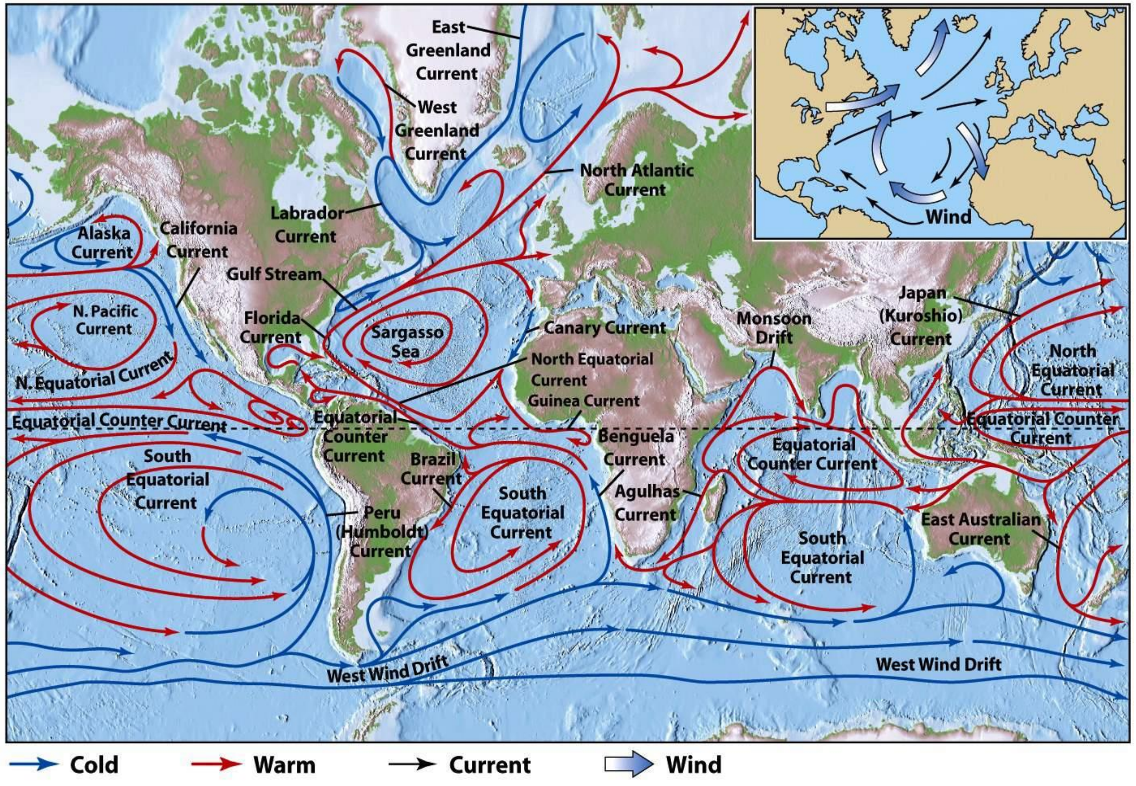
Ocean Water Temperature

- Surface temperatures are warm at equator, cool at poles.
  - Global average ~ 17°C; Max ~35°C; min -1°C
- Temperature becomes more uniform with depth.
  - Bottom nearly uniform, near freezing ~4C
  - Rapid transition from warm surface waters to cold deep water is the *thermocline*.



