A Hidden Reserve: Groundwater

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Groundwater

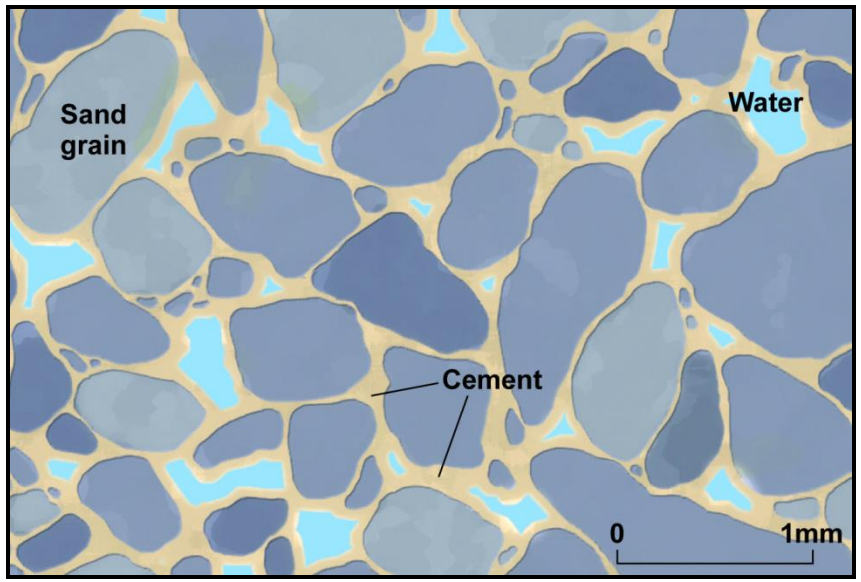
- **Significant amounts of water reside underground. Groundwater is:**
  - **a major component of the hydrologic cycle**
  - **a major source of water for a thirsty world**
  - **largely hidden from view; groundwater is:**
    - **poorly understood by many people**
    - **a precious resource that is susceptible to contamination**

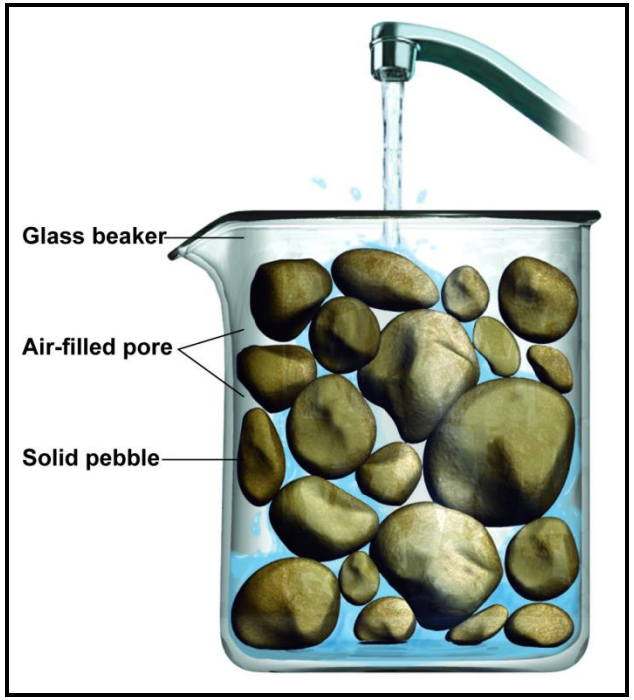
Groundwater

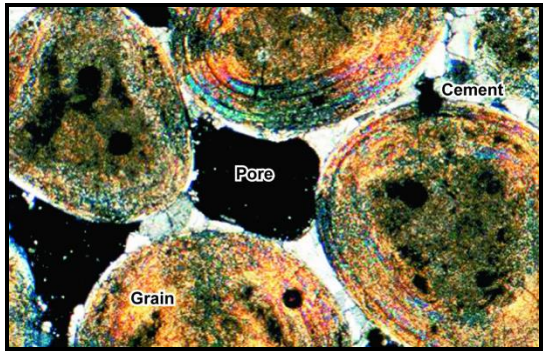
- Groundwater is a vital resource.
- Groundwater provides ~ 2/3 of freshwater resources:
  - Drinking water for people and livestock
  - Agriculture
  - Industry

Porosity

- **Two categories of porosity: primary and secondary.**
  - **Primary porosity—originally formed with the material.**
    - **Voids in sediment**
    - **Vesicles in basalt**
    - **Open-reef framework**







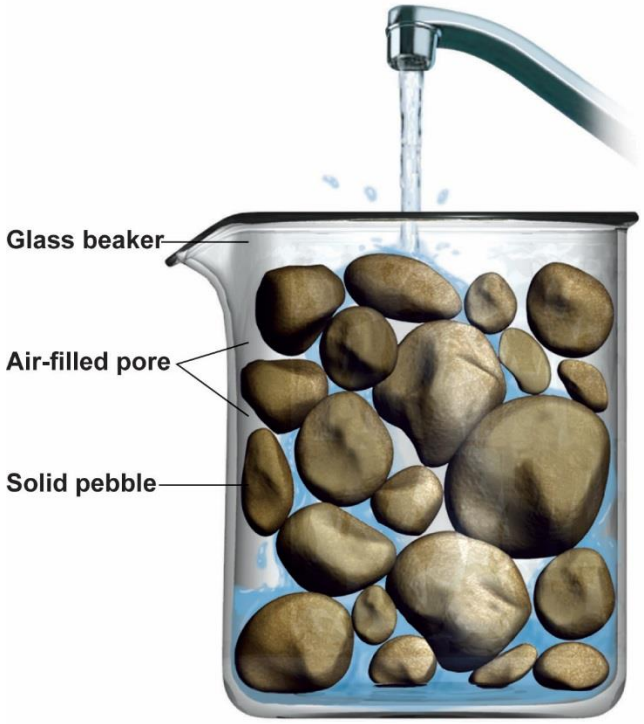
Porosity

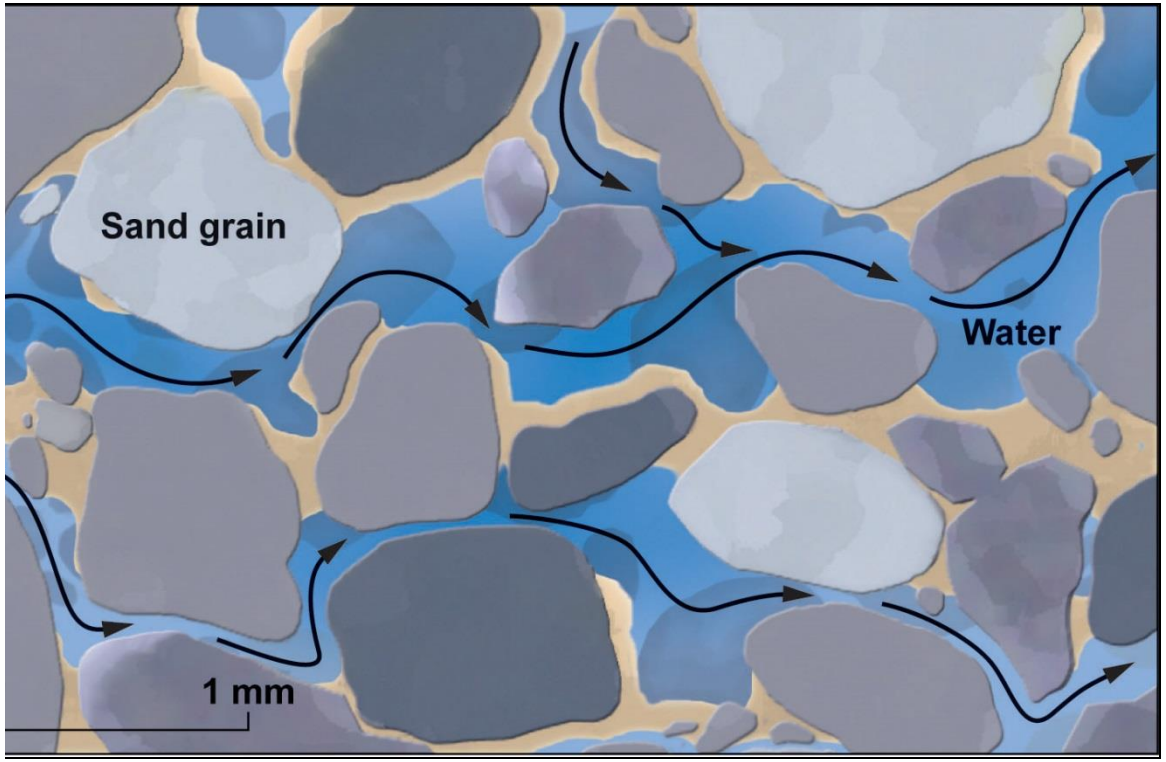
- **Two categories of porosity:**
  - **Secondary porosity develops later.**
    - **Fracturing**
    - **Faulting**
    - **Dissolution**

These fractures have been enlarged by dissolution.

Permeability

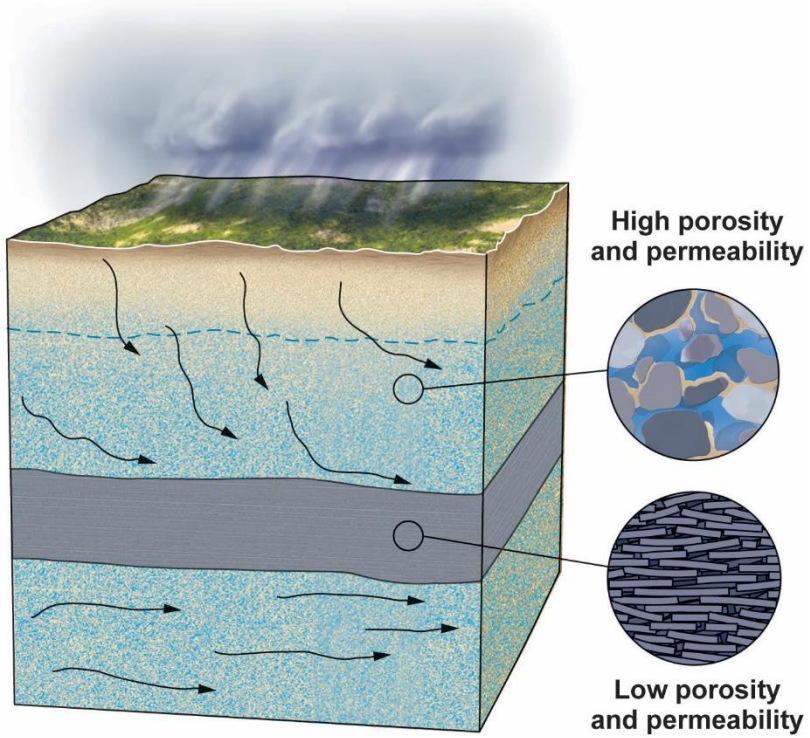
- The ease of water flow due to pore interconnectedness.
- Highly permeable material allows water to flow readily.
- Water cannot flow through impermeable material.
- Many large and straight flow paths enhance permeability.





