
# Lecture 14 – Water underground

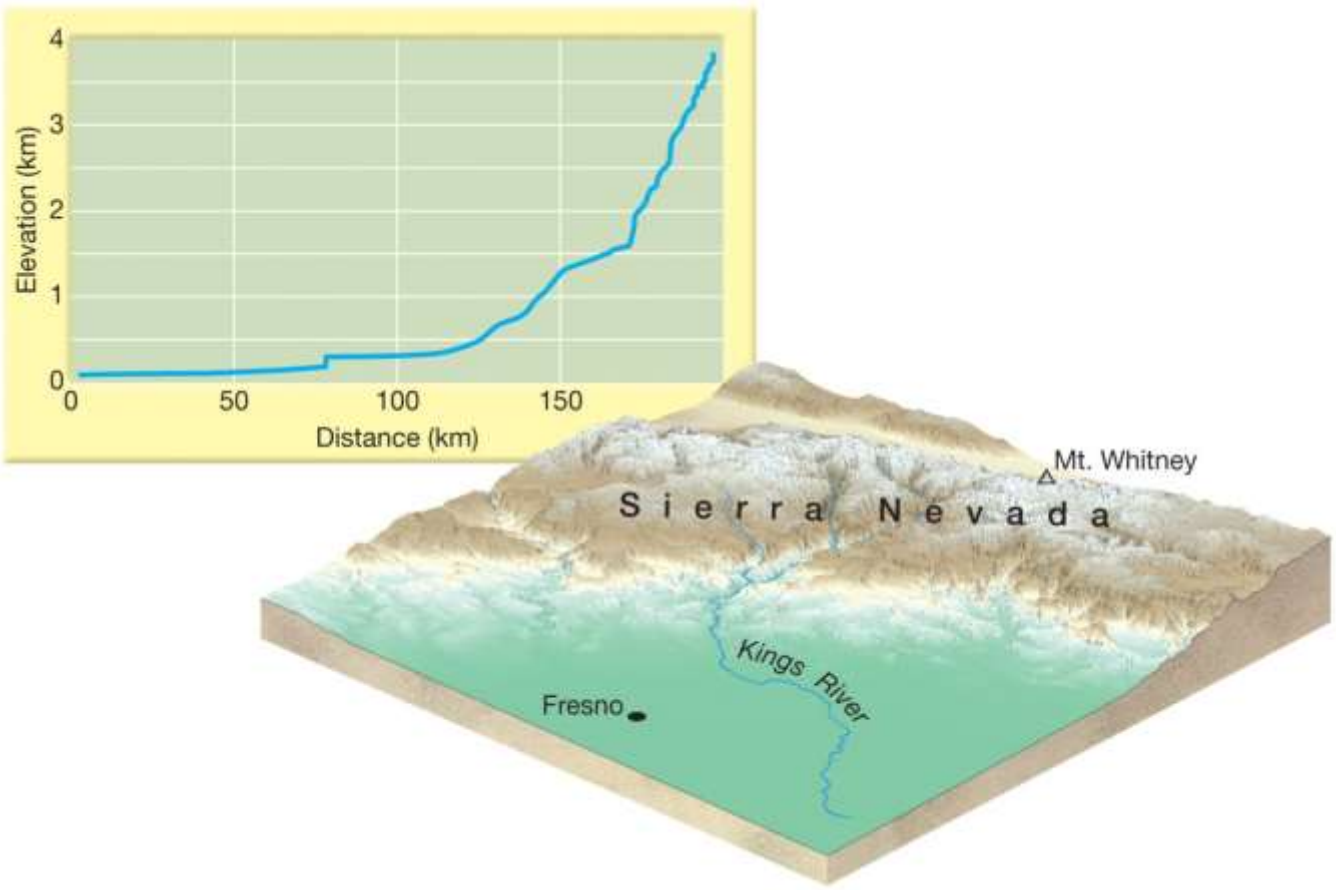
# Key concepts of the day

Geologic role of ground water
(weathering, movement, environments)

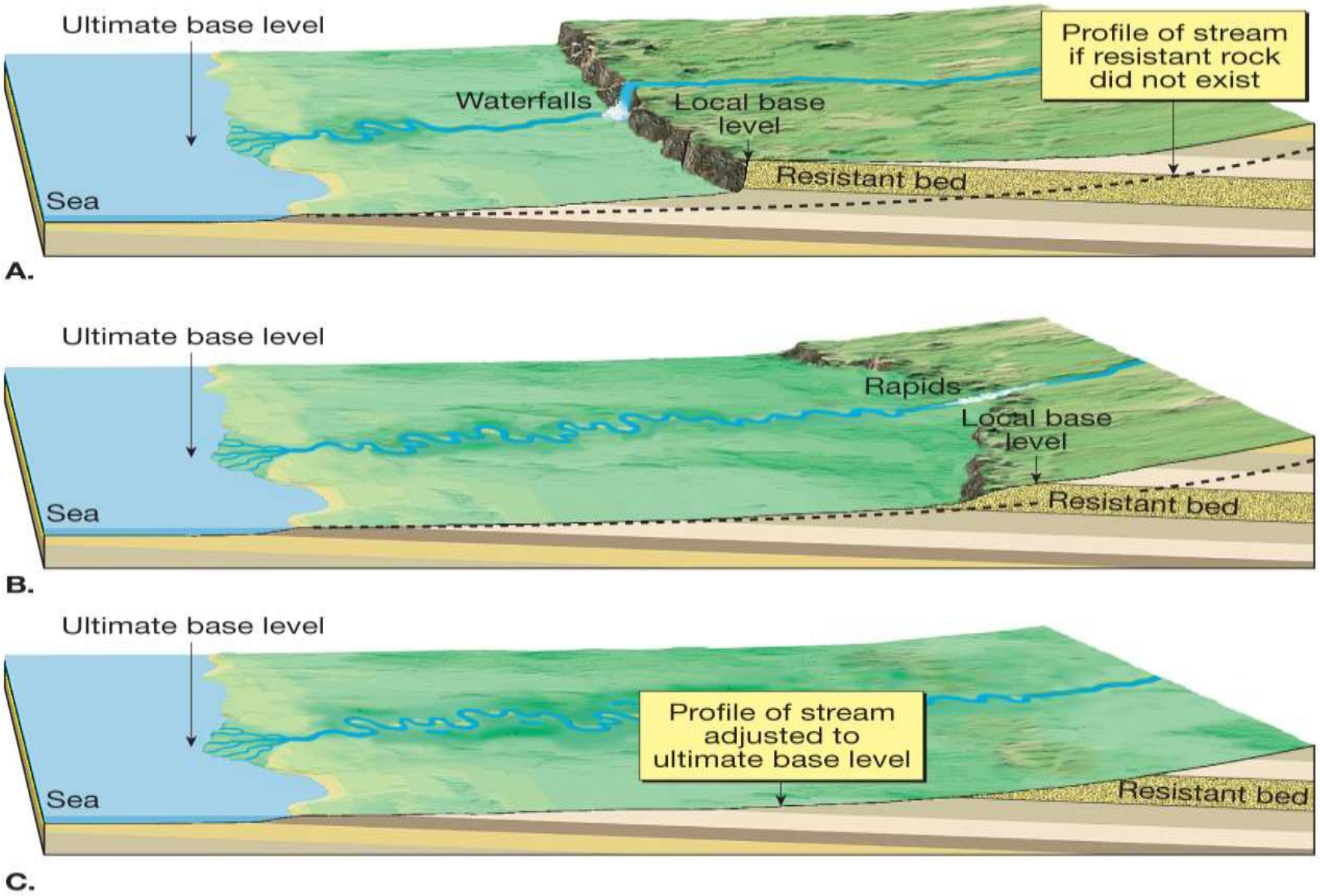
Porosity
Permeability
Movement of aquifers
How caves form
How sink holes form
How Karst topography forms
How we extract groundwater, and problems associated with groundwater extraction
Pollutants in groundwater
Geysers

# Longitudinal Changes

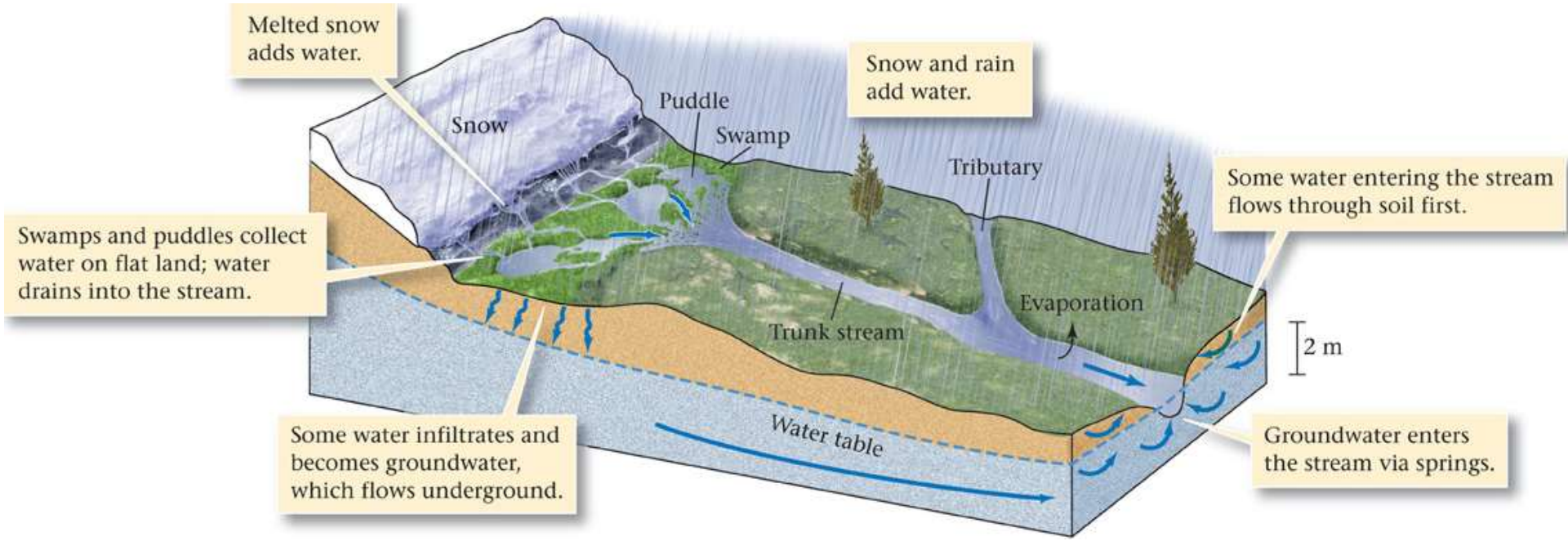
Cross-sectional view of a stream gradient from source (headwaters) to mouth