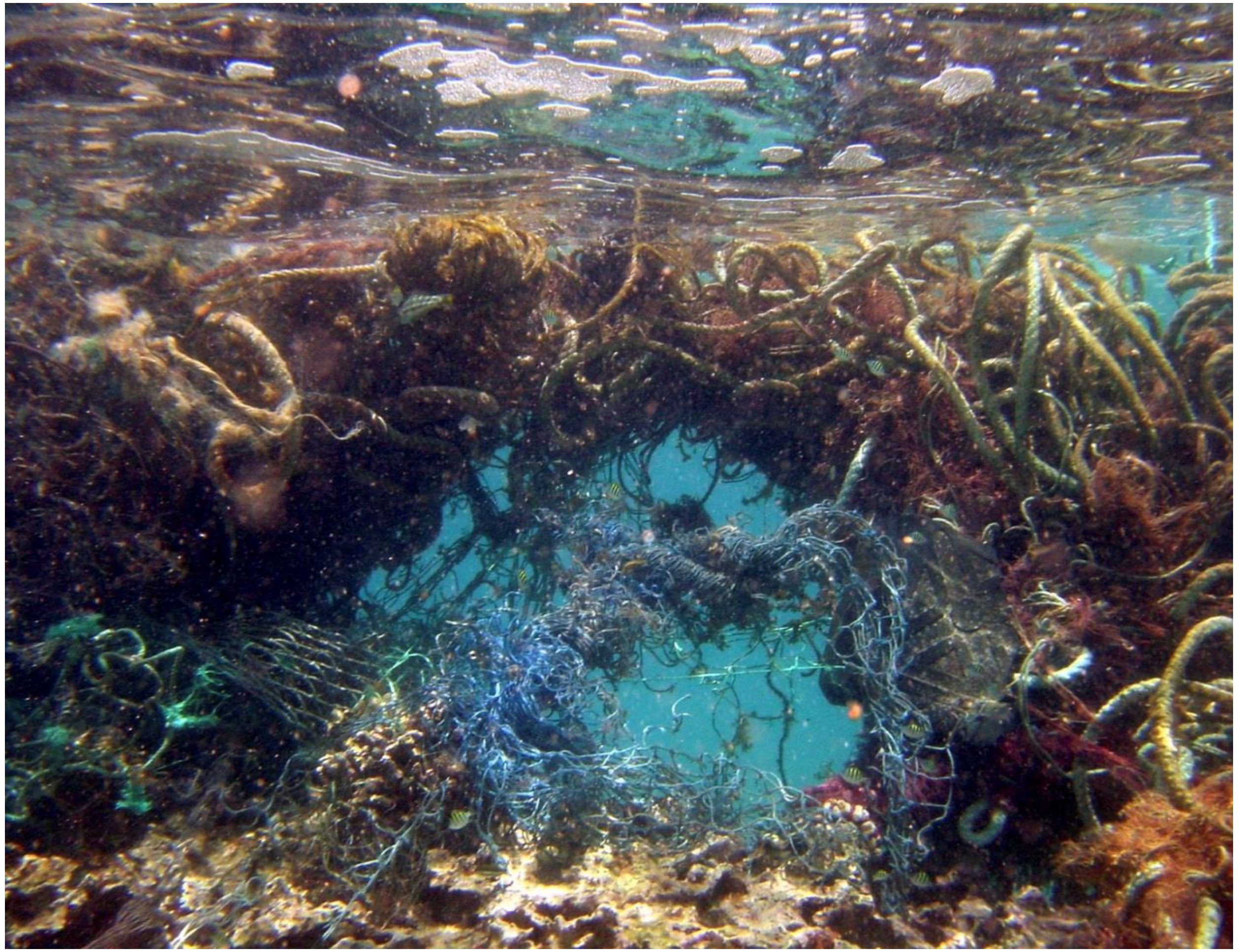
Ocean Currents

- Currents move ocean water in three dimensions.
- Surface currents (upper 100 m) due to wind shear.
- Deep currents keep the rest of the water in motion.
- All currents are modified by the Coriolis deflection:
  - Currents flow in large circles (gyres).
  - Direction of flow is different in northern and southern hemispheres.



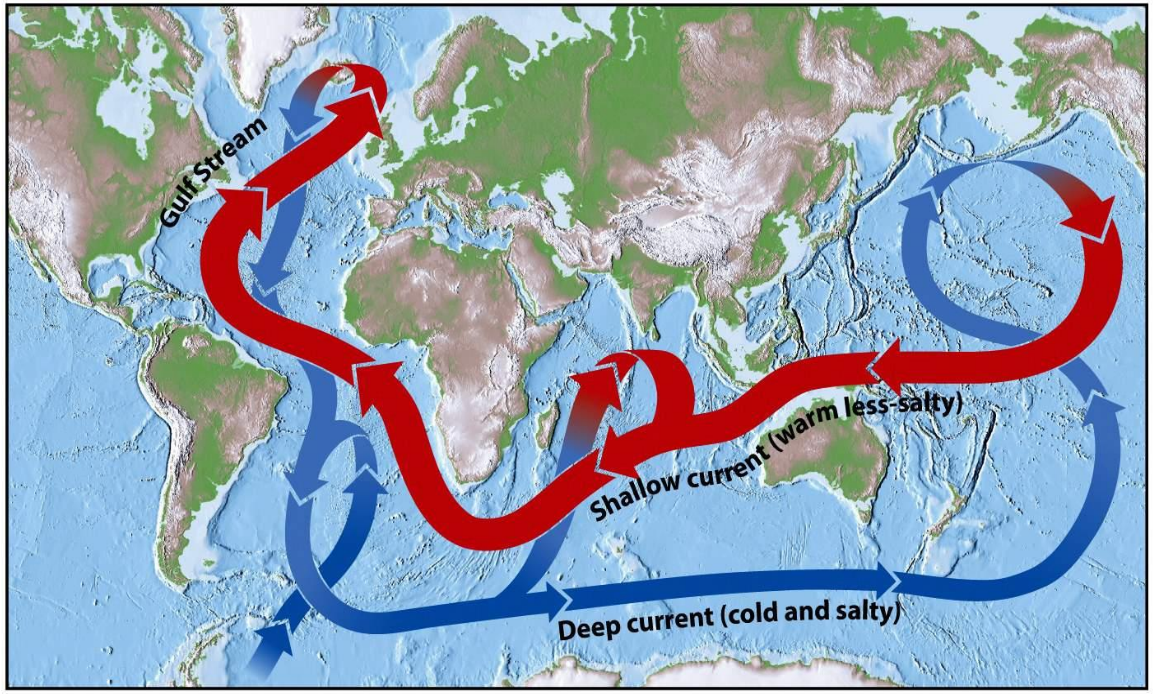
The Coriolis Effect

- In large oceans, the Coriolis effect forms nearly closed cells (gyres) that trap biologic materials and debris.
- Examples:
  - Sargasso Sea
  - North Pacific gyre, a.k.a. "Great Pacific Garbage Patch"