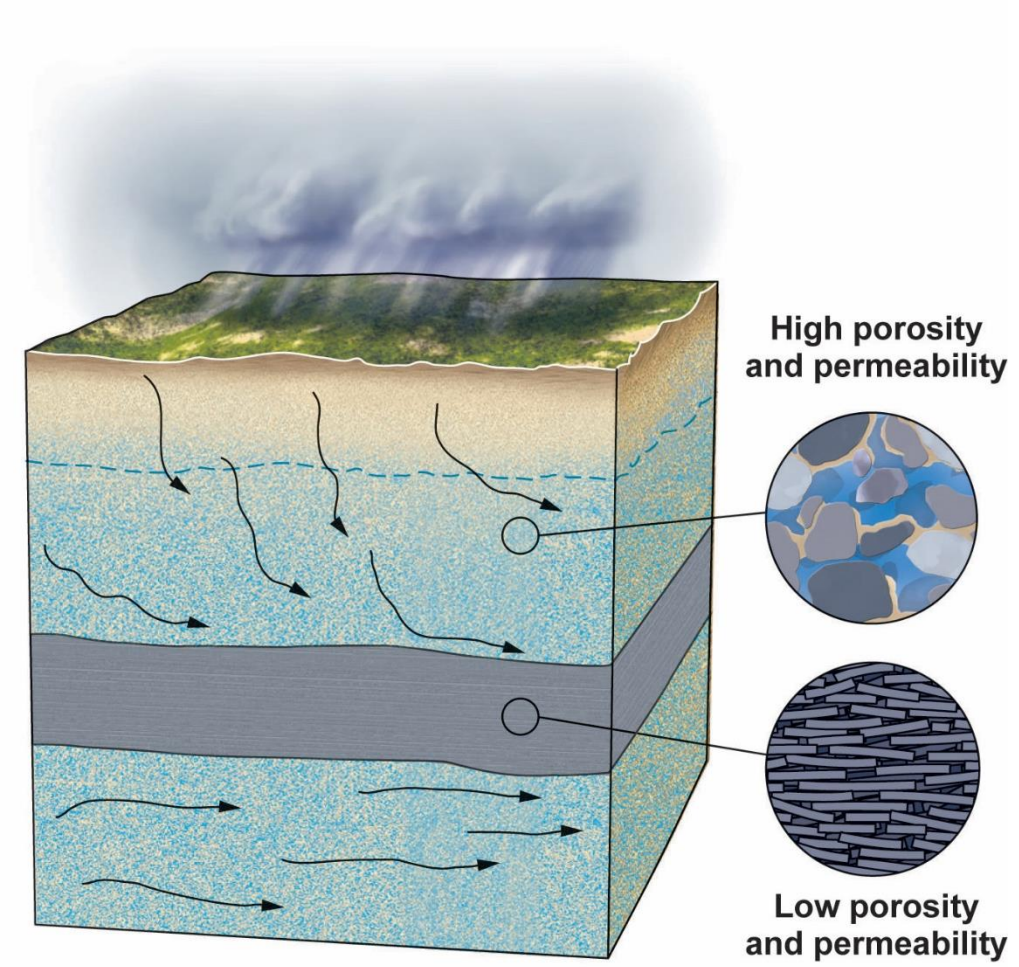
Aquifers and Aquitards

- **Aquifers and aquitards are commonly interlayered.**
  - **A: aquifer—sediment or rock that transmits water easily.**
  - **B: aquitard—impermeable or low permeability sediment or rock that hinders water flow.**



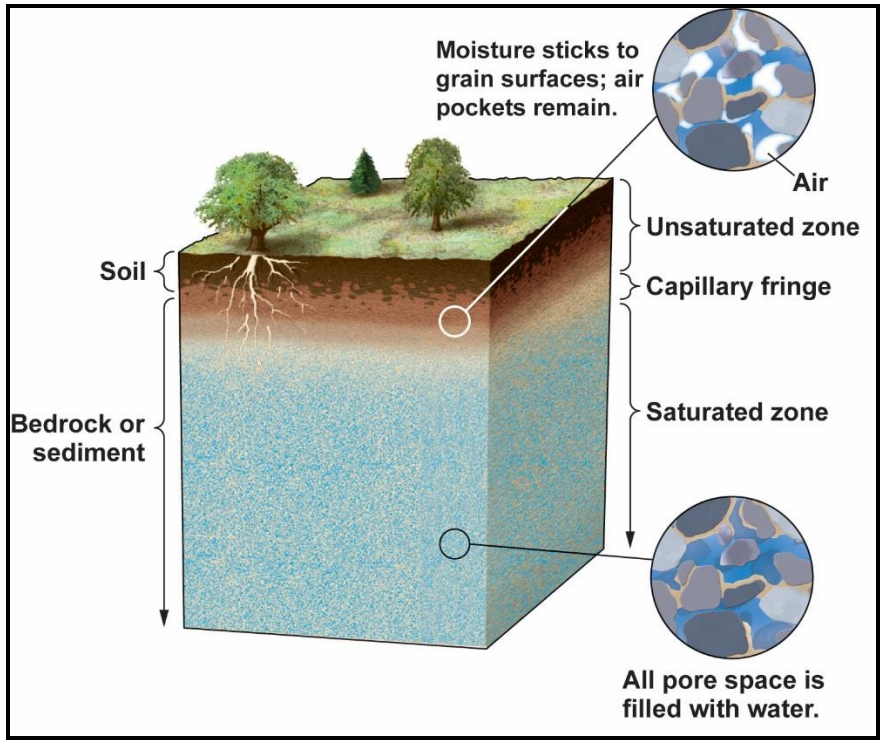
Aquifers and Aquitards

- **Unconfined—an aquifer that intersects the surface**
  - **In contact with the atmosphere**
  - **Easily contaminated**
- **Confined—an aquifer beneath an aquitard**
  - **Isolated from the surface**
  - **Less susceptible to pollution**



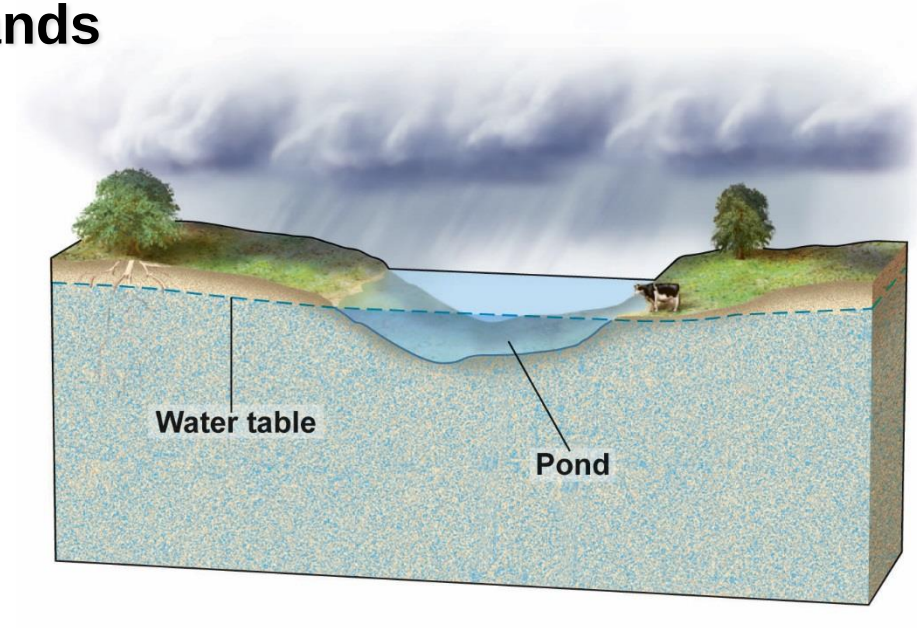
The Water Table

- The water table is a subsurface boundary.
  - Above the water table, pores are mostly filled with air.
    - This is called the unsaturated zone.
  - Below the water table, pores are filled with water.
    - This is called the saturated zone.
  - The capillary fringe separates the two zones.
    - Formed of moisture wicked upward above the water table.



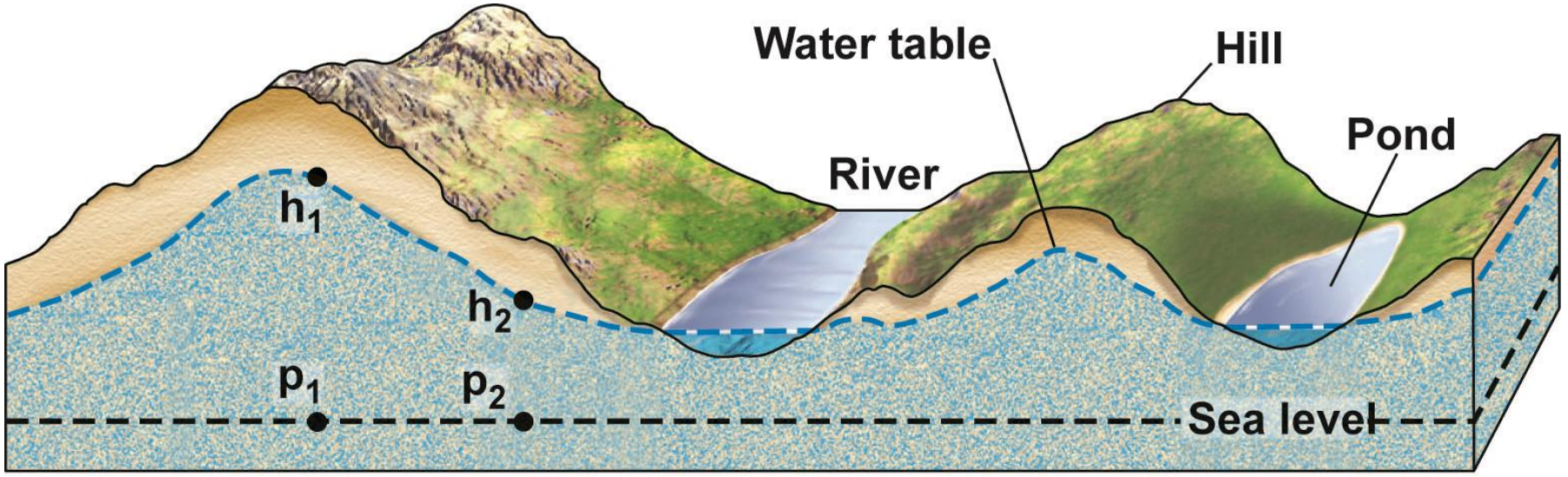
The Water Table

- The depth to the water table is variable.
  - In humid settings, the water table is closer to the surface.
  - In arid settings, it may be tens to hundreds of meters down.
- Perennial surface water marks the water table.
  - Streams
  - Lakes and ponds
  - Wetlands



Water Table Topography

- The water table is not flat; it is a sloping surface.
- The water table is a subdued replica of the topography.
  - The water table is high where the land is high.
  - The water table is low where the land is low.
- Water flows from higher elevations to lower elevations.
- Topography is useful for estimating groundwater flow.