# Adjustment of base level to changing conditions



# Runoff vs Infiltration



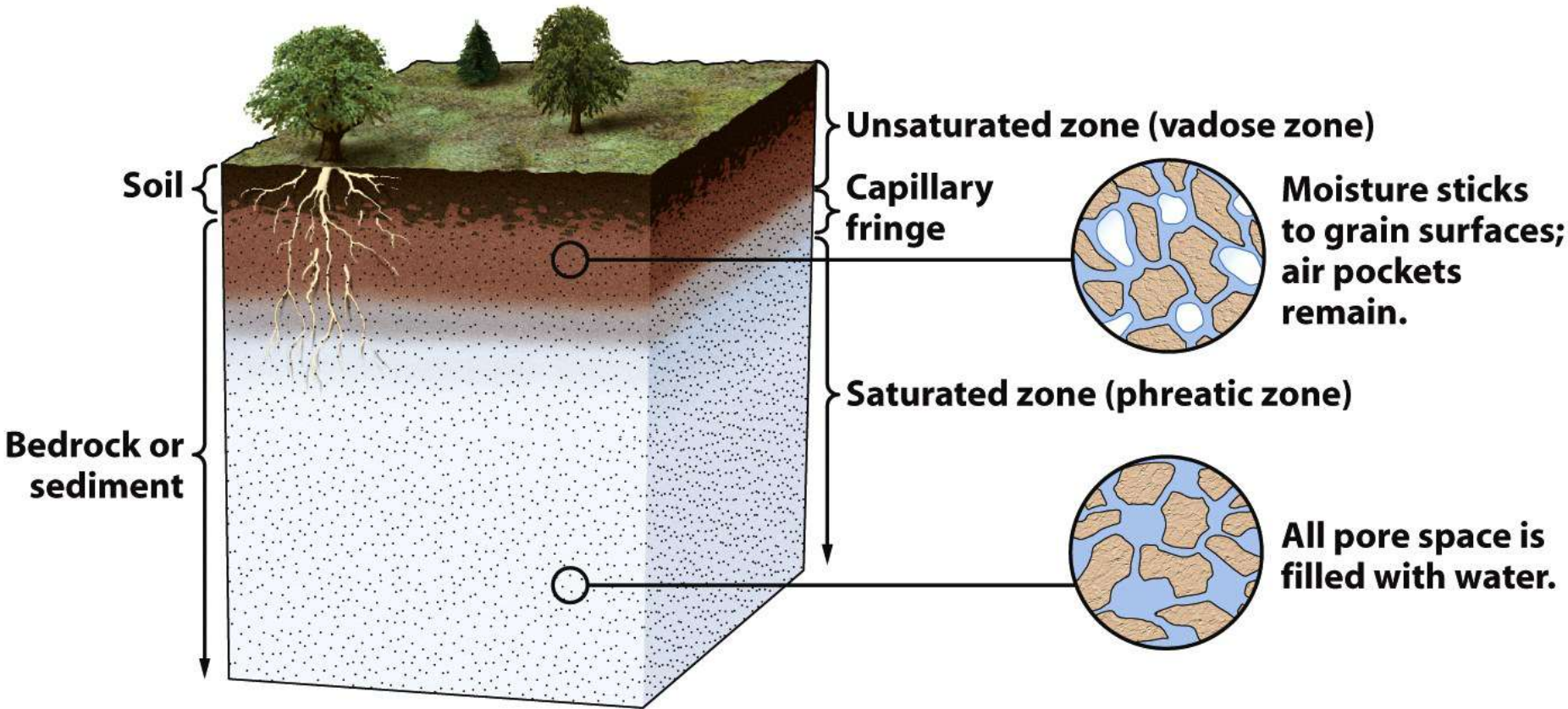
# Groundwater importance

- Importance to people:
  - Drinking water, agriculture, industry

- Geological importance:
  - Erosional agent: Dissolution
  - Contributes to lakes and streams

# The Water Table

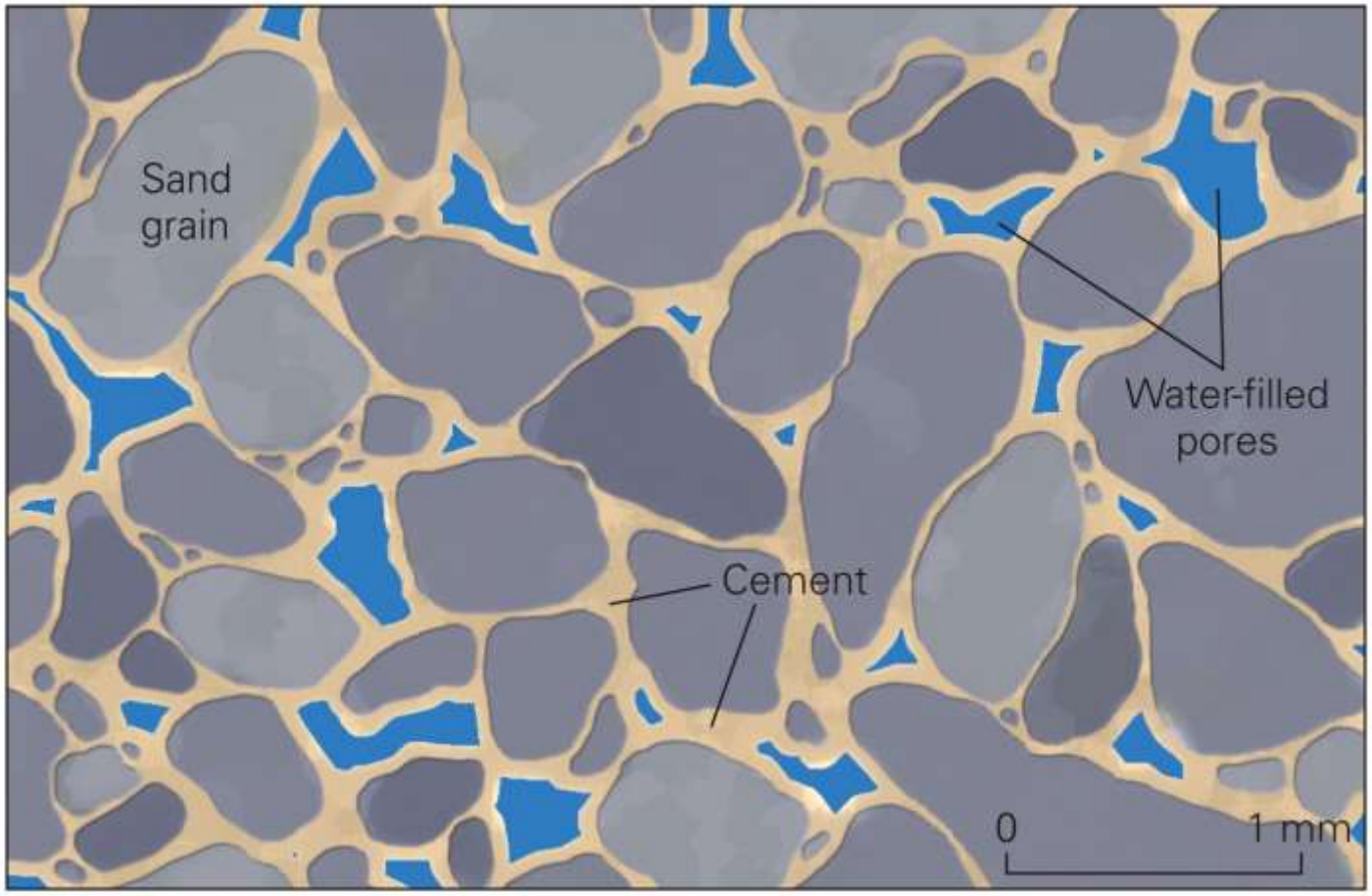
- Above the water table, pores contain some air
- Below the water table, pores are filled with water
- The capillary fringe separates the two zones



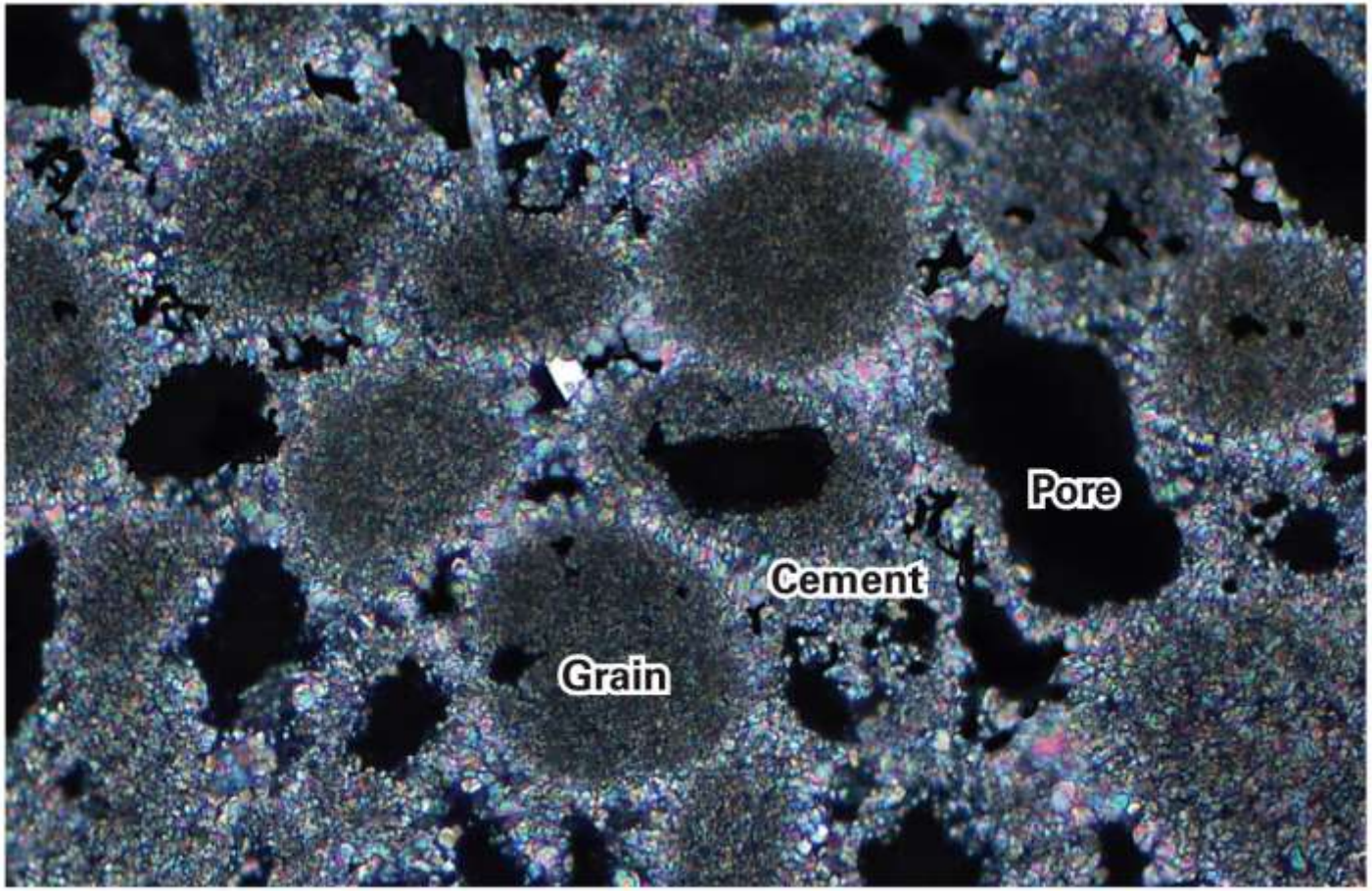
# Porosity

- Groundwater resides in subsurface pore spaces
- Geologic materials exhibit a wide range of porosities