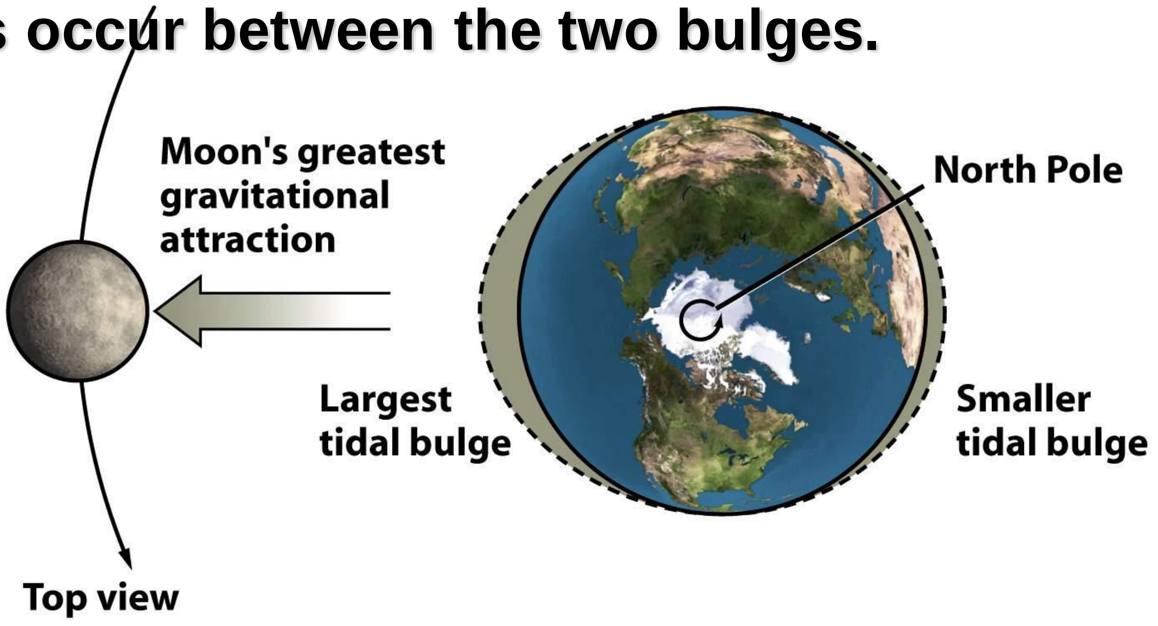
Thermohaline circulation

- Worldwide, linked flow called "global conveyor belt."
  - Sinking of waters occurs mostly at polar latitudes.
  - Warmer surface waters flow from tropics in response.
  - Flow toward poles transfers heat away from tropics.
- Important regulator of global climate



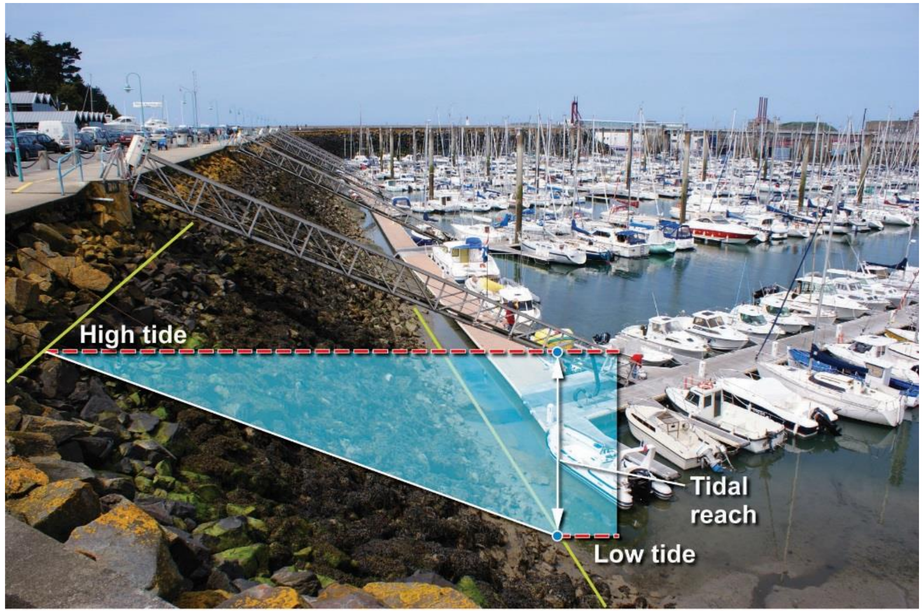
Tides

- Tide-generating force results in two tidal bulges.
  - Highest tides align with position of the Moon
    - Moon’s gravitational pull is strongest of contributors to force.
    - Sun’s attraction is weaker, contributing about 30% of force
  - Secondary bulge (opposite side of Earth)—is also high tide.
  - Low tides occur between the two bulges.