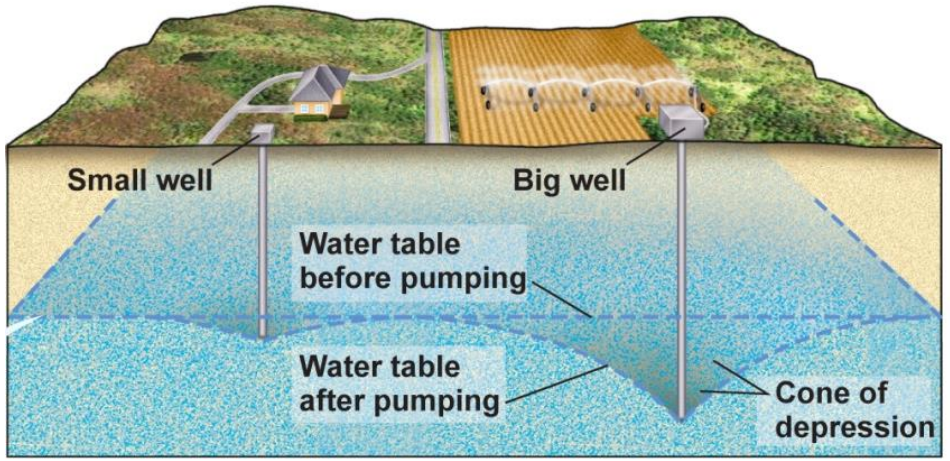


Tapping Groundwater Supplies

- Groundwater is obtained in two ways.
  - Wells—holes excavated or drilled to obtain water
  - Springs—natural groundwater outlets
- There are many types of wells and springs.

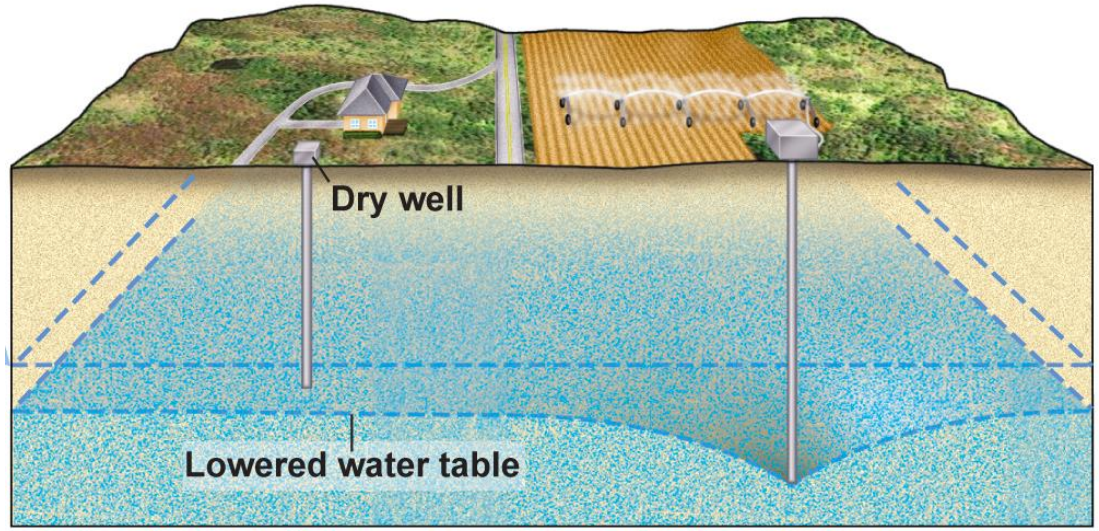
Tapping Groundwater Supplies

- With drawdown, the water table near the well drops.
- Water-table decline forms a cone of depression:
  - a downward-pointed conical-shaped surface
  - steepest near the well; flattens with distance
  - The cone may expand outward with continued pumping.



Tapping Groundwater Supplies

- Drawdown, from multiple wells in an area, is additive.
- Cones of depression often interfere.
  - A small well creates a small cone.
  - A large well creates a large cone.
  - One may dewater the other.
- Competing uses often conflict.

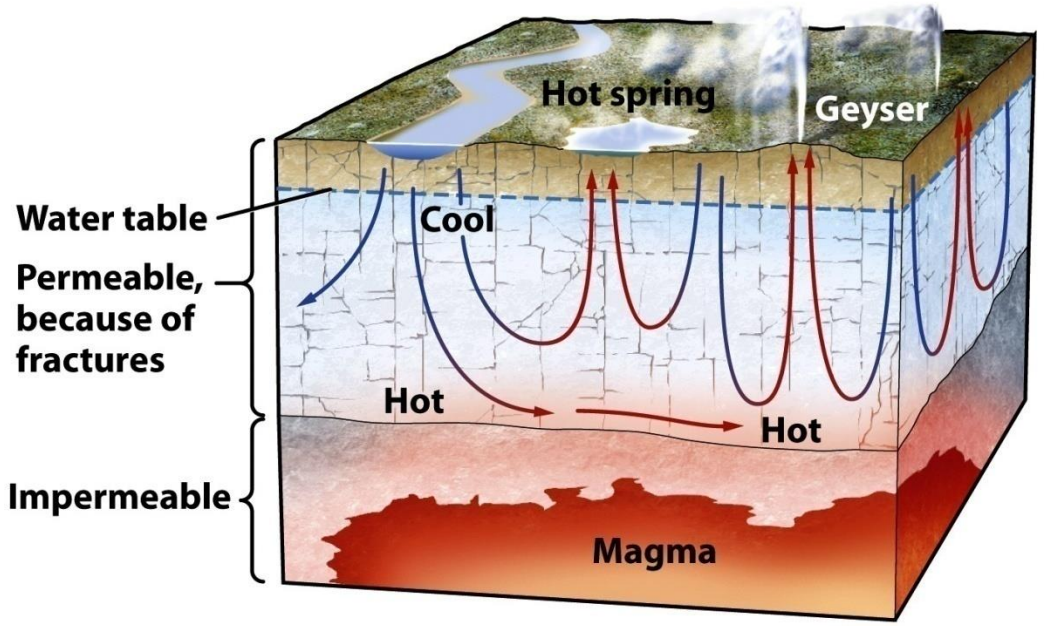


Hot Springs and Geysers

- Hot springs are groundwater discharges of hot water.
  - Temperatures range from 30ºC to 104ºC.
  - The waters are usually high in dissolved minerals.
- Hot springs develop in two settings:
  - where deep groundwater surfaces along faults
  - in geothermal regions

Hot Springs and Geysers

- **Where deep groundwater surfaces along faults:**
  - **Deep groundwater is warm.**
  - **The source of heat is the geothermal gradient.**
- **In geothermal regions:**
  - **High geothermal gradients are linked to shallow magma.**
  - **Circulation returns heated groundwater to the surface.**



Hot Springs and Geysers

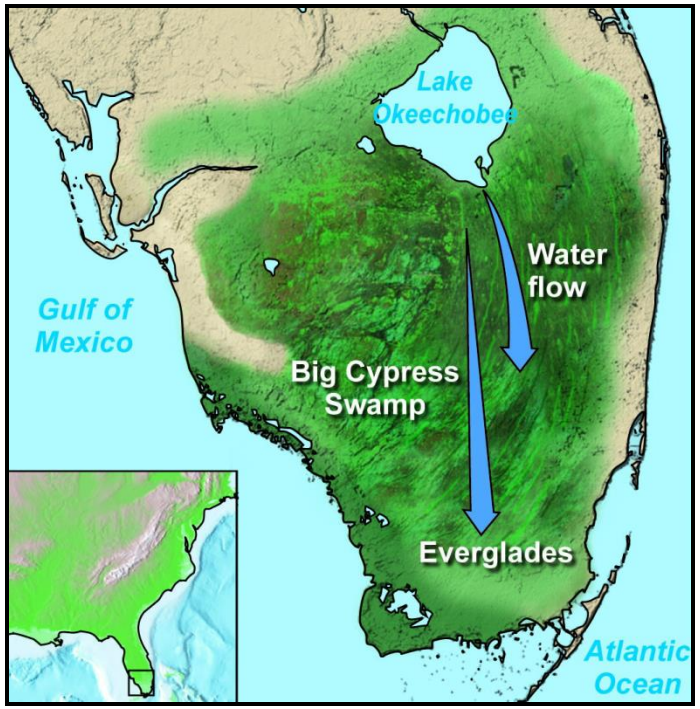
- **Distinctive geological features:**
  - Mineral-rich hot springs are tourist attractions.
  - Boiling springs create bubbling mudpots.
  - Hot springs precipitate dissolved minerals upon cooling. These minerals crystallize as deposits of travertine.
  - Geothermal springs may appear as brightly colored pools. Colors are due to bacterial metabolism of sulfur minerals.

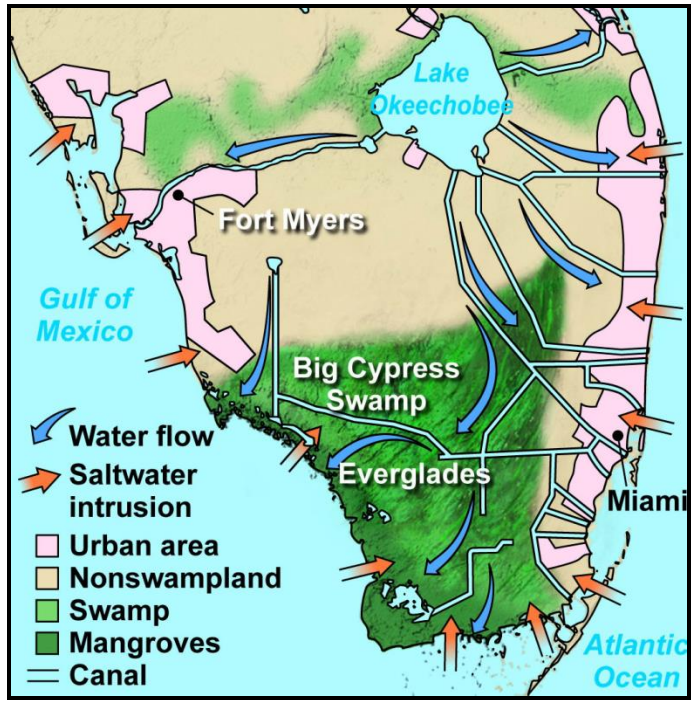
Hot Springs and Geysers

- **Boiling water and steam erupts cyclically from geysers.**
  - **Water is heated to the boiling point in a vertical spring.**
  - **Pressure exerted by the water column prevents boiling.**
  - **Some water escapes and pressure is reduced.**
  - **The water boils, turns to steam, and erupts as a geyser.**
  - **The cycle repeats after the emptied chamber is refilled.**