# The Water Table



# The Water Table

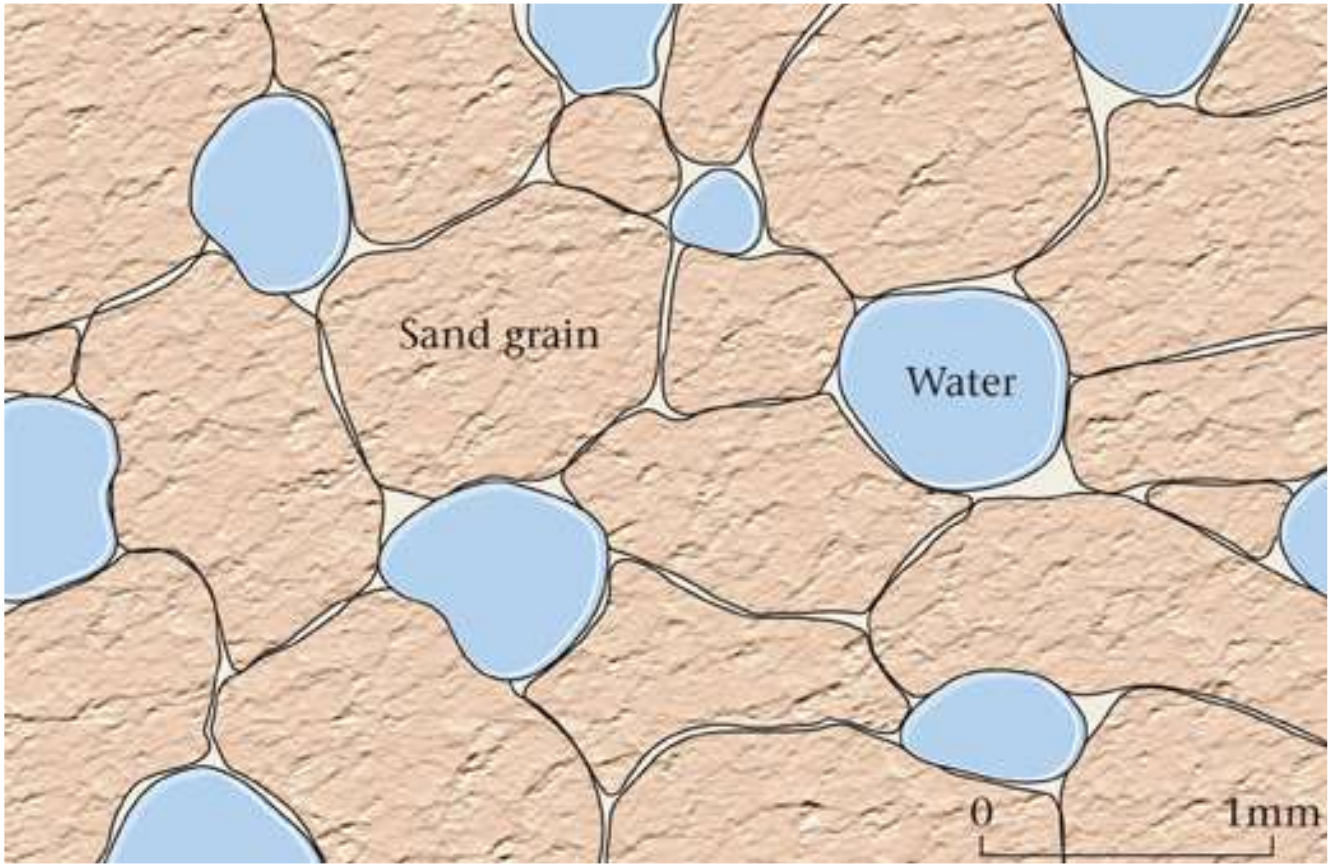


# Two categories of porosity

- Primary porosity – originally formed with the material
    - E.g. Voids in sediment, vesicles in basalt
  - Primary porosity may decrease with burial compaction and with cementation
  - Crystalline rocks have very little primary porosity
- Secondary porosity - develops later
    - Fracturing
    - Faulting
    - Dissolution

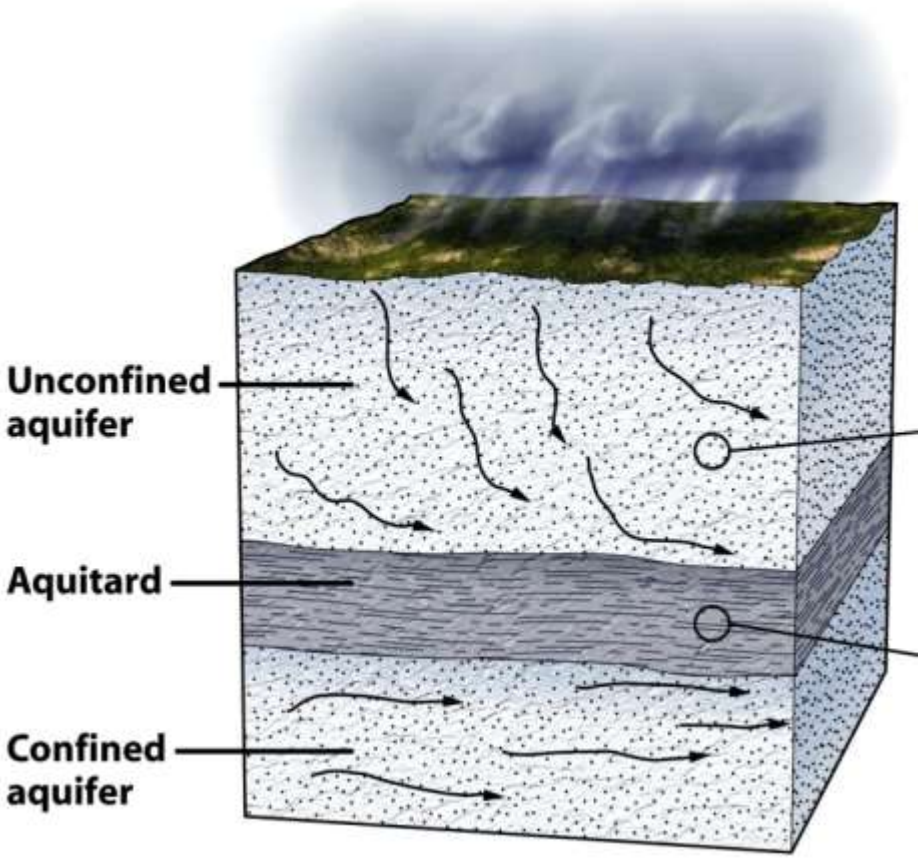
# Permeability

- The ease of water flow due to pore interconnectedness
- Large and straight flow paths enhance permeability

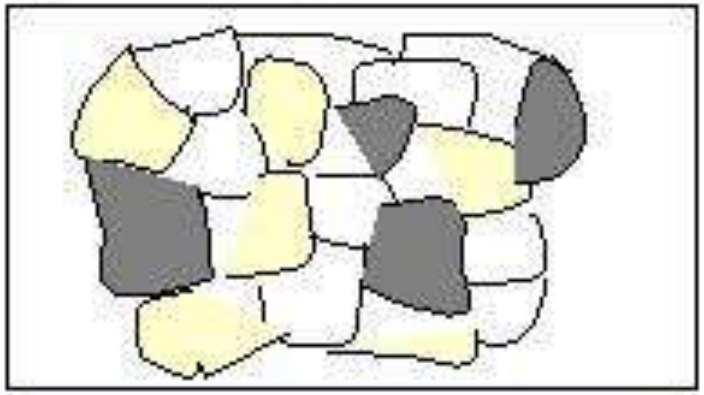


# Storage and movement of groundwater

- Aquifers: *porous* and *permeable* rocks or sediment that freely transmit groundwater
- Aquitards: impermeable layers that hinder or prevent water movement