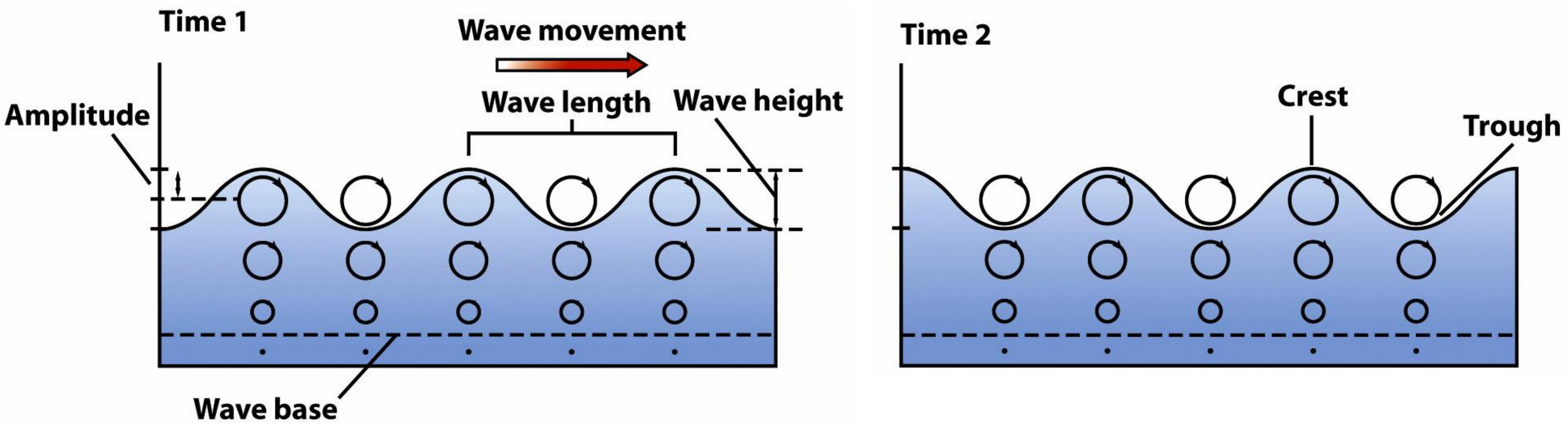
Tides

- Tides rise and fall twice daily along most coastlines.
  - Timing and magnitude varies with coastal configuration.
- Tidal reach = elevation change between high, low tides.
  - Largest tidal reach on Earth is Bay of Fundy, Canada = 16.8m.
  - The intertidal zone lies between tides.