Lowering the Water Table

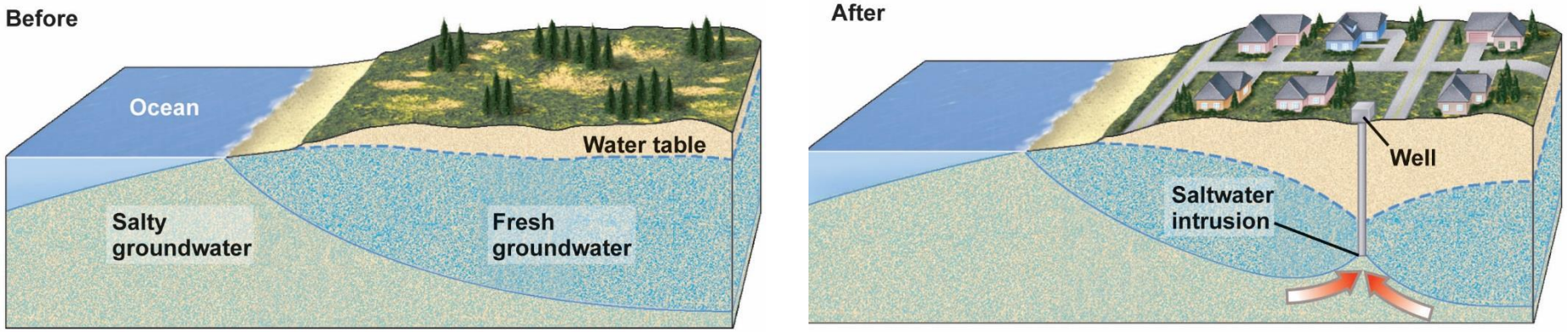
- **Altering surface water flow can cause severe water-table decline.**
  - **Diverting water from the recharge areas of the Everglades into canals has caused parts of the Everglades to dry up.**





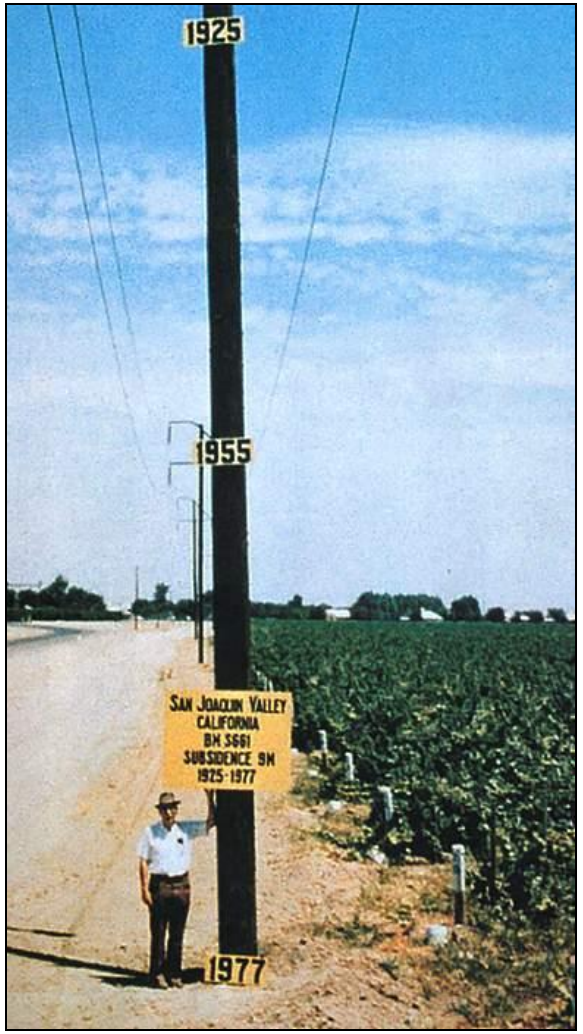
Saline Intrusion

- **Saltwater intrusion renders the water unpotable.**
  - **Beneath coastal land, freshwater "floats" on saltwater.**
  - **Pumping causes the fresh/salt boundary to rise.**
  - **Eventually, saltwater may enter the pumping well.**



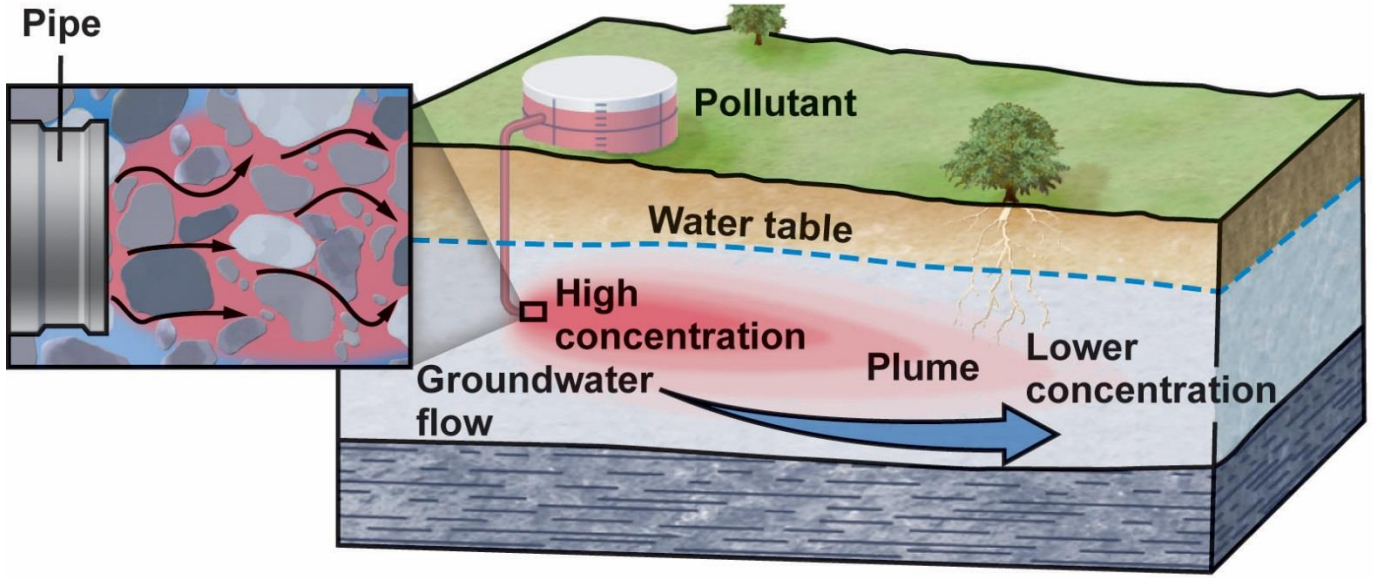
Pore Collapse and Land Subsidence

- **Dramatic examples of subsidence are well known.**
  - **The Leaning Tower of Pisa, Italy.**
  - **Sinking buildings in Venice, Italy.**
  - **The San Joaquin Valley, California.**



Groundwater Contamination

- Human activities add pollutants to groundwater flow:
  - Agricultural wastes (pesticides, fertilizers, animal wastes)
  - Industrial wastes (organic and inorganic chemicals)
  - Effluent from landfills and septic tanks
  - Acids leached from coal and metal mine wastes.
- Groundwater transports pollutants away from a source.



Groundwater Contamination

- **Agricultural wastes:**
  - **Fertilizers**
  - **Pesticides**

Groundwater Contamination

- **Toxic chemicals:**
  - **Industrial wastes**
  - **Paints and thinners**
  - **Degreasers and solvents**

Sources of Contamination

- Toxic chemicals
  - Petroleum storage
    - Underground storage tanks (USTs)
    - Gas stations
    - Petroleum terminals

Sources of Contamination

- **Toxic chemicals**
  - **Landfill leachate**

Sources of Contamination

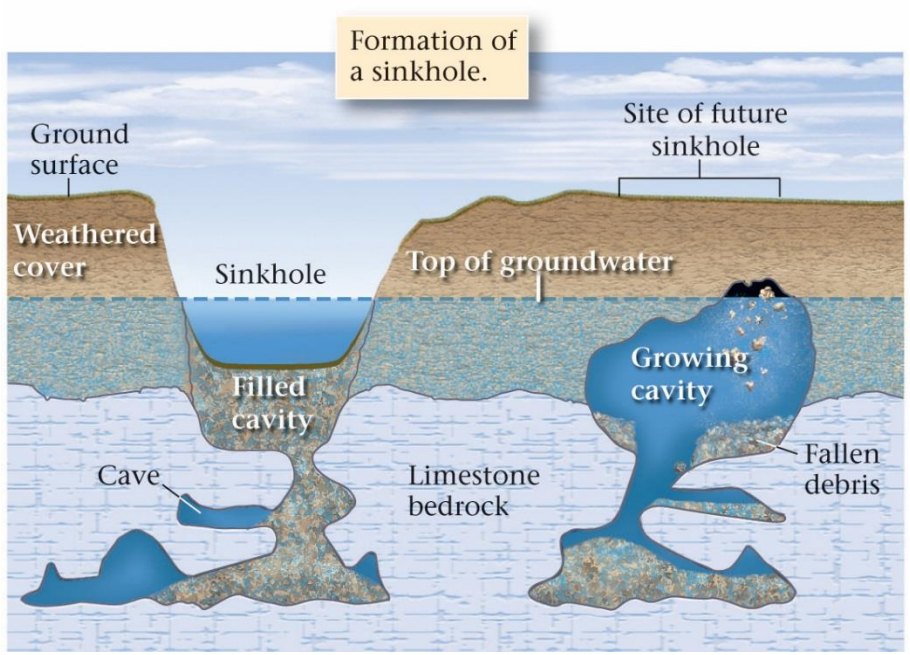
- **Toxic chemicals**
  - **Mining wastes:**
    - **Mine overburden and spoil**
    - **Mill processing tailings**

Caves and Karst

- Caves develop when groundwater dissolves limestone.
- Groundwater is weakly acidic.
  - CO_2 in air and soils reacts with water to form carbonic acid.