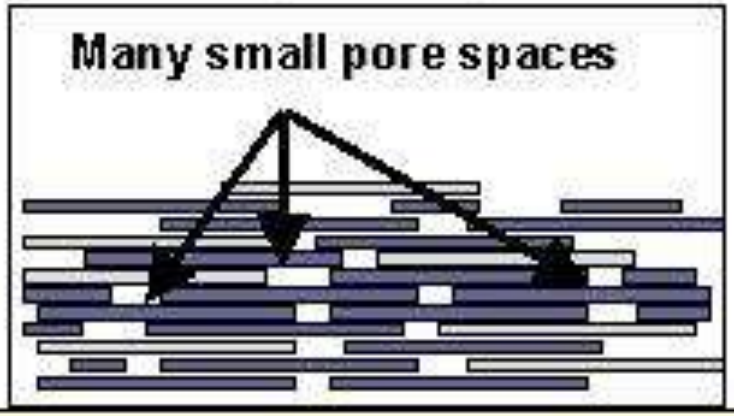


## Crystalline Igneous Rock



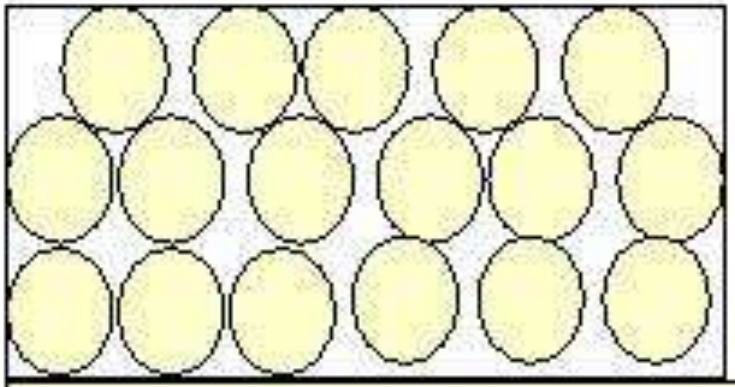
Low porosity & low permeability

## Clay-rich layer



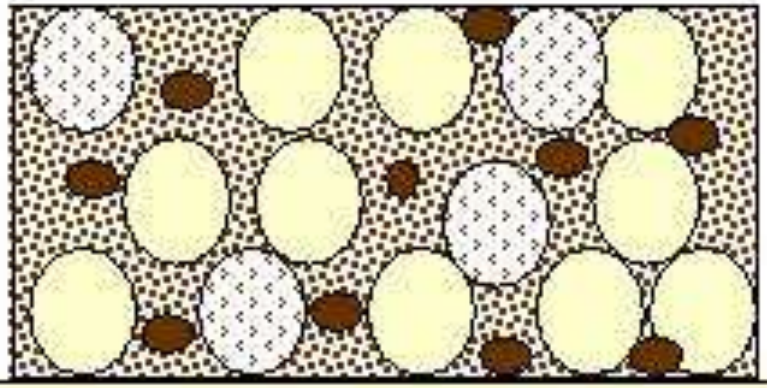

Hi porosity & low permeability

## Quartz sandstone

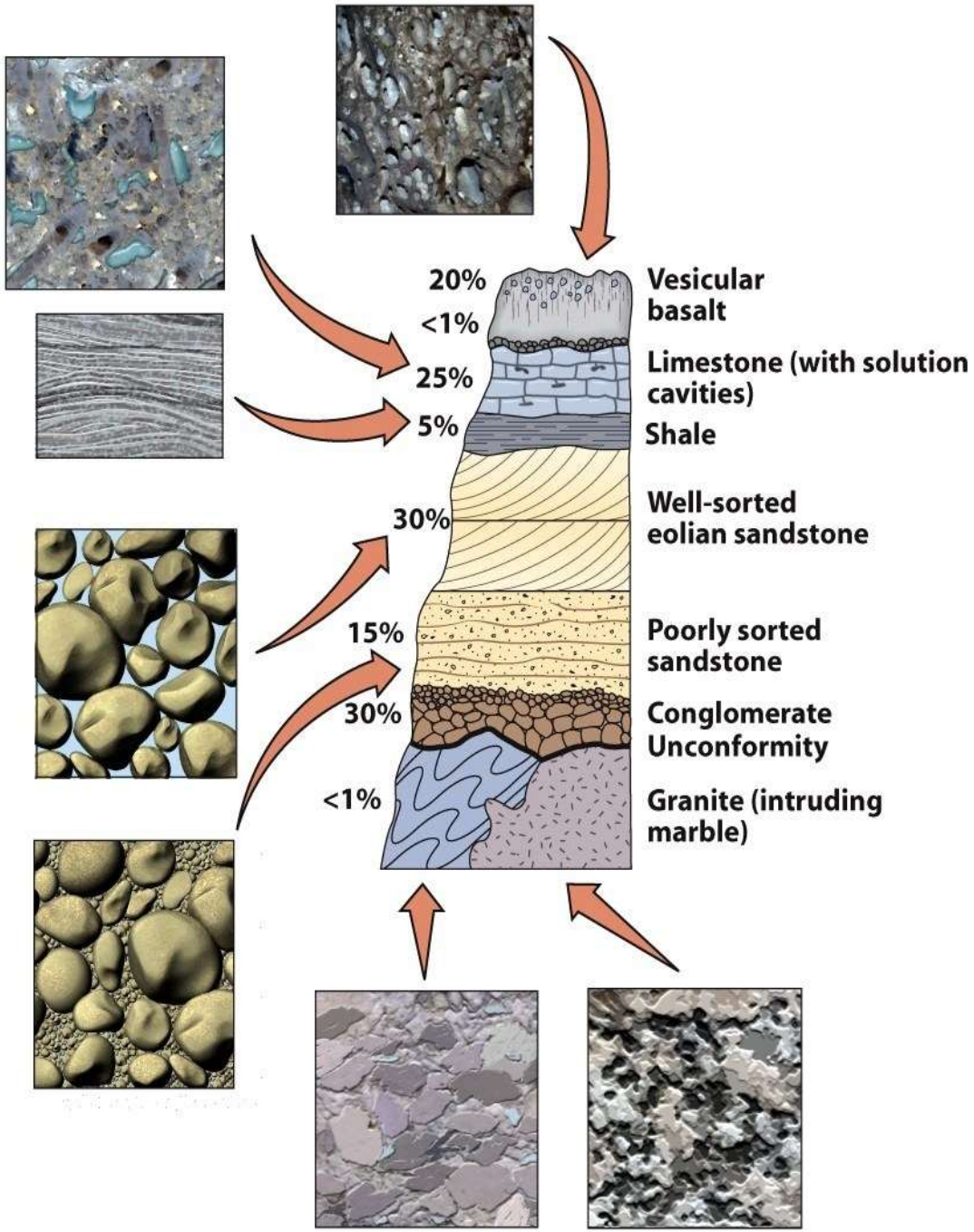


Hi porosity & hi permeability

## Glacial Till

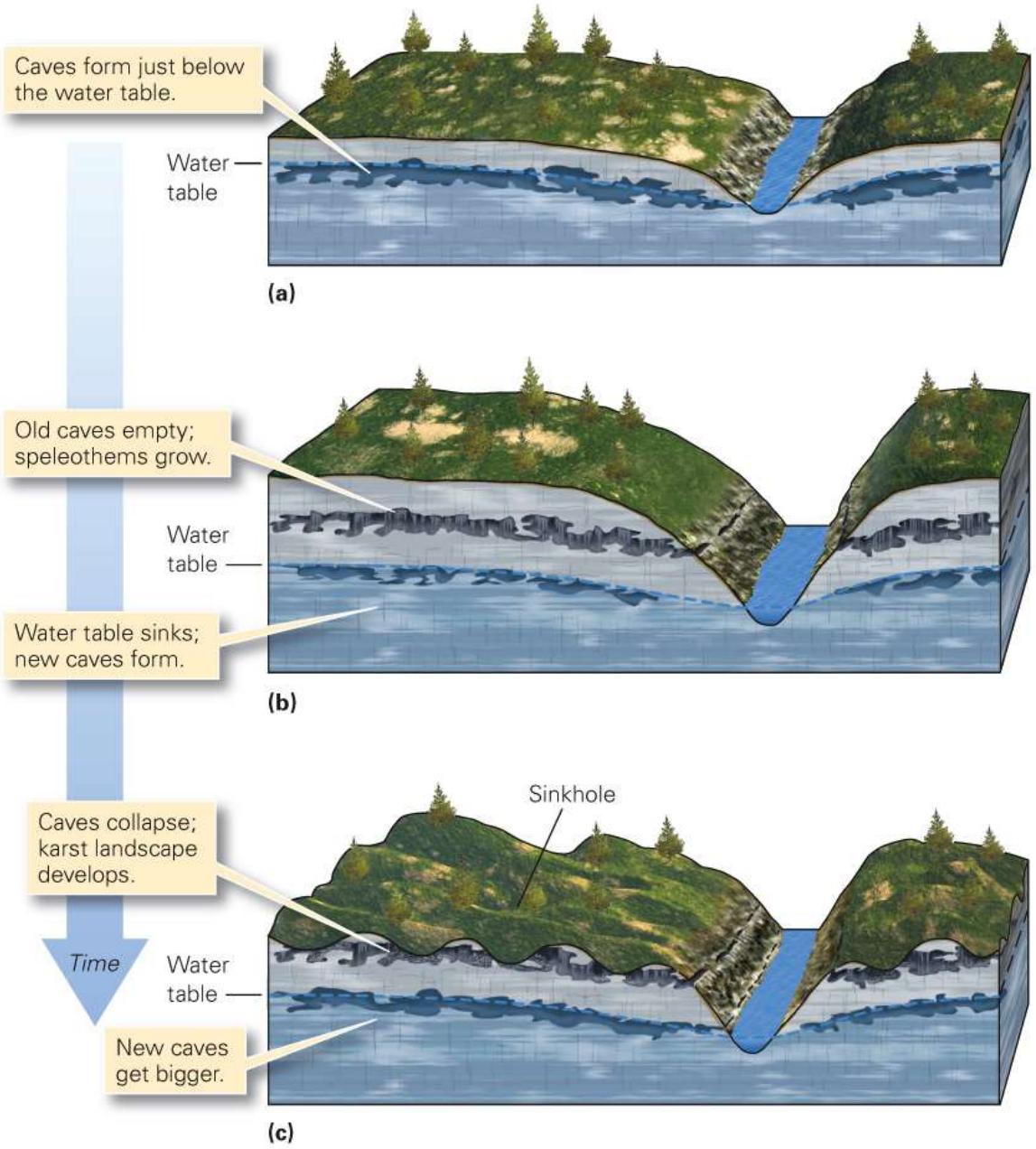


Low porosity & low permeability


20%
Vesicular basalt
<1%
Limestone (with solution cavities)
25%
Shale
5%
Well-sorted eolian sandstone
30%
Poorly sorted sandstone
15%
Conglomerate
30%
Unconformity
<1%
Granite (intruding marble)

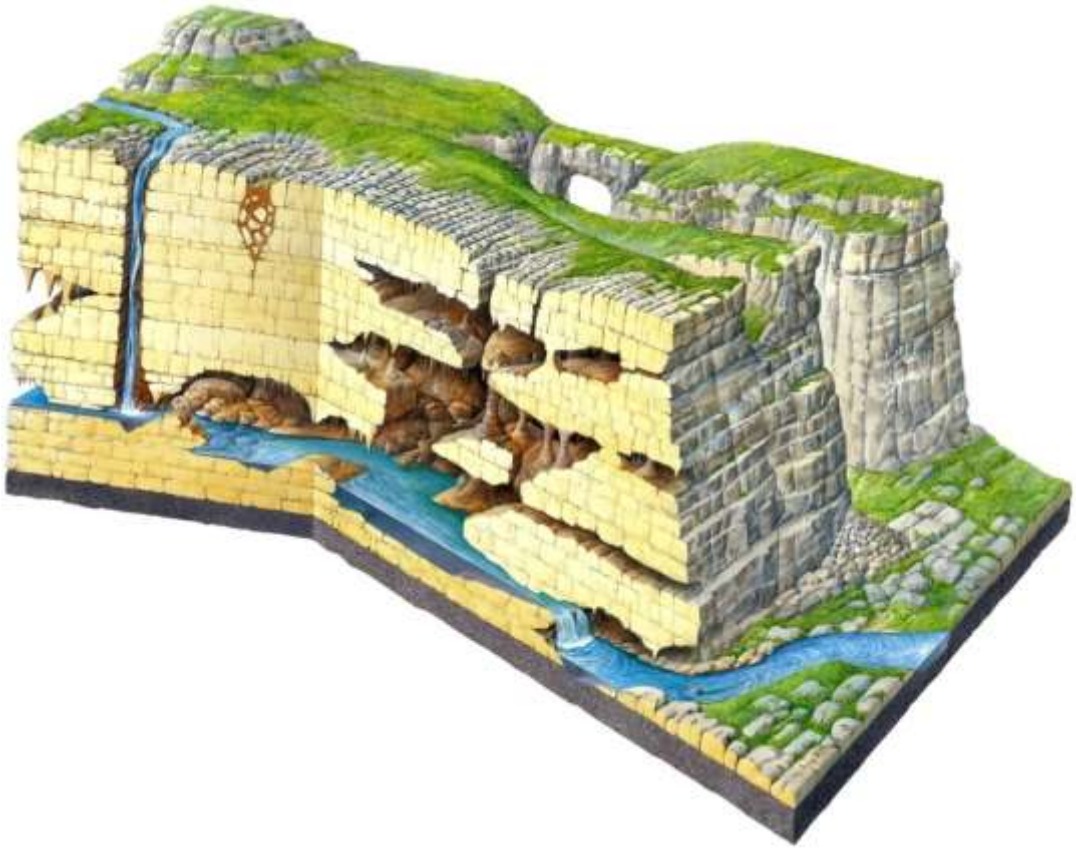
# Caves and karst

- formed by the geological work of groundwater
- groundwater is weakly acidic so will dissolve limestone