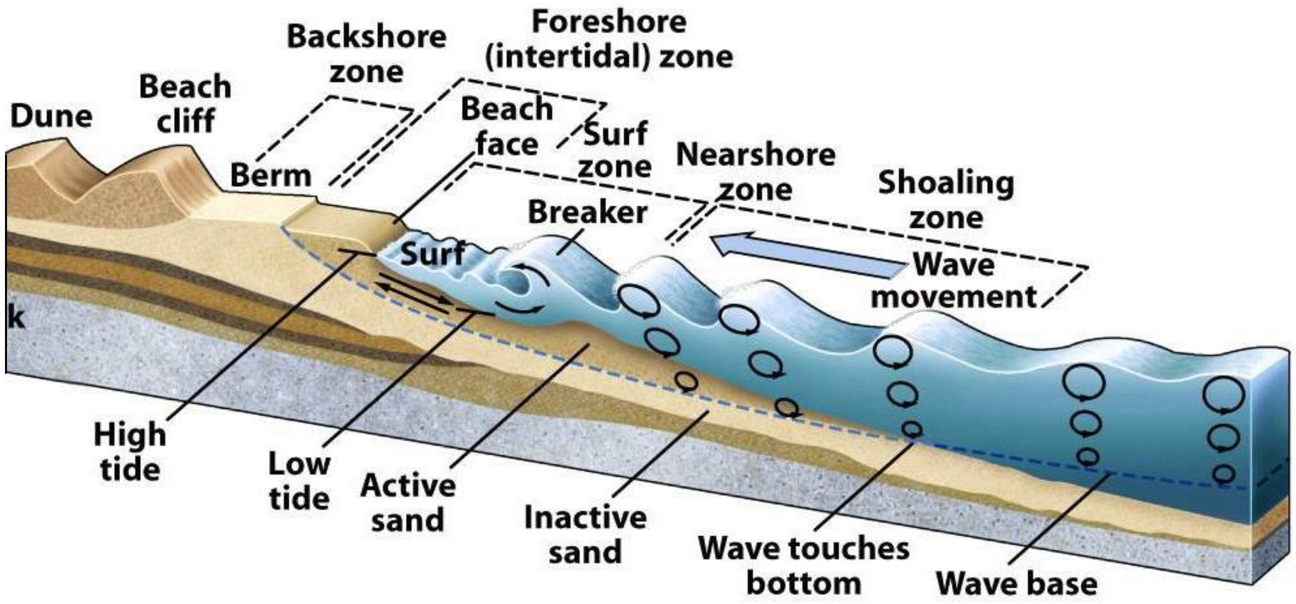
Waves

- Water molecules in a wave move in a vertical ellipse.
  - Ellipse diameter is largest at surface, decreases with depth.
  - Wave base is depth at which there is no more movement.
    - Wave base is equal to ½ wavelength.
    - Wavelength is distance between successive wave crests.
    - Waves have no effect on deep ocean floor below wave base.



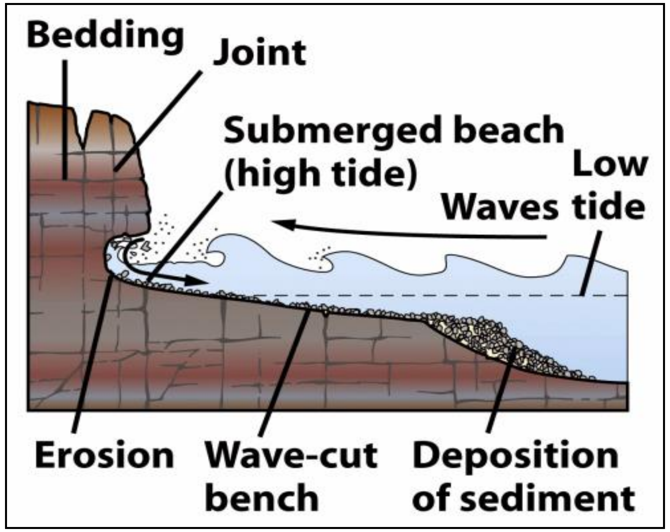
Waves

- As a wave approaches shore, wave base hits sea bottom.
  - Drag at sea bottom slows the bottom part of wave.
  - The upper part of wave continues at unchanged speed.
  - Wave slows, oversteepens, forms breakers, crashes.
  - Backwash drags eroded materials from shoreline.



Rocky Coasts

- Over time, wave erosion may form a wave-cut bench.
  - Wave-cut benches are often exposed at low tide.
  - May be uplifted as terraces along some coastlines.



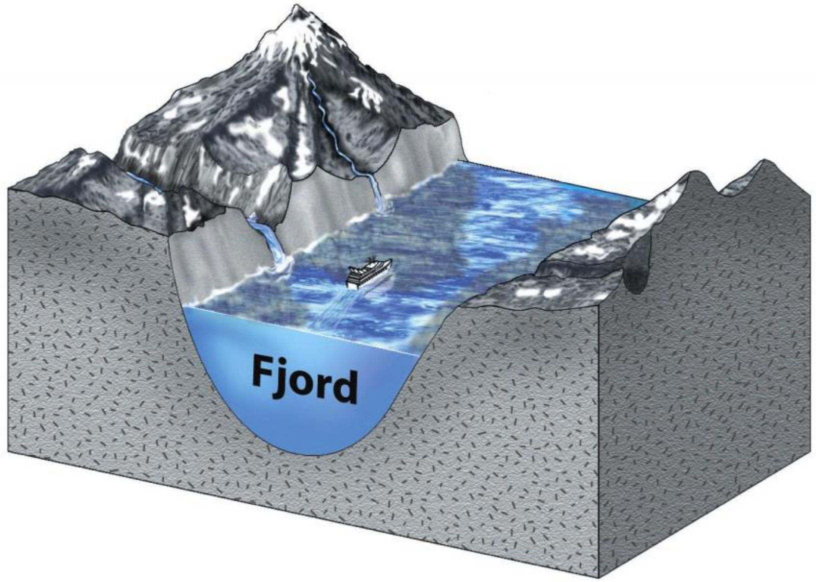
Estuaries

- Estuaries: where rivers meet the sea
  - Characterized by mixing of freshwater and seawater
  - Modern estuaries formed by sea-level rise (deglaciation)
    - Rivers carved canyons during sea-level lows.
    - Sea-level rise inundated the canyons.
    - Sediments dropped out as base level rose.
  - Complex ecosystems
    - Organisms adapted to large changes in salinity.
    - Valuable fisheries resources