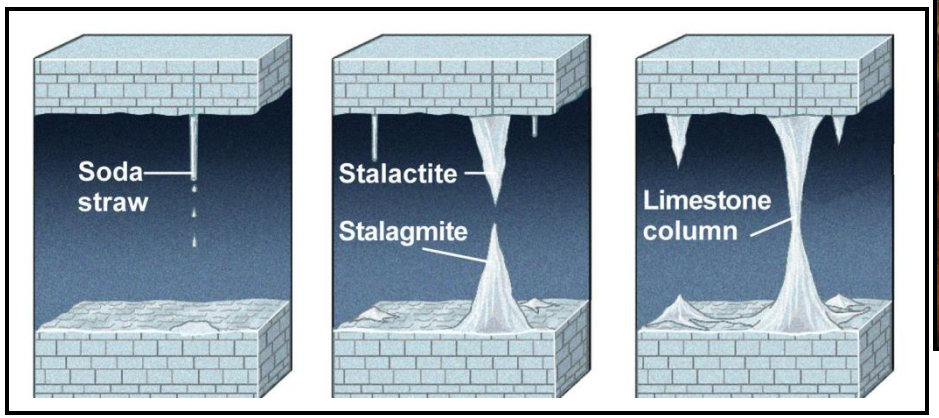
$$H_2O + CO_2 \rightarrow H_2CO_3$$

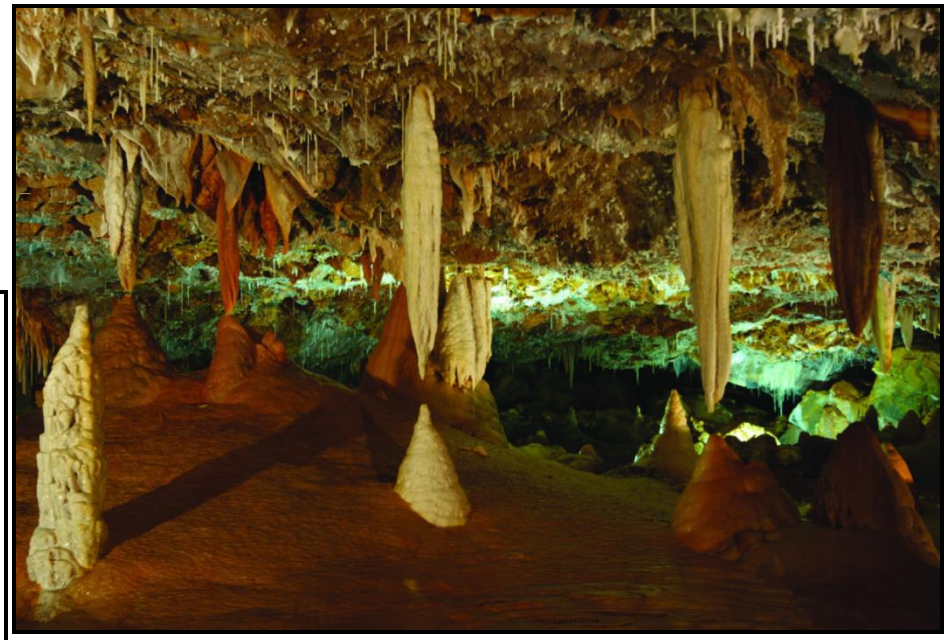
  - Carbonic acid interacts with limestone to dissolve the rock.

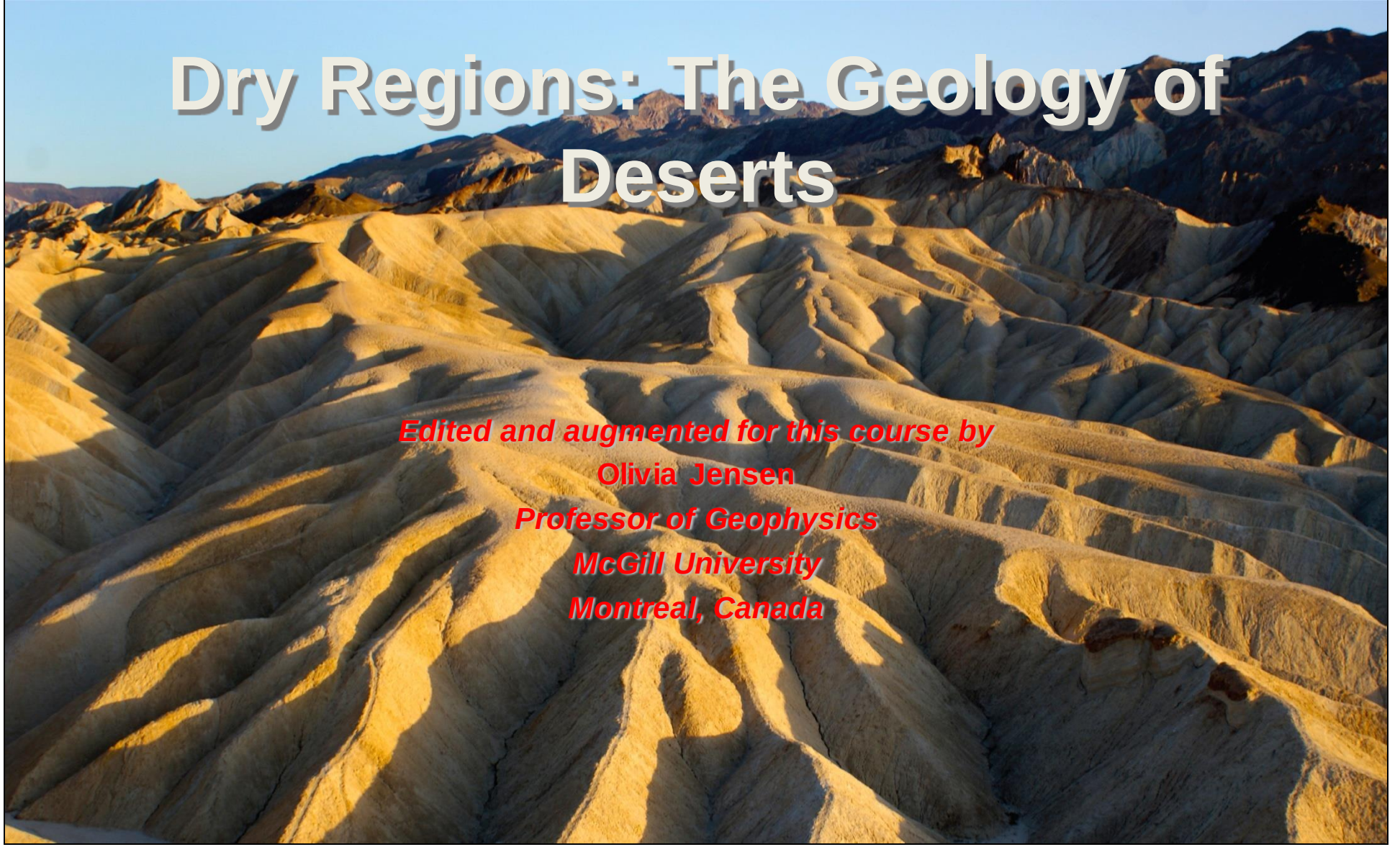


Caves and Karst

- **Speleothems are formed from the formation of dripstone.**
  - **Develop when groundwater entering a cave degasses CO_2.**
  - **$CaCO_3$ is precipitated from this water on interior surfaces.**
  - **Over time, $CaCO_3$ coatings grow into spectacular forms.**
    - **Stalactites—hang down**
    - **Stalagmites—point up**
    - **Columns.**







Dry Regions: The Geology of Deserts

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Deserts

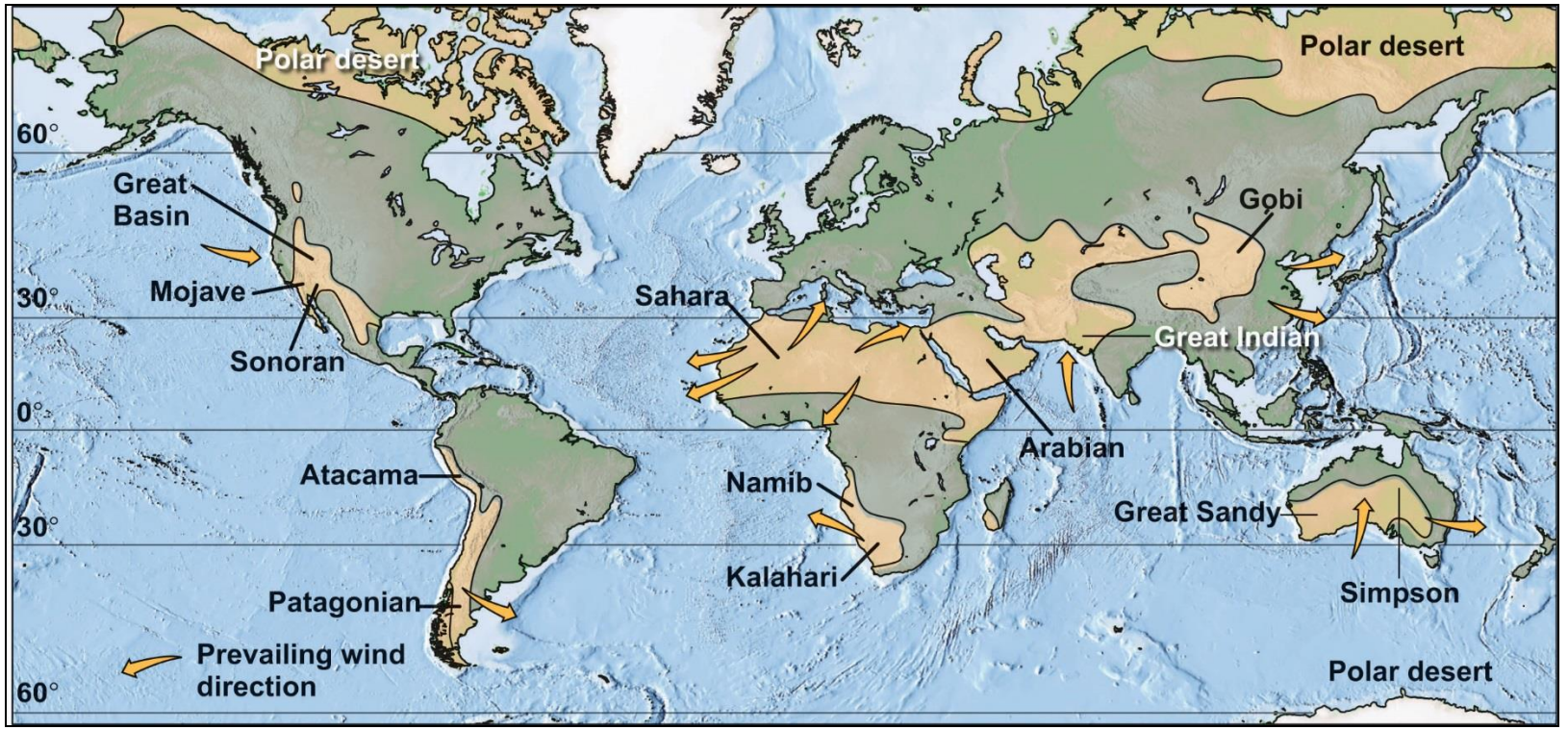
- Deserts cover ~25% of Earth's land surfaces.
- Unique and lovely, deserts are characterized by:
  - Extreme dryness. They may be hot or cold.
  - Specialized ecosystems and low human populations
  - Unique geologic processes

What Is a Desert?