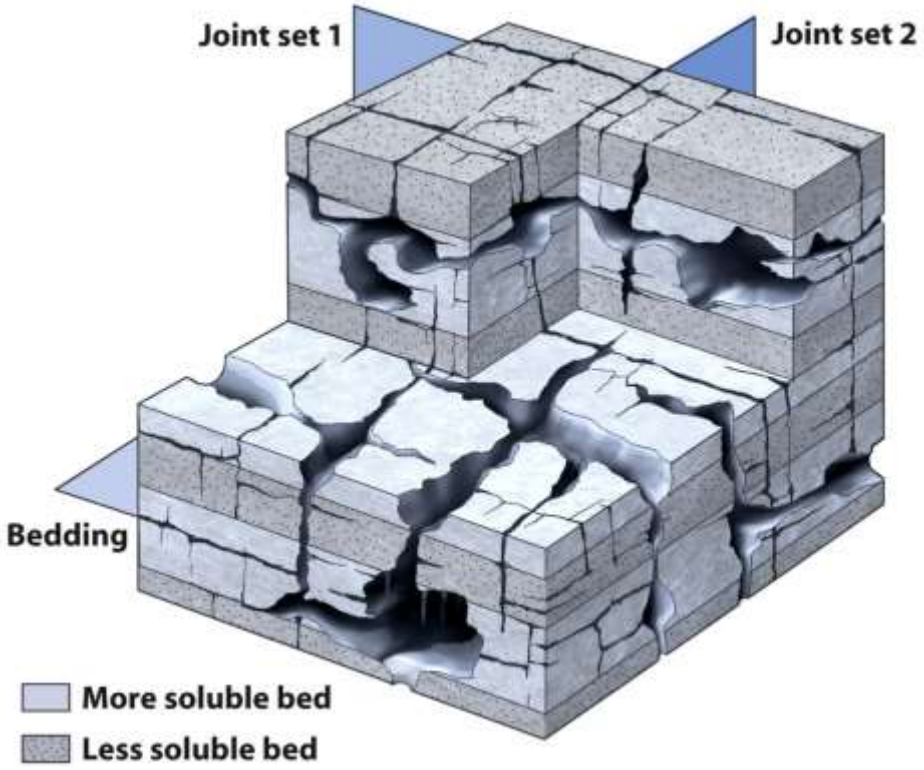
# Caves and Karst

- Limestone dissolution creates unique karst landscapes
- Karst landforms bear evidence of dissolution:
  - Disappearing streams
  - Natural bridges
  - Caves
  - Speleothems
  - Sinkholes
  - Springs
- Karst creates irregular terrain



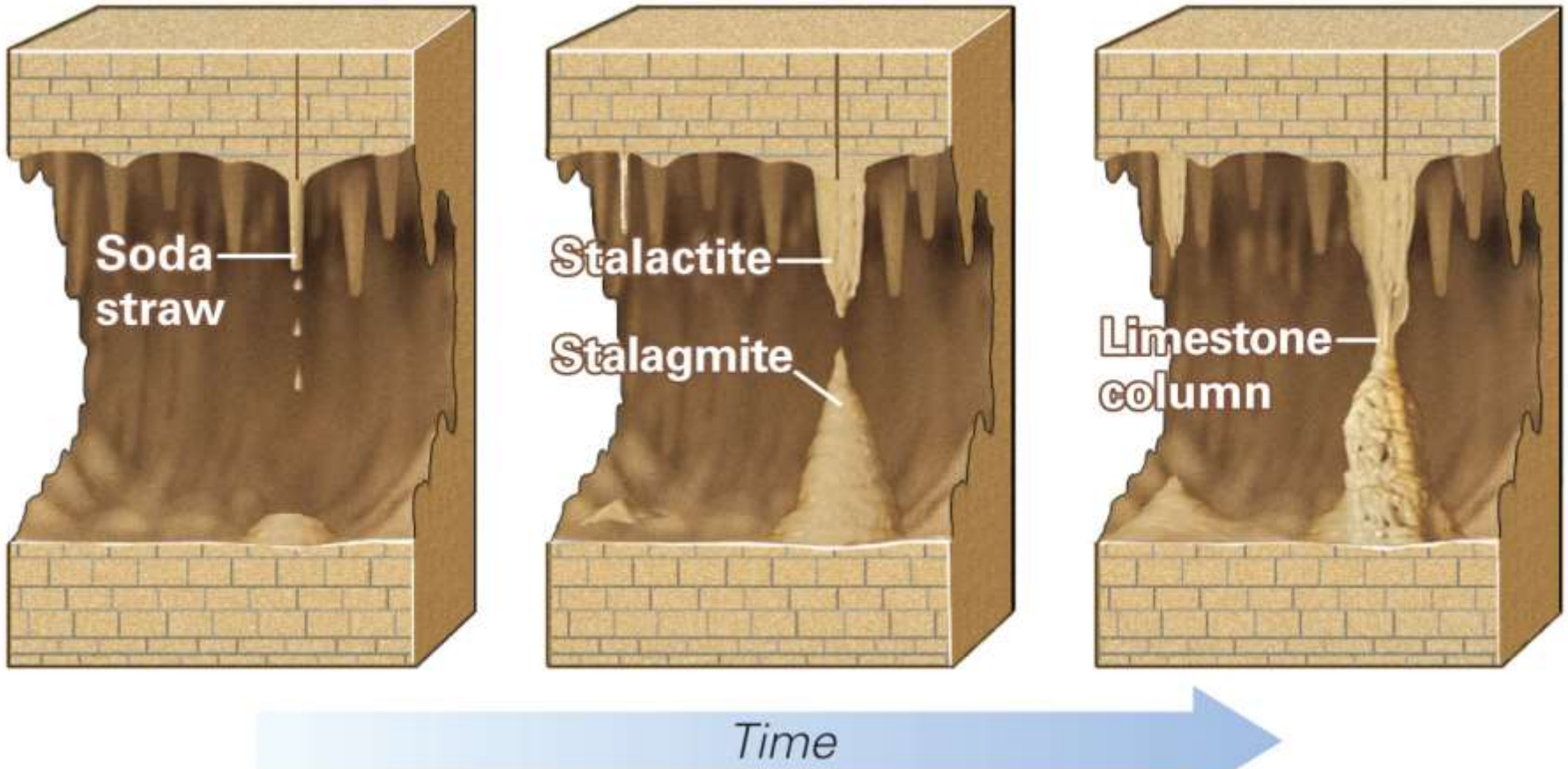
# Caves

- Cave networks develop when proper conditions exist
  - Limestone bedrock
  - Abundant freshwater
- Caves grow as joints are enhanced by solution
  - Cave geometry reflects the joint pattern



# Caves and Karst

- Speleothems are cave deposits
  - Groundwater entering a cave degasses $CO_2$
  - $CaCO_3$ is precipitated from this water



# Caves and Karst

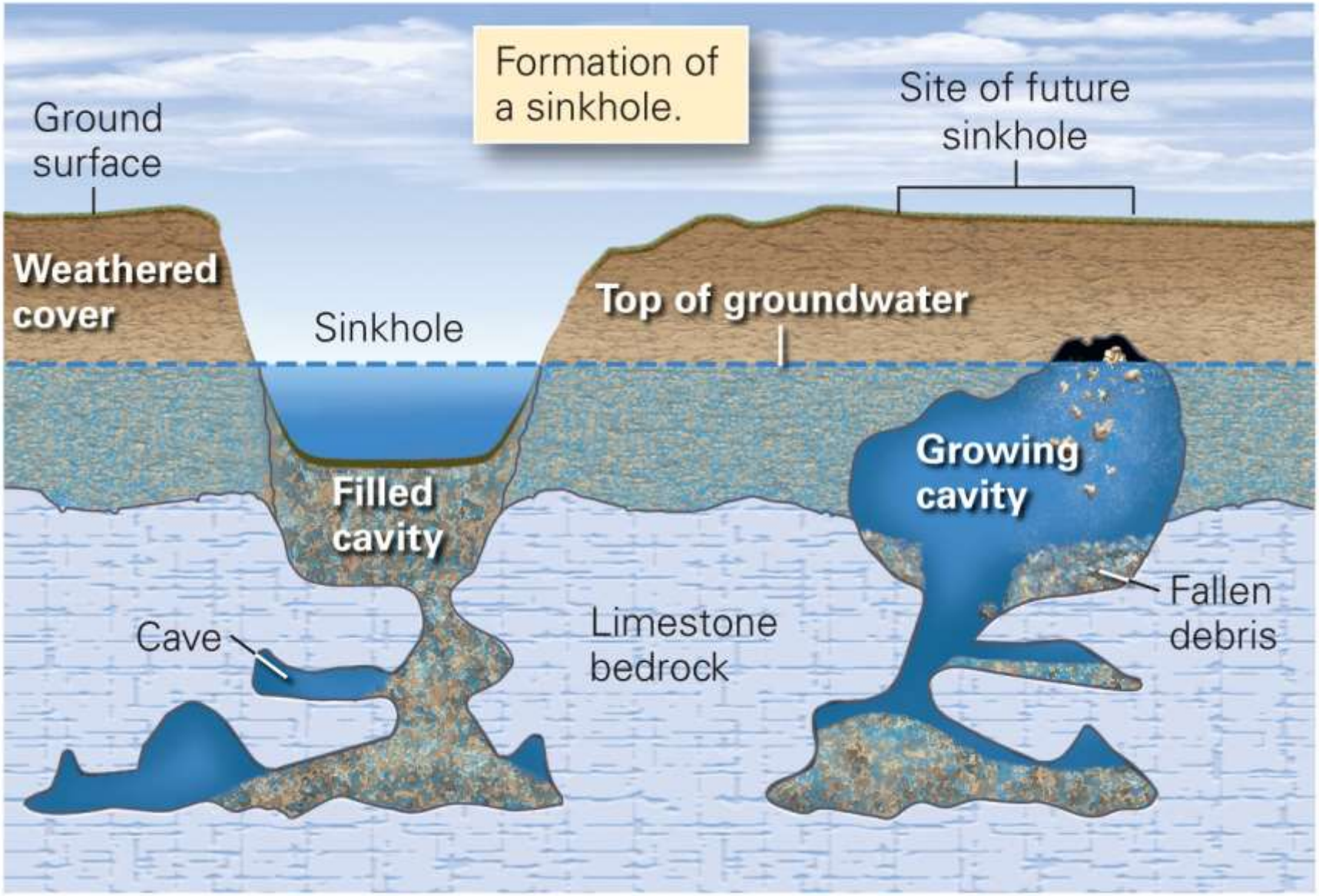
# Caves and Karst

# Soda straw stalactites

# Karst Landforms

- Sinkholes result from roof collapse
- Sinkholes decorate large regions of karst landscapes

B.