Cowichan Estuary
Photo by Pamela Williams

Fjords

- Glacier-carved, deep, U-shaped valleys found at sea level
  - Flooded as sea levels rose and glaciers retreated
  - Common along rocky coastlines in polar and subpolar regions

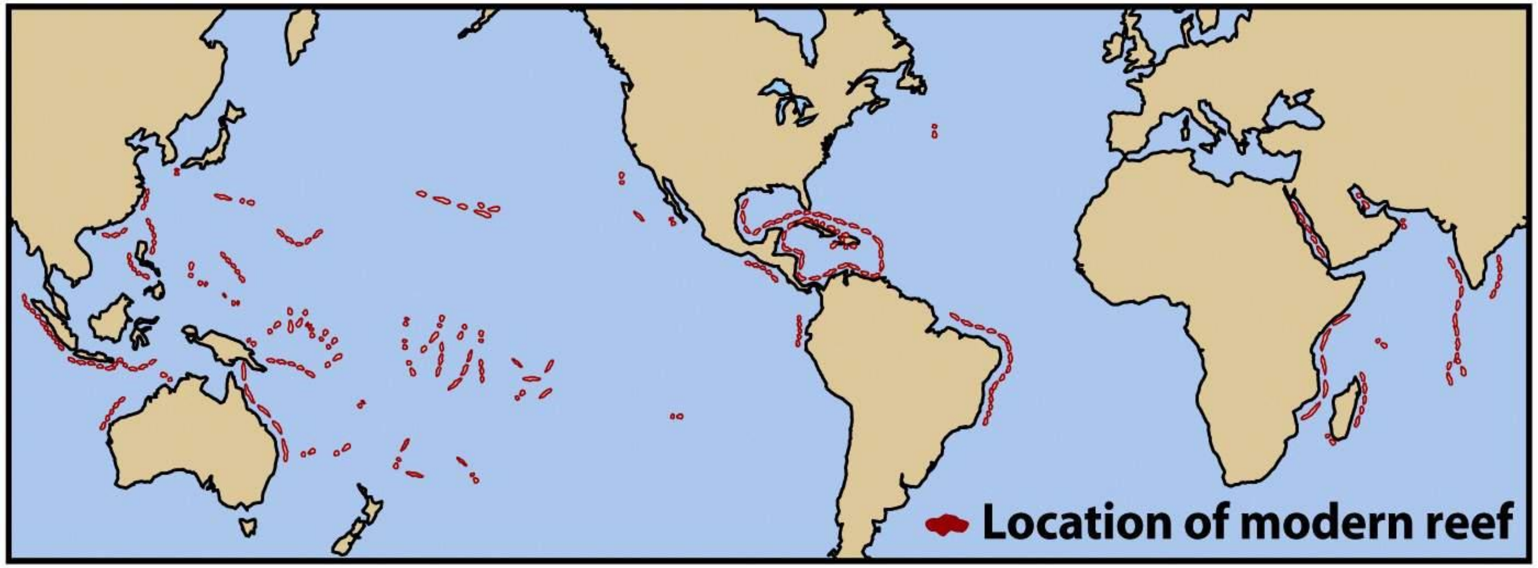


Coastal Wetlands

- Gentle slopes, low wave action, extensive vegetation
- Cover large areas of coastal regions
  - Brackish swamps, marshes, bogs
  - Mangrove swamps in tropics and subtropics
- High biological productivities
  - Sometimes called “organic coasts”

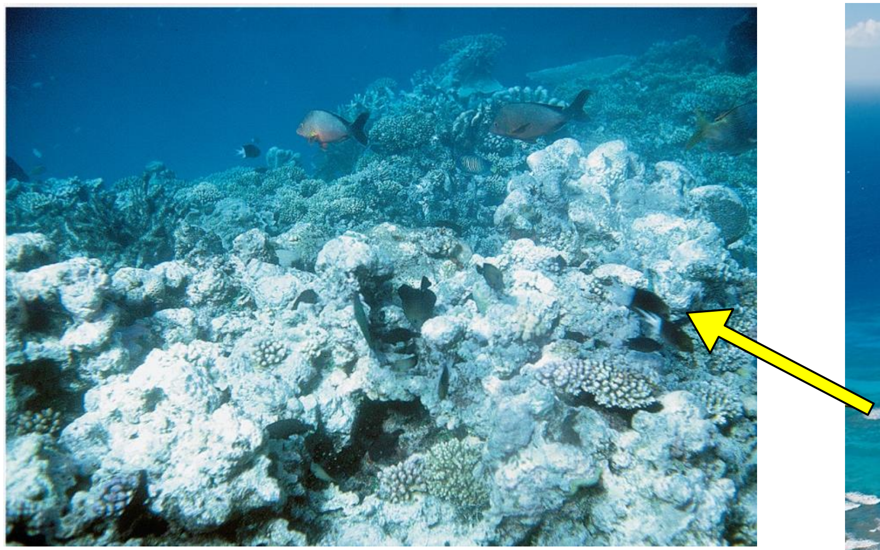
Coral Reefs

- Calcite-rich structures with skins of living organisms
- Shallow, clear, warm, well-lit, normal-salinity water
  - Generally between 30ºN and 30ºS latitude
  - Water temperatures 18–30ºC
  - Corals range from just below low tide level to 60 m depth



Coral Reefs

- Corals have a range of forms:
  - Brains, antlers, fans, mounds
- Many associated organisms live on and around coral.
  - Sea anemones, sponges, corals, many fish
- Barrier reefs protect coastlines.