- **Land that is so extremely arid that:**
  - **No permanent streams flow, except those entering from temperate regions elsewhere.**
  - **Vegetation covers less than 15% of its surface.**
  - **Annual rainfall amounts to less than 10 inches (25 cm).**
- **Deserts exist in both hot and cold climates.**

Hot versus Cold Deserts

- **Hot deserts:**
  - Low latitudes
  - Low elevations
  - Far from oceans
- **Cold deserts:**
  - High latitudes
  - High elevations
  - Near cold ocean currents.

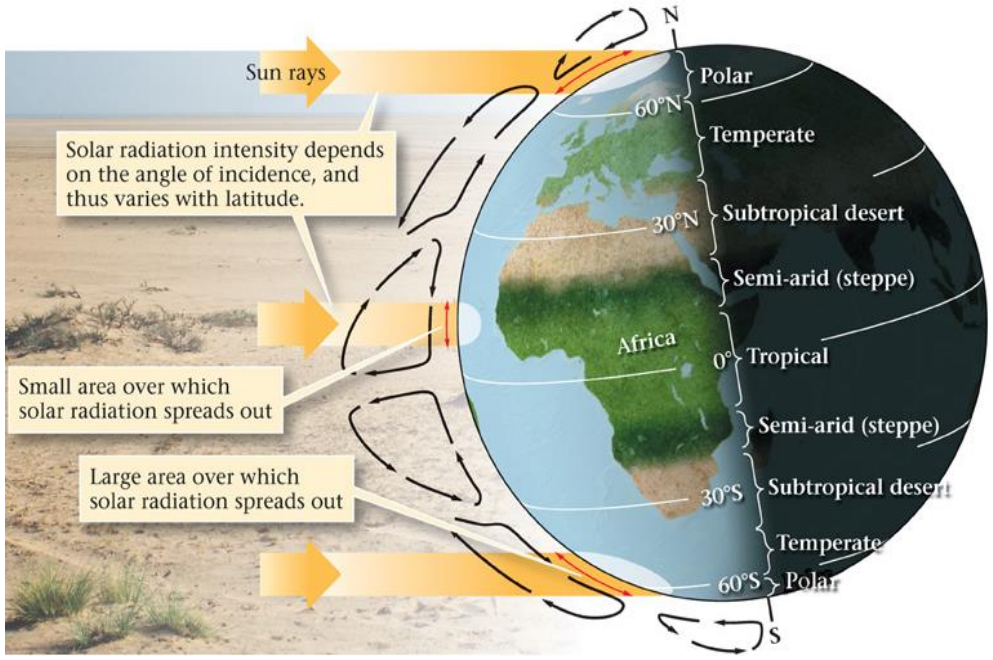


Types of Deserts

- **Five types—with distinctive landscapes and biota:**
  - **Subtropical deserts (Sahara, Arabian, Kalahari)**
  - **Rain-shadow deserts (Eastern Oregon, BC interior)**
  - **Coastal deserts (Atacama)**
  - **Continental interiors (Gobi)**
  - **Polar deserts (Antarctica)**

Subtropical Deserts

- Subtropical deserts are Earth's largest.
- Form due to patterns of atmospheric convection.
  - Equator—0º latitude
    - Solar energy evaporates water, which rises as hot, moist air.
    - Rising air cools and expands, dropping abundant rain on the equatorial rainforests.
    - This air, stripped of moisture, flows to the north and south.
  - Subtropics—20º to 30º N to S.
    - Cool, sinking air wicks water from the surface.
    - The air heats up and the landscape dries out.

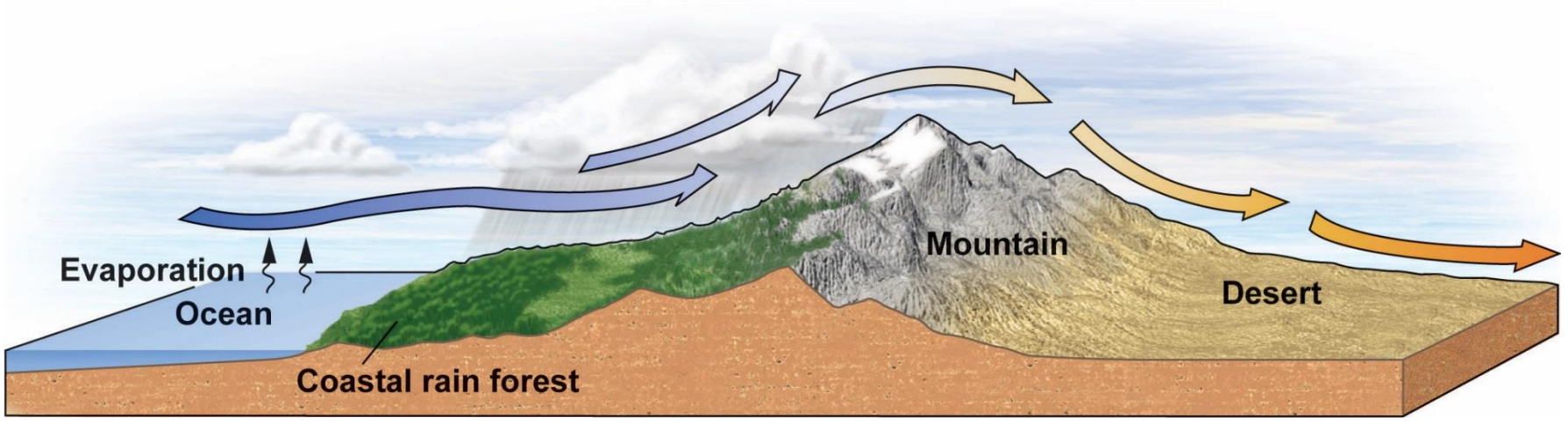


Subtropical Deserts

- Occur at 20º to 30º N and S latitude
- African deserts bracket the equator:
  - Sahara and Arabian to the north
  - Rainforest straddling equator
  - Namib and Kalahari to the south

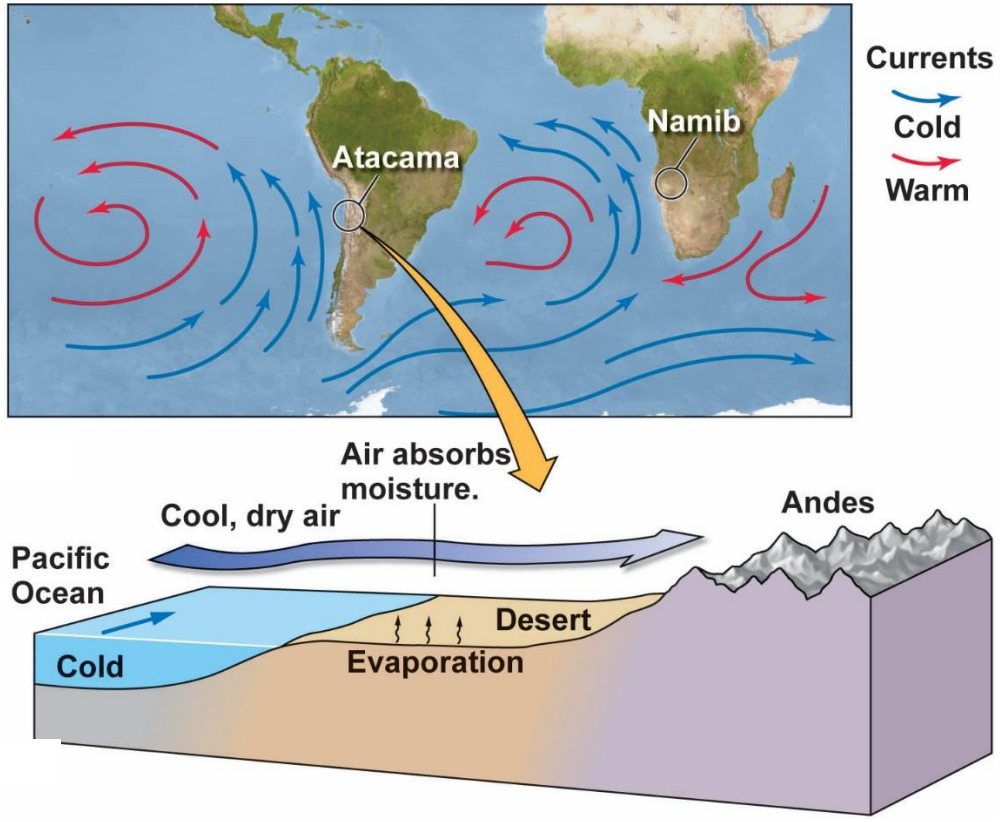
Rainshadow Deserts

- Moist ocean winds are driven up and over mountains.
  - Windward air is forced to rise, expand, and cool.
  - Moisture condenses, rains fall, which create a rain forest.
  - Leeward air, stripped of moisture, sinks toward the surface.
    - Sinking air warms, compresses, absorbs water from land.
    - Dry, arid region forms.



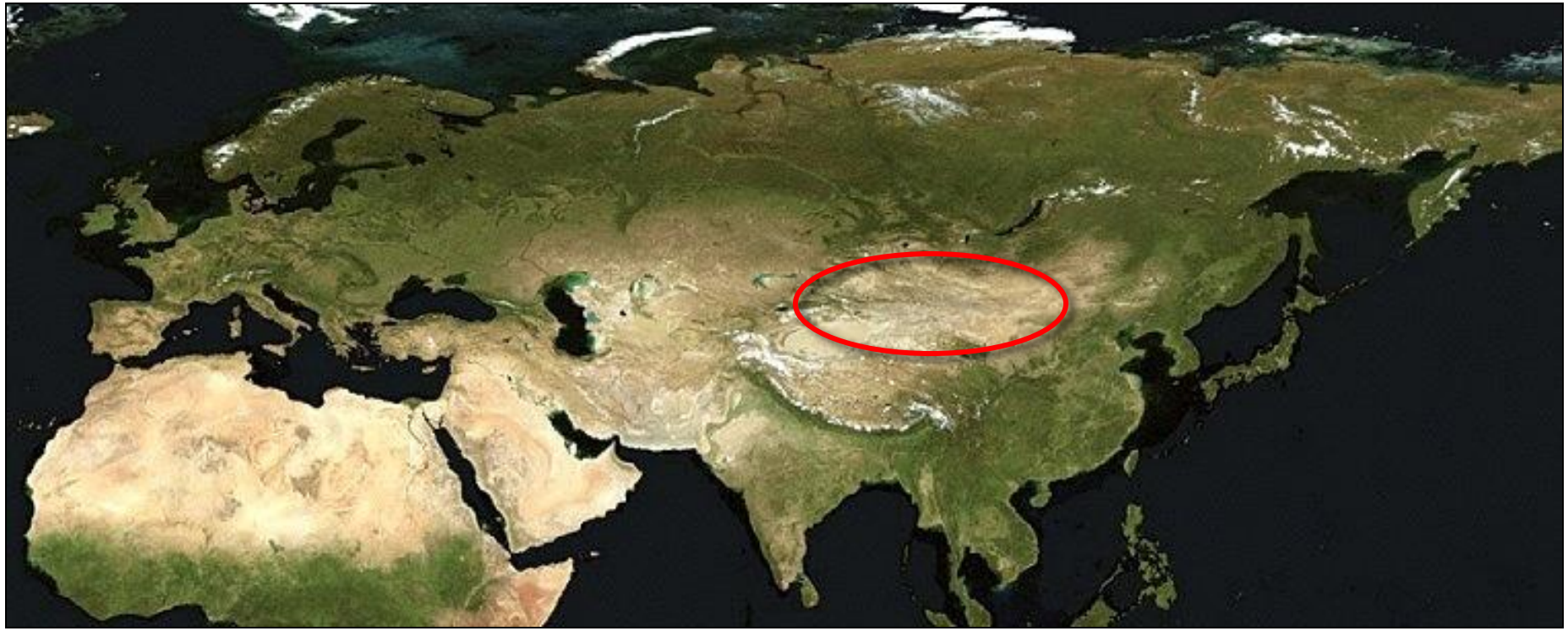
Coastal Deserts

- Cool air over cold ocean water holds little moisture.
  - This air absorbs moisture when it interacts with land.
  - The Atacama Desert (Peru) is the driest inhabited place on Earth.