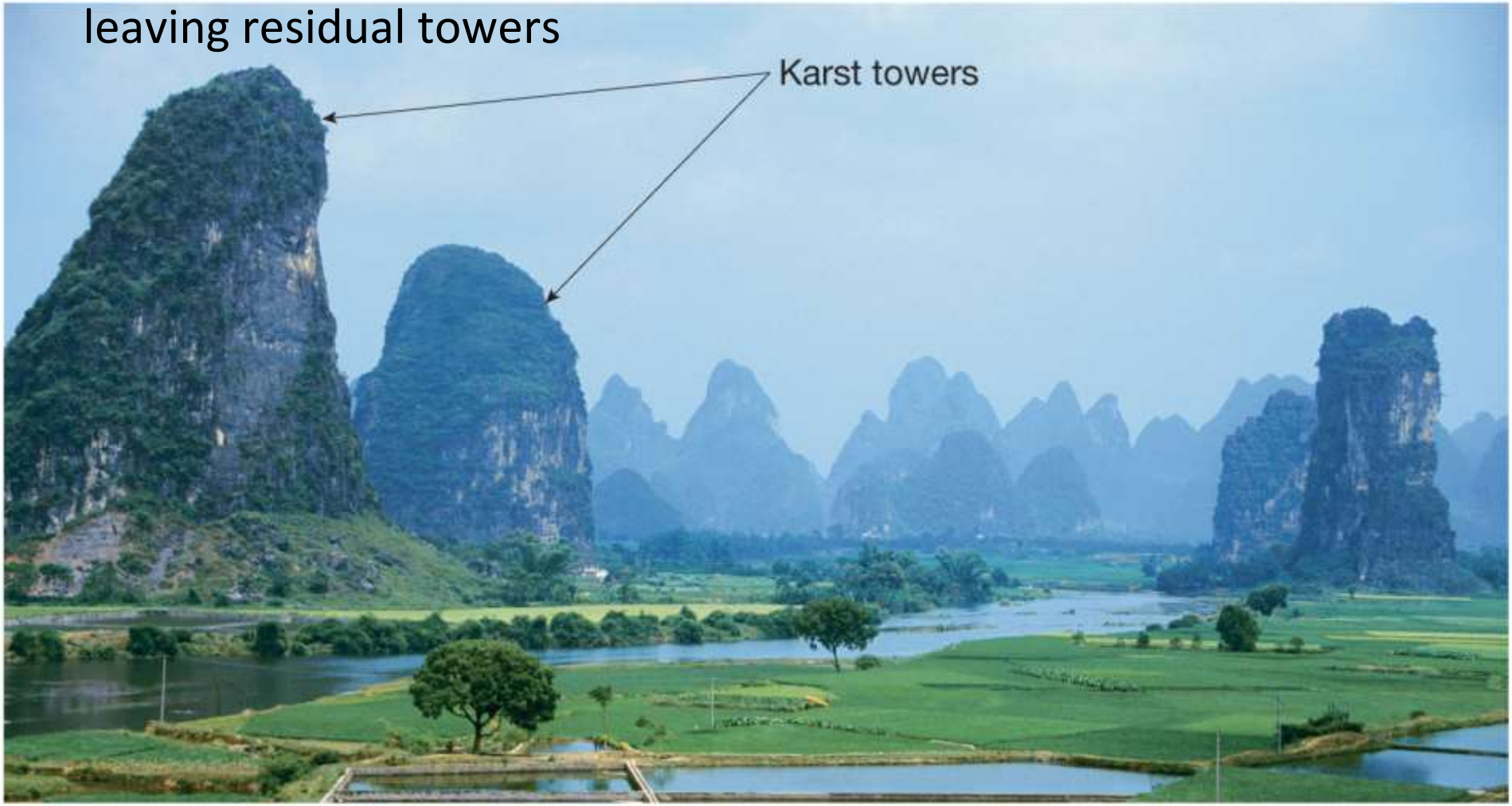
# Caves and Karst


(a)

(b)

# Caves and Karst

B. Tower karst is formed when jointed limestone is dissolved away, leaving residual towers



# Caves and Karst

The landscape is treeless today, a consequence of industrialization policies in the 1950s.

# Group Question

- Which of these is NOT a reason that groundwater is acidic?

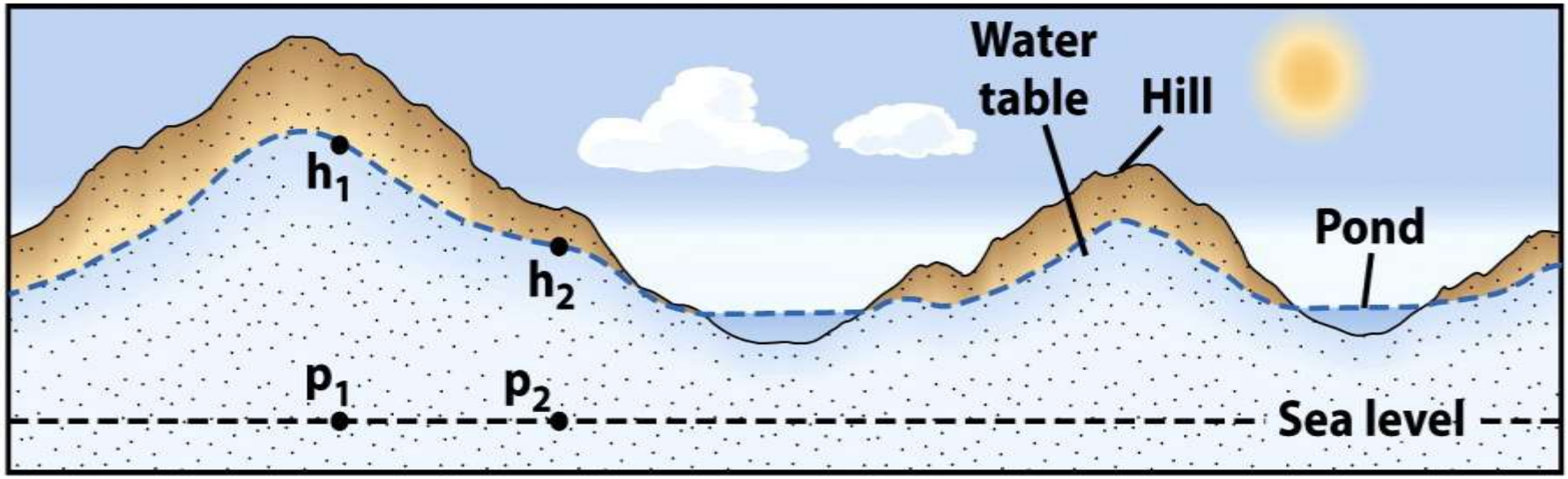
a) Groundwater usually begins as rainwater
b) It travels through soils
c) It dissolves carbonate rocks
d) Certain pollutants

# Group Question

- Can you predict how will water move though a rock?

# Water Table Topography

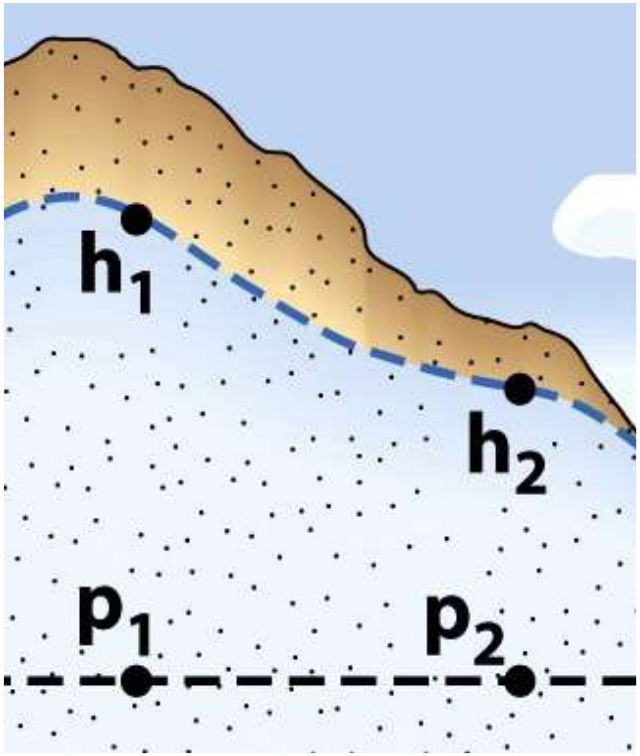
- Subdued replica of the topography
- Water flows from higher elevations to lower elevations
- Topography is useful for estimating groundwater flow



# Groundwater Flow

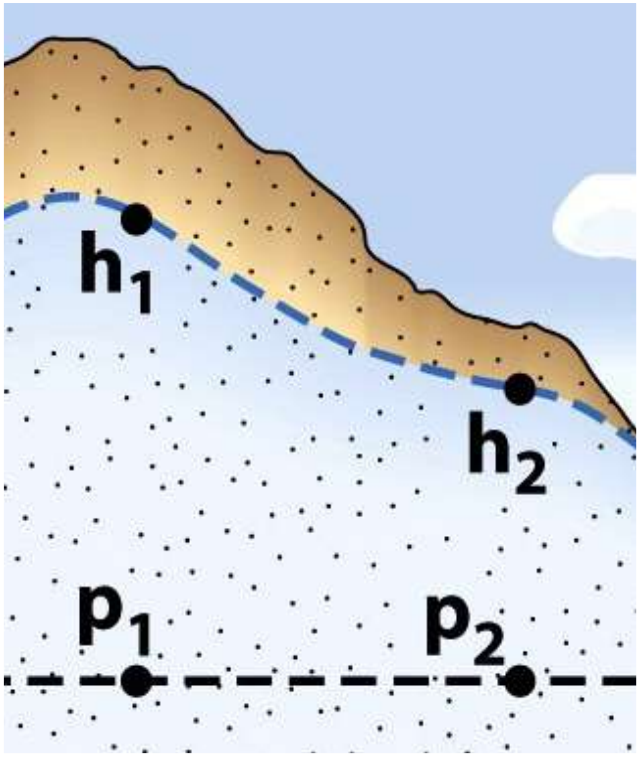
- Which direction would water flow between the two lower points?