Causes of Coastal Variability

- **Plate tectonic setting determines the style of coastline.**
  - **Passive margin—broad, low-lying coastal plains common**
  - **Active margin—uplifted, rocky coasts dominate**

Coastal Variability

- Shoreline character strongly linked to sediment supply.
  - Balance between accumulation and erosion
    - Accretionary coasts—net sediment accumulation
    - Erosional coasts—net sediment loss

Coastal Problems and Solutions

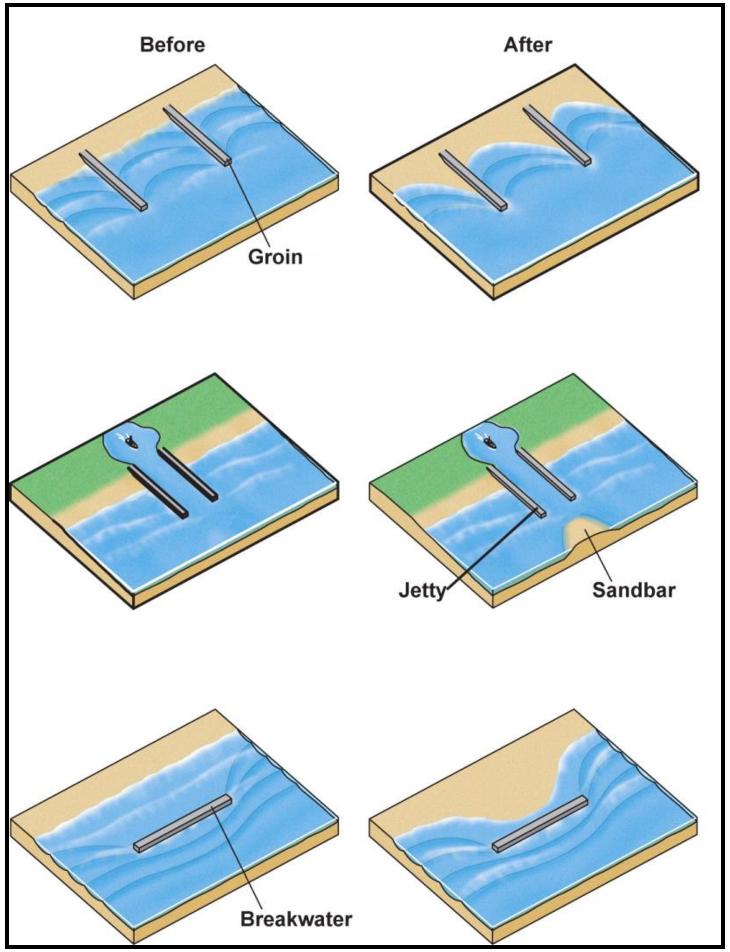
- **Contemporary sea-level changes:**
  - **Sea level is slowly rising! Global average ~3.5mm/year.**
  - **Rates of sea-level rise will increase greatly if ice sheets melt.**
  - **People living near sea level are at risk if ice sheets melt rapidly.**

Coastal Problems and Solutions

- Contemporary sea-level changes:
  - As sea-level rises, shoreline migrates landward.
  - Coastal erosion is accelerated.
  - Barrier islands migrate landward.
  - Mangroves and salt marshes are being destroyed, leaving coasts vulnerable to storm attack.

Coastal Problems

- Man-made barriers can reduce beach erosion.
  - Groins, jetties, and breakwaters slow sediment transport.
  - Unintended consequences:
    - Sediment builds up on up-current side.
    - Sediment loss occurs on down-current side.