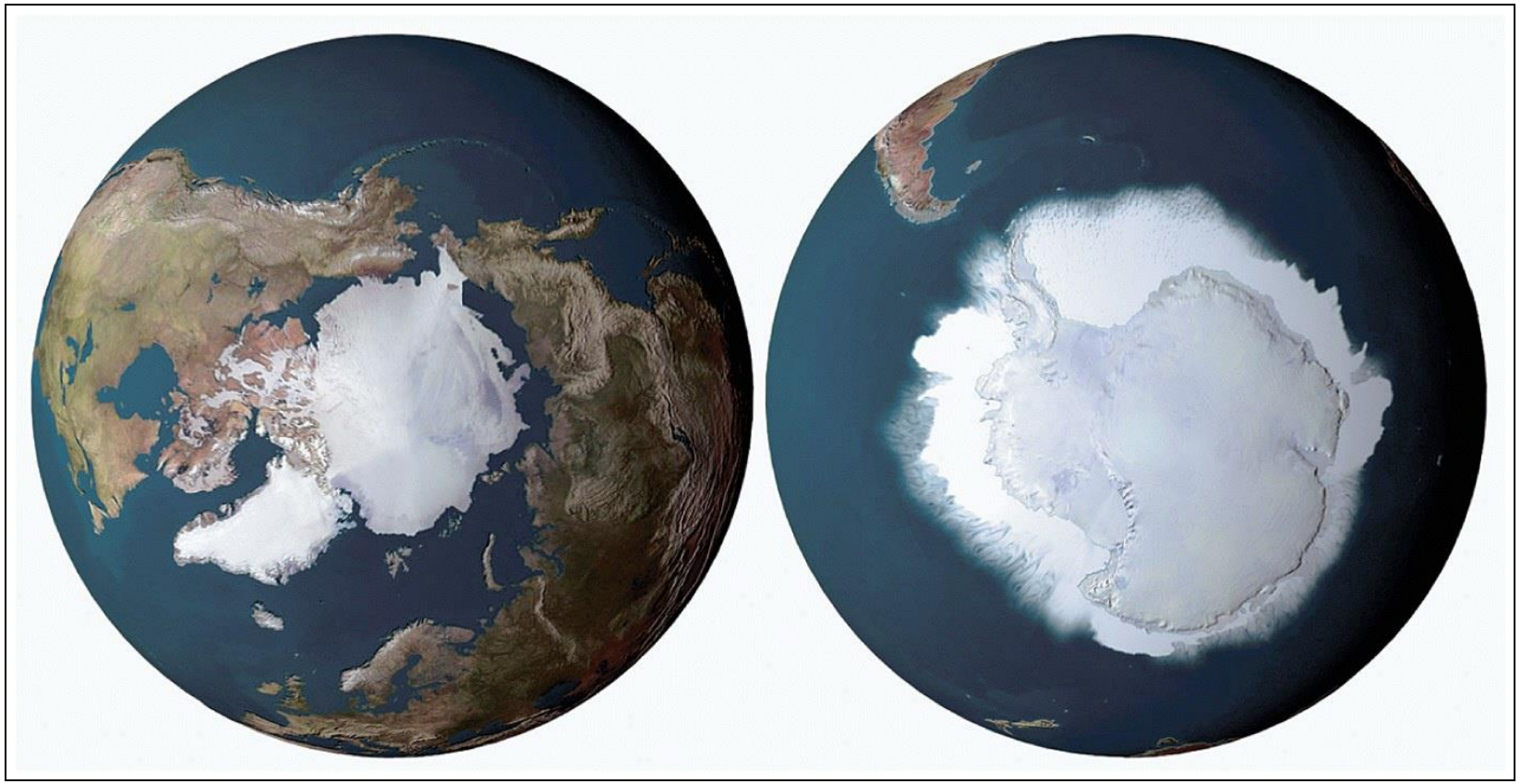
Interior Deserts

- Air loses moisture as it crosses continents.
- Land far from ocean moisture can be very dry.
- The Gobi Desert in Mongolia is a prime example.



Polar Deserts

- **Above 66° N and S latitudes there is little air moisture.**
  - **Air circulation carries dry air to polar regions.**
  - **It is so cold; the air can't hold moisture.**



Polar Deserts

- **The driest place on Earth is in Antarctica in an area called the Dry Valleys, which have seen no rain for nearly 2 million years.**

There is absolutely no precipitation in this region and it makes up a 4800 square kilometer region of almost no water, ice or snow

Desert Processes

- Surface processes help characterize deserts.
  - Erosion by water and wind
  - Weathering
  - Soil formation
  - Deposition

- These processes result in unique landscapes.

Arid Weathering

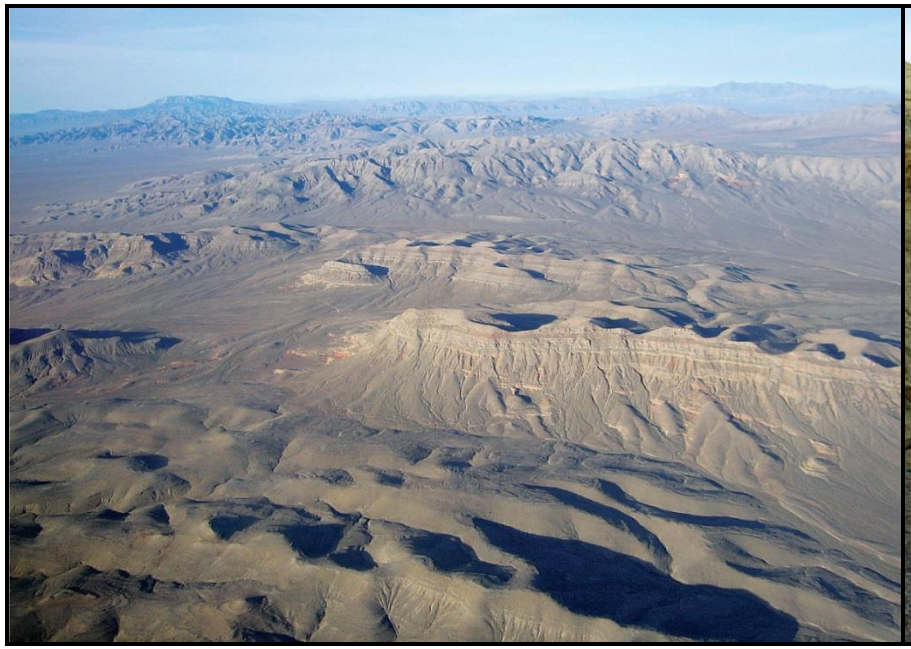
- **Physical weathering dominates.**
  - **Joints split rocks into pieces.**
  - **Rare chemical weathering leaches ions.**
  - **Calcite precipitates beneath surface, forming calcrete.**
  - **Evaporation salts both break and cement grains.**

Arid Weathering and Desert Soils

- Desert soils are thin, with poorly defined horizons.
- Iron oxides in rock weather to produce vibrant colors.
- Painted Desert, Arizona, named for bedrock colors.

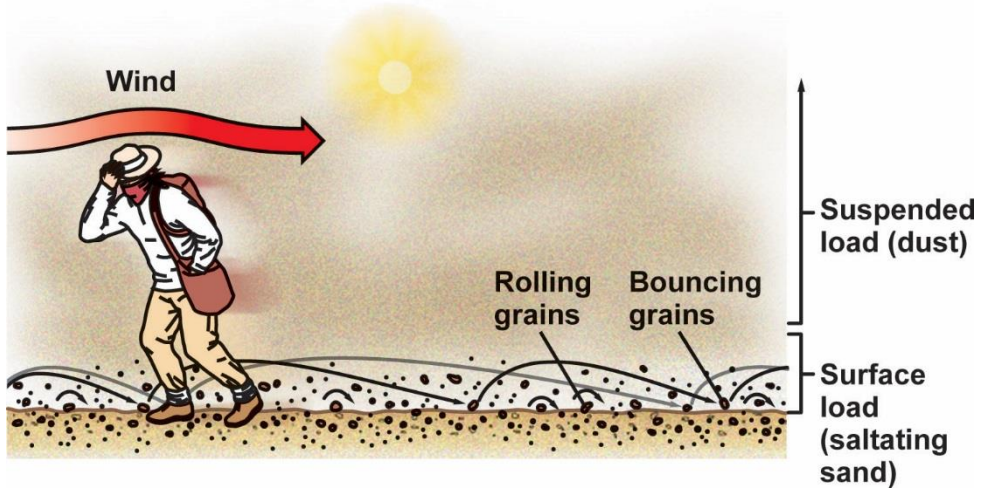
Water Erosion

- Though rare, water shapes desert landscapes.
  - Lack of roots magnifies sediment erosion and transport.
  - Torrential rains generate dangerous flash floods.
    - Rapid flow of thick, muddy, and viscous water.
    - Flash floods quickly infiltrate dry stream beds.
- Dry stream channels called *dry washes*, *arroyos*, *wadis*.



Wind Erosion

- Sparsely vegetated ground is scoured by wind.
- Sand and silt-sized sediment is lifted and moved.
  - Surface load—grains move in contact with land surface.
  - Saltation—sand skips and bounces by grain impact.
  - Suspended load—sediment carried in the air.
- High winds can carry dust across entire oceans.