a) Left to right
b) Right to left



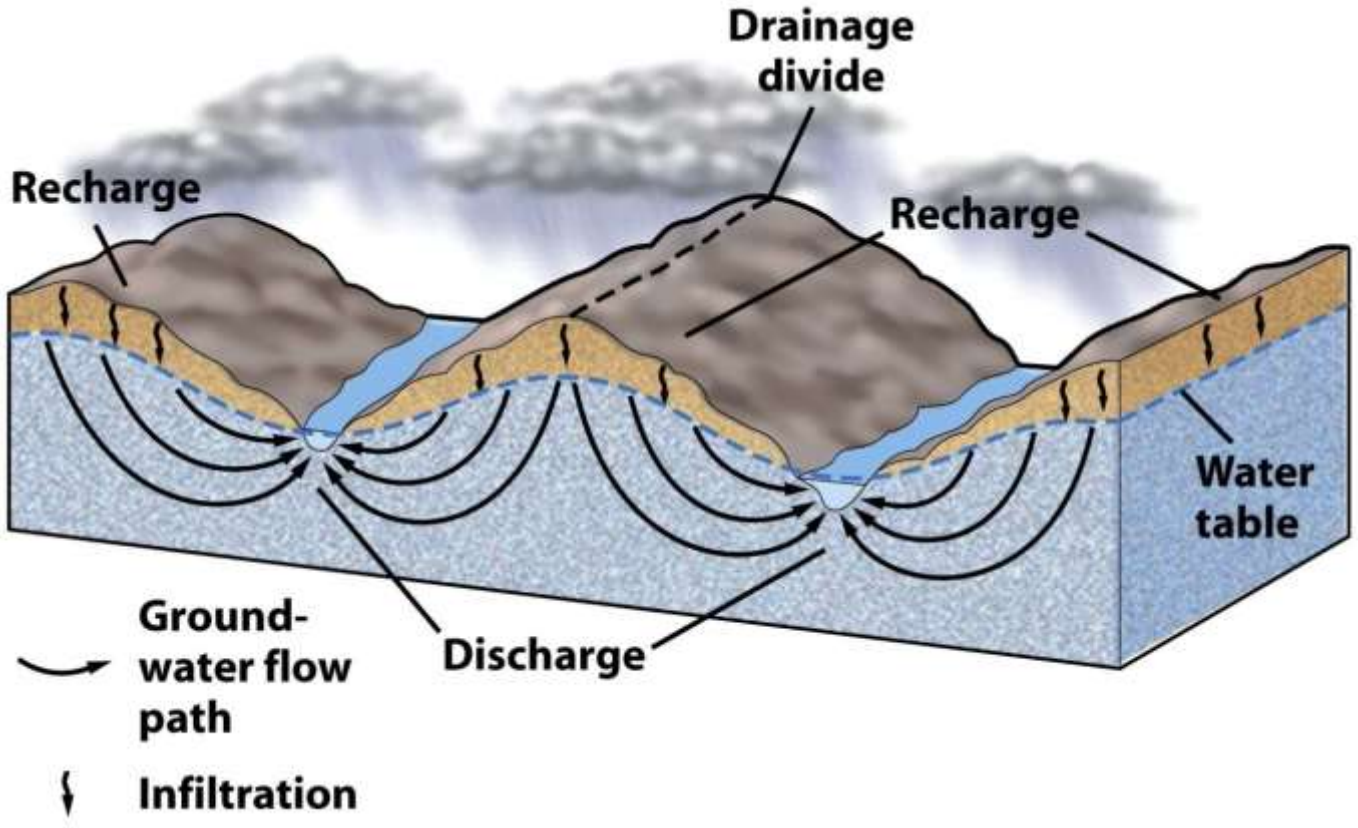
# Groundwater Flow

- Hydraulic head, potential energy driving flow, is due to…
  - Elevation above sea level
  - Pressure exerted by weight of overlying water



# Groundwater Flow

- Unsaturated zone = straight down due to gravity
- Saturated zone = curved due to gravity and pressure



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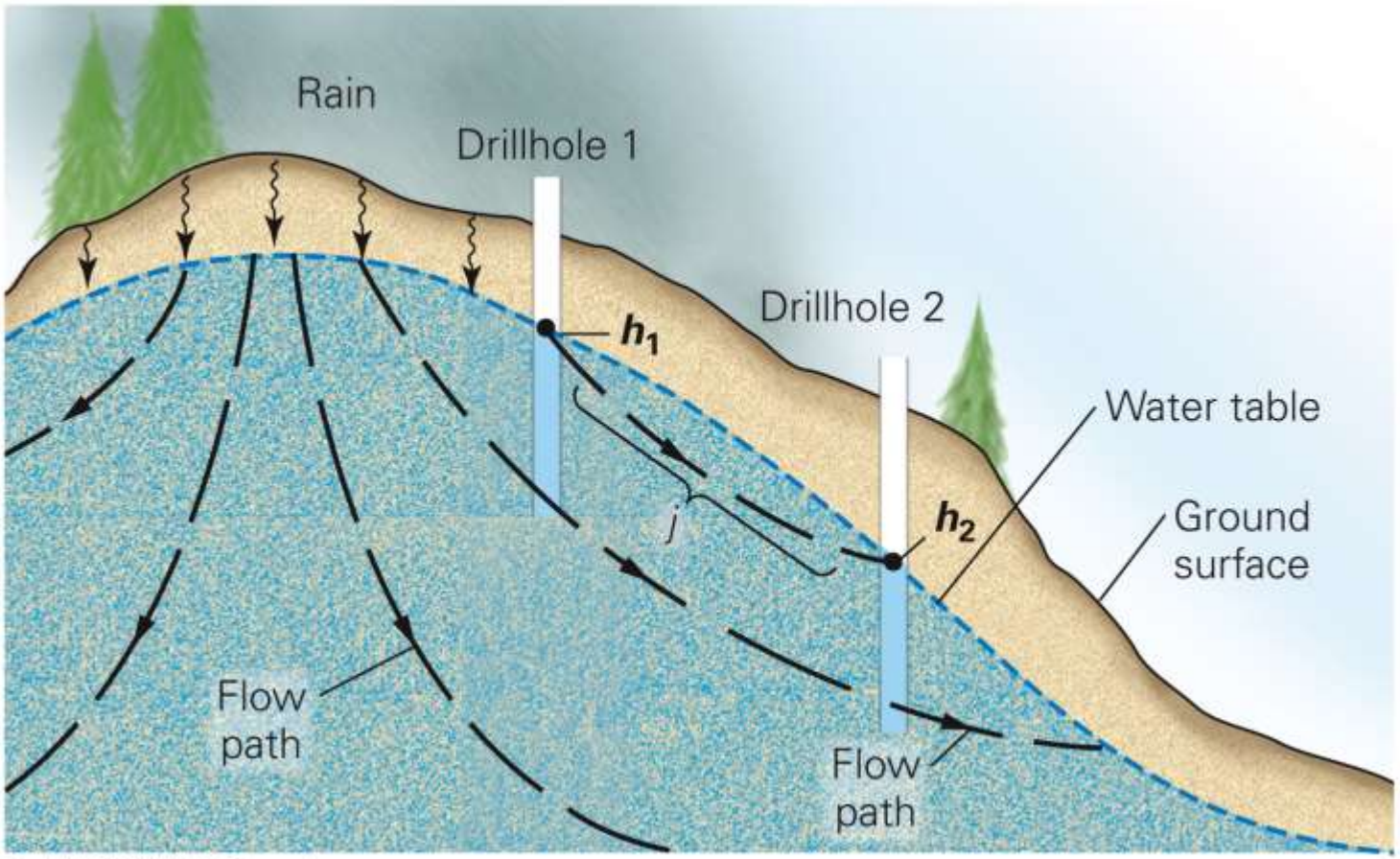
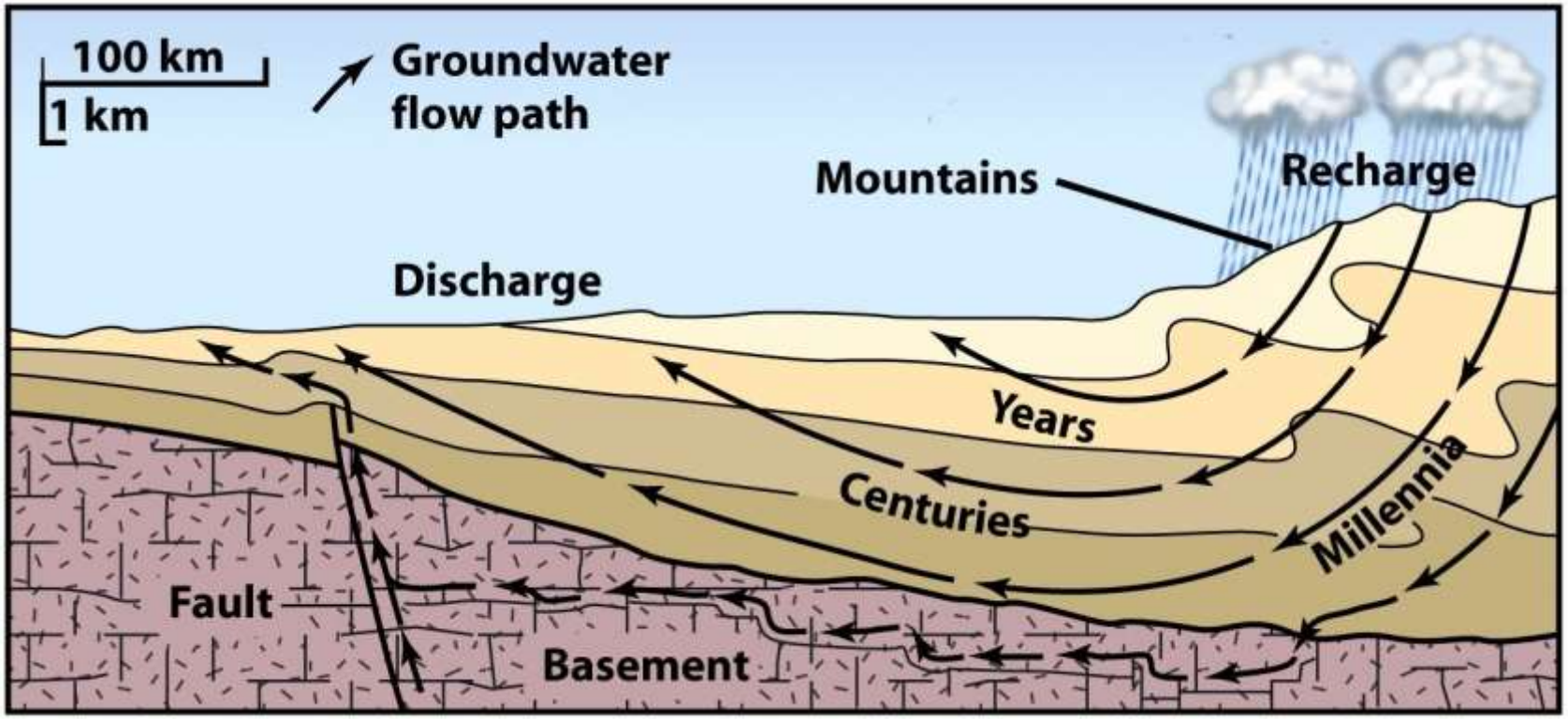


# Groundwater Flow

- Groundwater flow occurs on a variety of scales



# Groundwater Flow Rates

- Groundwater movement is slow relative to surface water. Why?
- Typical rates of flow:
  - Ocean currents ~3 km per hour
  - Steep river channel ~30 km per hour
  - Groundwater ~0.00002 km per hour

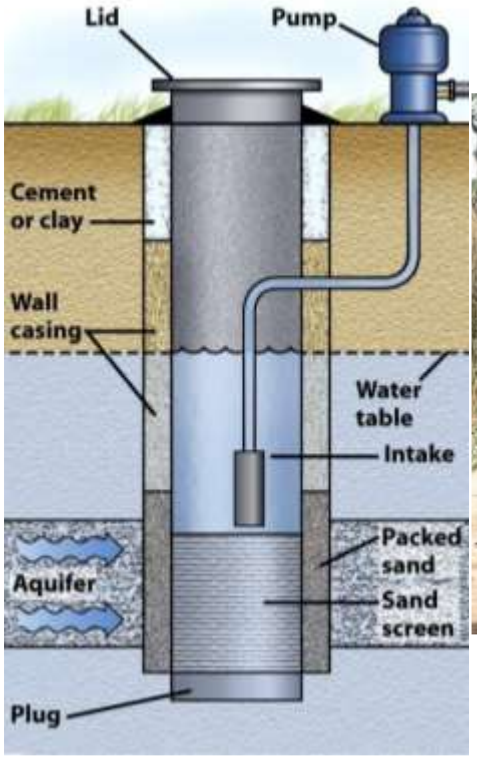
# Group Question

- Which of these rocks would have high porosity and high permeability?