Coastal Problems

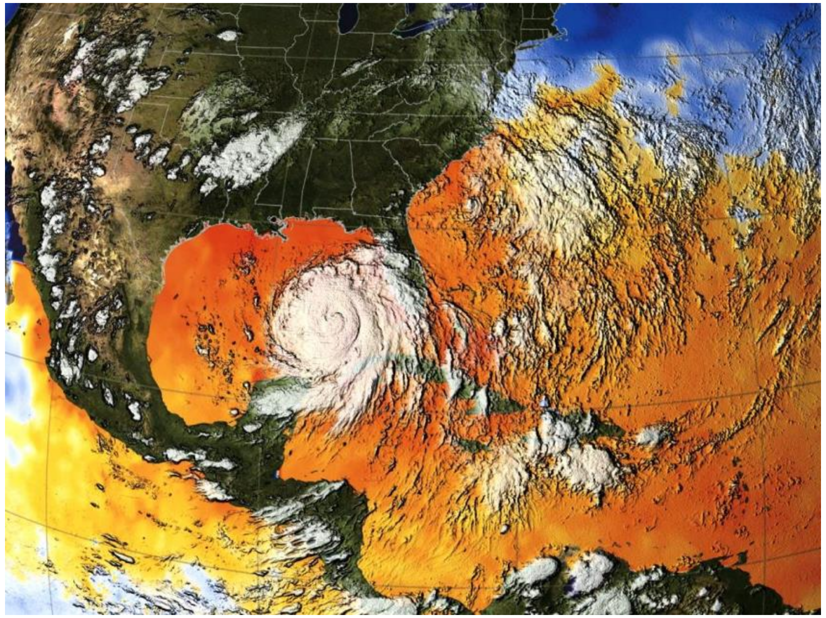
- Concrete or rock seawalls are temporary fixes against wave erosion.
- Seawalls may hasten erosion:
  - Wave energy is concentrated at the base of a seawall.
  - Seawalls fail during storms.

Coastal Problems

- **Destruction of Wetlands and Reefs**
  - **Chemical pollutants:**
    - **Oil spills and leaks (2010 BP Oil/*Deepwater Horizon* release).**
    - ***Dead zones* from fertilizer runoff and sewage releases.**
  - **Wetlands filled or drained for coastal development.**
  - **Reefs are damaged by boat collisions, anchors, dredging.**
  - **Chemical, particulate, and debris runoff from urban areas.**
  - **Estimates that 20–70% of wetlands, 90% of reefs destroyed**

Hurricanes—A Coastal Calamity

- Hurricanes develop in summer and late fall.
  - Cyclonic low-P "tropical disturbances" pull air inward.
  - Warm air flows over the ocean, absorbs moisture.
  - This air rises, cools, and condenses, forming clouds.
  - If enough moisture, large thunderstorms form and grow.
  - Over time, the storm gains size and strength.
    - Tropical disturbance
    - Tropical depression
    - Tropical cyclone
      - Rotating storm
      - Winds > 119 km/hr
      - 300–1500 km across



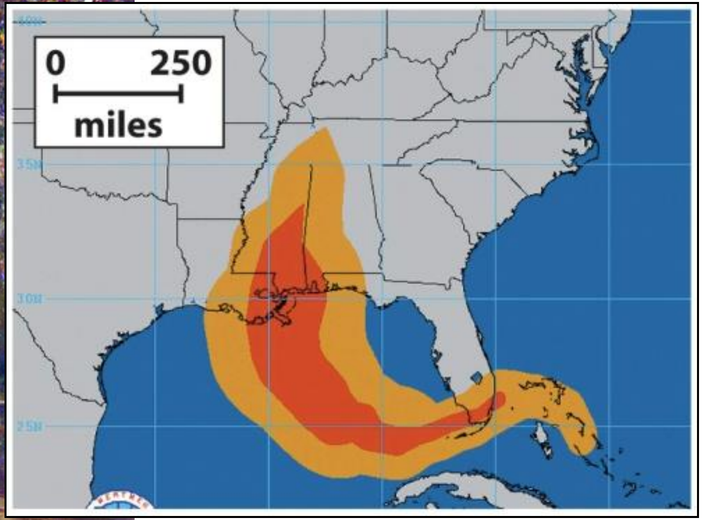
Hurricanes—A Coastal Calamity

- Tropical cyclones are called:
  - Hurricane in Atlantic & eastern Pacific
  - Typhoon in western Pacific
  - Cyclone around Australia and India
- In Atlantic, hurricane tracks move north and west, often crossing land.
- Storms die out when they run out of warm water.
- Strength classified using Saffir-Simpson Scale.
  - 1 (weakest) to 5 (strongest)

https://en.wikipedia.org/wiki/List_of_retired_Atlantic_hurricane_names

Hurricane Katrina

- Katrina is the most destructive US hurricane on record.
  - Category 5 hurricane in Gulf of Mexico, 325km across
  - Weakened to Category 4, striking Louisiana & Mississippi
  - Record storm surge, rising 7.5m (25 ft.) above sea level



Hurricane Katrina

- Wreaked destruction on a grand scale.
  - Reshaped barrier islands.
  - Destroyed coastal marsh and croplands.
  - Wiped entire coastal communities off the map.

Hurricane Katrina

- New Orleans lies in subsiding region, 2 m below sea level.
- Lake Pontchartrain rose, topping levees and flood walls.
- 80% of New Orleans was under water.
  - Estimated losses of $80 billion
  - At least 1,300 deaths