Desert Deposition

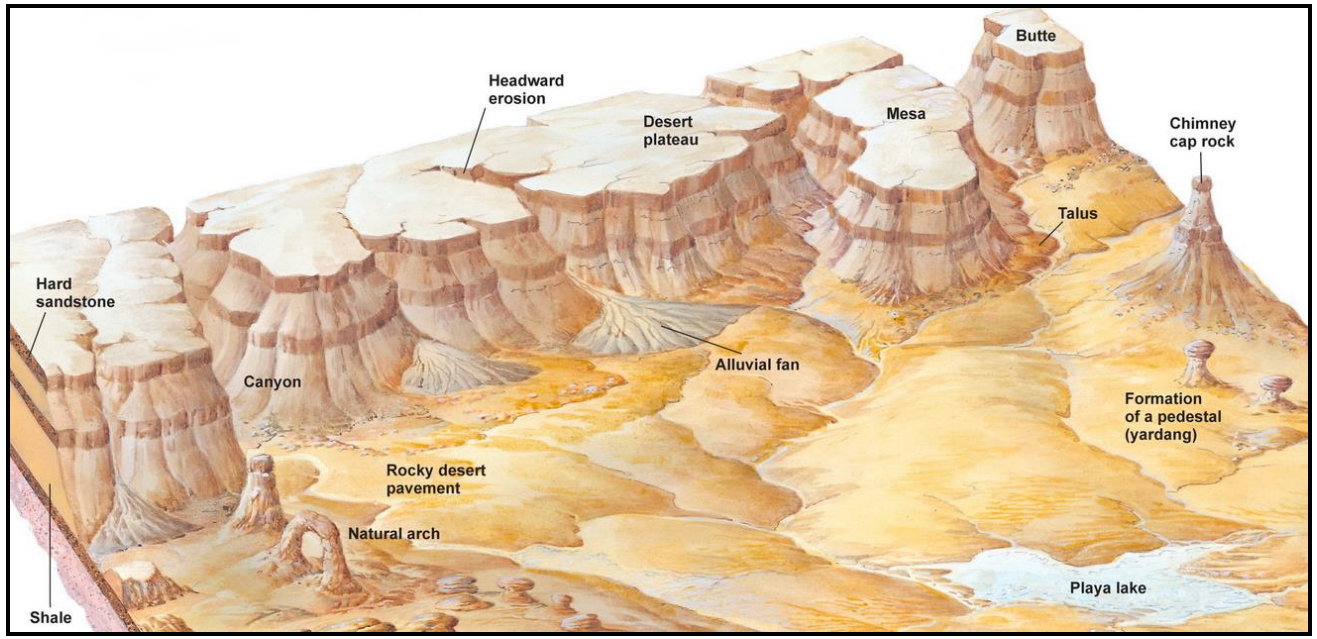
- Alluvial fans—conical accumulations of sediment
  - Water exiting a canyon spreads out and drops sediment.
- Alluvial fans grow outward from source over time.
  - Sediment characteristics depend on fan position.
    - Near the source, channel sediments are coarse.
    - Sediment grains become finer away from the source.

Deposition from the Wind

- **Wind carries two types of sediment load:**
  - **Surface load—coarser sand-sized particles**
  - **Suspended load—finer-grained silt-sized “dust”**
  - **Sand forms dunes inside deserts.**
  - **Vast areas of dunes are called *sand seas*.**

Desert Landscapes

- **Rocky cliffs and mesas: bedrock controls landforms.**
  - **Bedrock exposed along cliffs breaks away along joints.**
  - **Cliff retreat in a plateau of flat-lying rocks evolves into:**
    - **Mesas—large; top may be several square km**
    - **Buttes—medium-sized features**
    - **Chimneys—end result: height exceeds top surface area.**

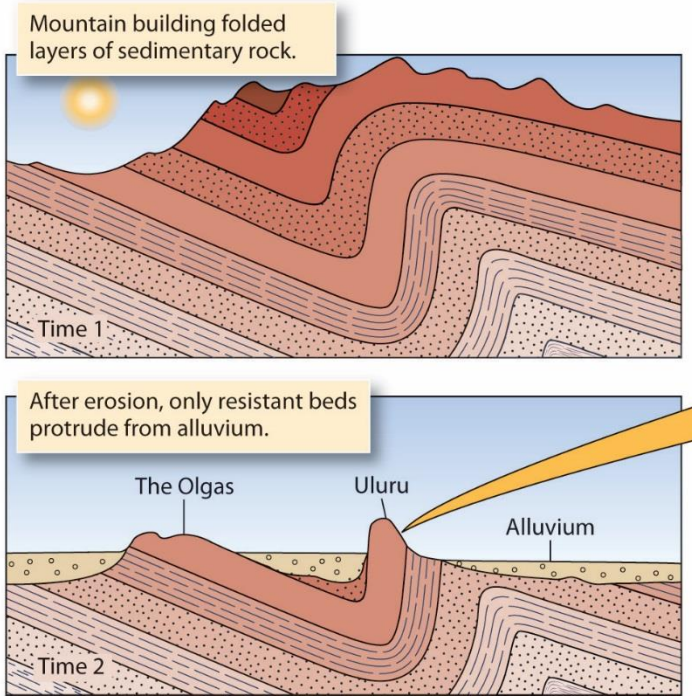


Desert Landscapes

- **Cliffs and mesas: rock layers and weathering determines appearance.**
  - **Resistant layers form steep vertical cliffs.**
  - **Weak layers weather to form rubble-covered slopes.**

Desert Landscapes

- **Shape of inselbergs can vary depending on the rock type or the orientation of the stratification.**
  - **Sharp-crested**
  - **Plateau-like**
  - **Loaf-shaped**



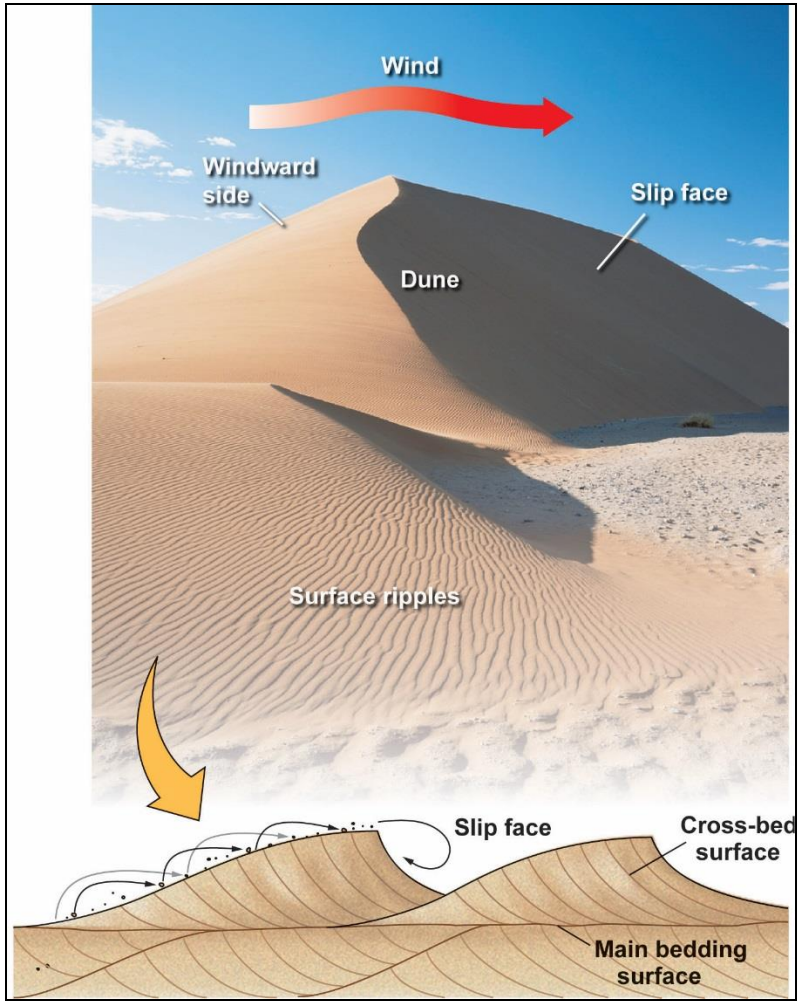
Uluru (Ayers Rock) in central Australia.

Desert Landscapes

- Stony plains: gently sloping, gravelly alluvial fans.
- Pediments: ramp-like bedrock surfaces that slope up toward a mountain front.
  - Sheetwash during floods carries sediment away from mountain front, erodes bedrock surface.

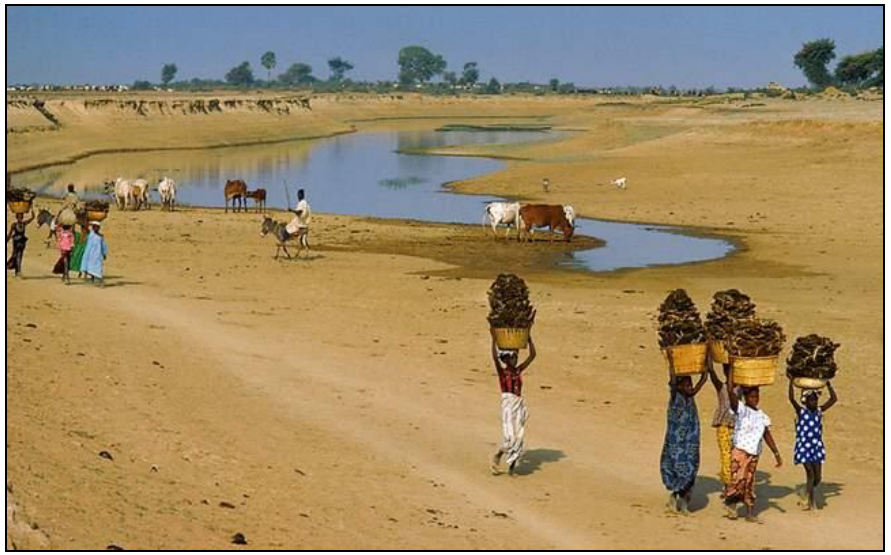
Desert Landscapes

- **Sand Dunes: windblown accumulations of sand.**
  - **Sand carried by wind accumulates around an obstacle.**
  - **Over time, a dune grows and begins to move downwind.**
    - **Sand saltates up windward side.**
    - **Sand tumbles down the slip face.**
  - **Dunes generate enormous cross beds.**



Desert Problems

- **Desertification—aridification of nondesert areas.**
  - **Human activity aggravates natural processes.**
    - **Overpopulation**
    - **Overgrazing**
    - **Careless agricultural practices**
    - **Diversion of water supplies**
  - **The semi-arid Sahel has become a desert.**



Desert Problems

- Desertification facilitates large dust storms that:
  - Cross entire ocean basins.
  - Carry diseased organisms.
  - Destroy homes and land.
- Dust-bowl era of 1930s in the U.S. turned Great Plains farmland into wasteland.