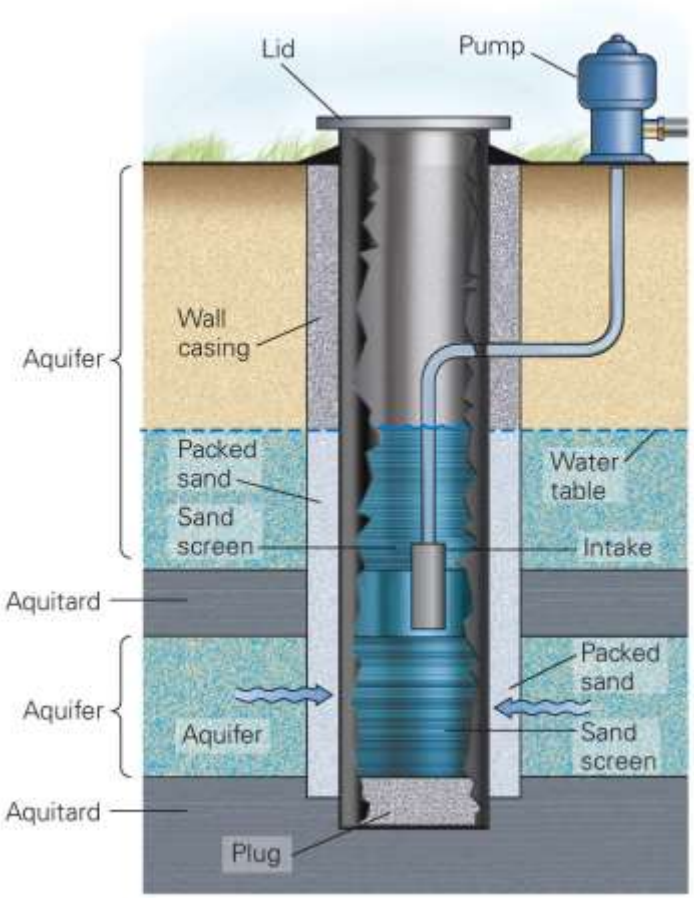
a) Crystalline igneous rocks
b) Clays
c) Well sorted sandstone
d) Glacial sediments

# Tapping Groundwater

- Wells are holes drilled or dug into the saturated zone
- Springs are where groundwater naturally reaches surface
- What happens if removal of water is faster than replacement flow?

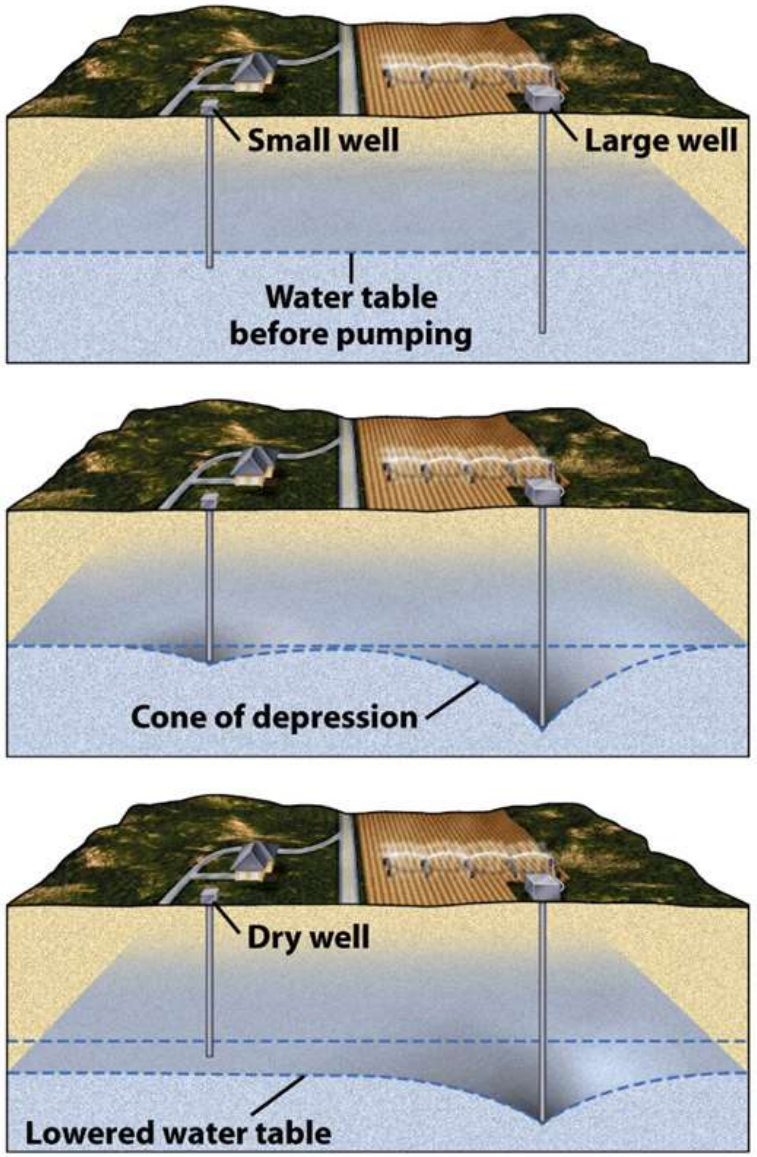



# Tapping Groundwater



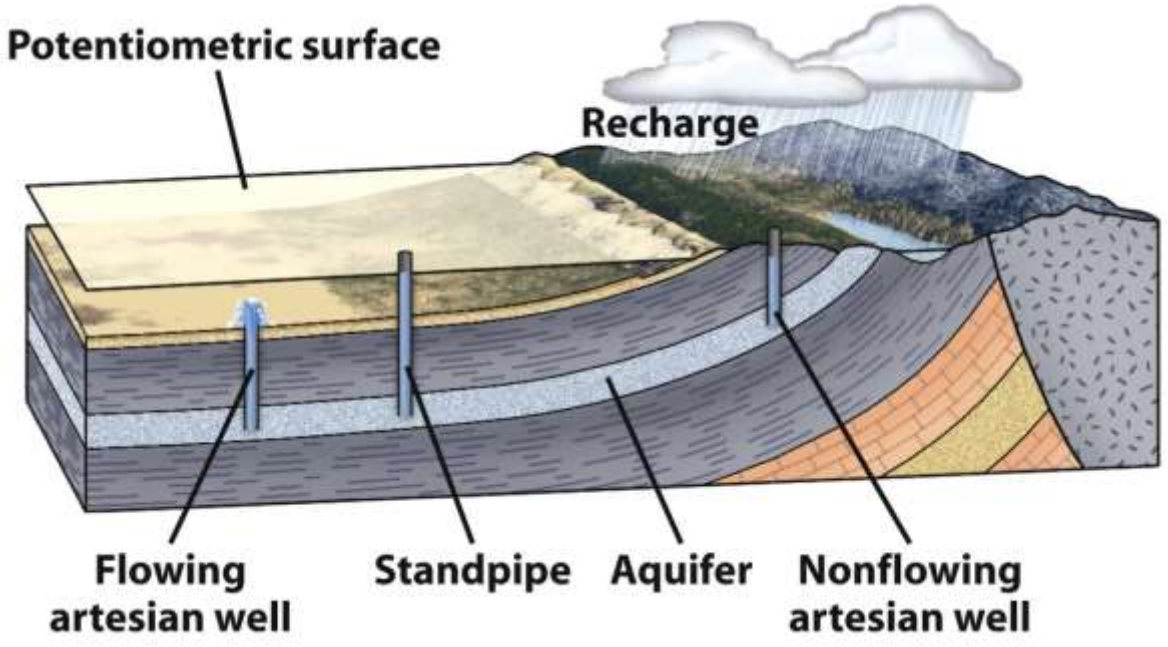
# Tapping Groundwater

- With drawdown, the water table near the well drops and forms a cone of depression
- Drawdown, from multiple wells in an area, is additive
- Competing users often conflict



# Tapping Groundwater

- Artesian wells tap confined, tilted aquifers
  - Water rises in artesian wells to the potentiometric surface



# Tapping Groundwater

- Water distribution systems mimic artesian aquifers

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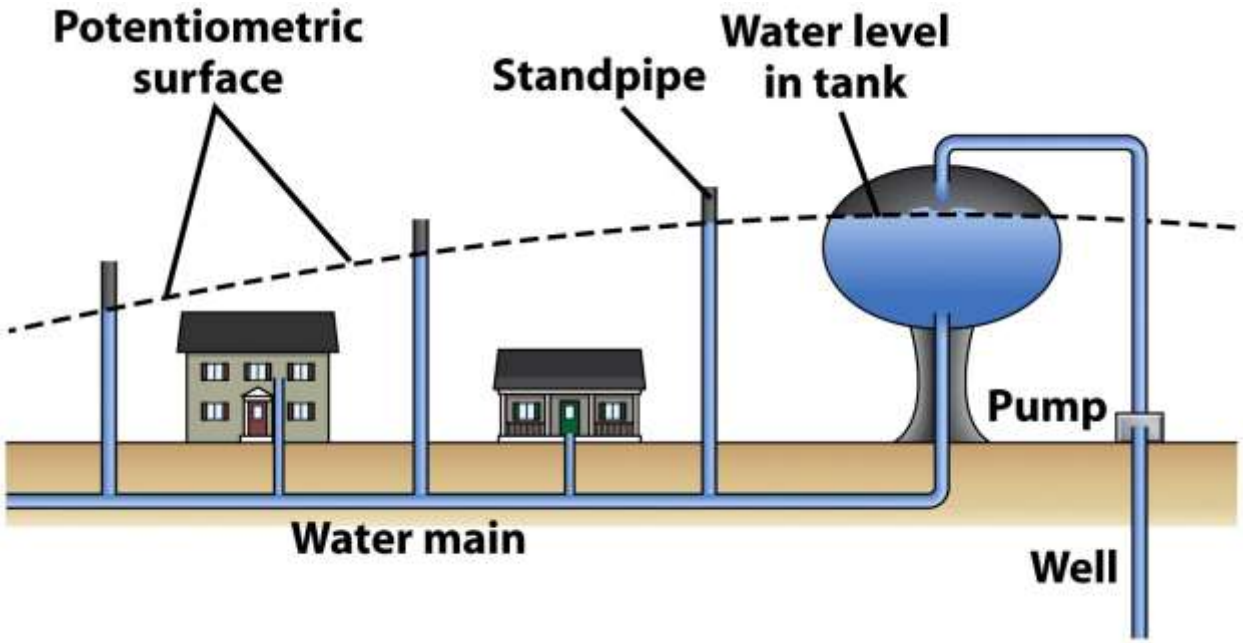
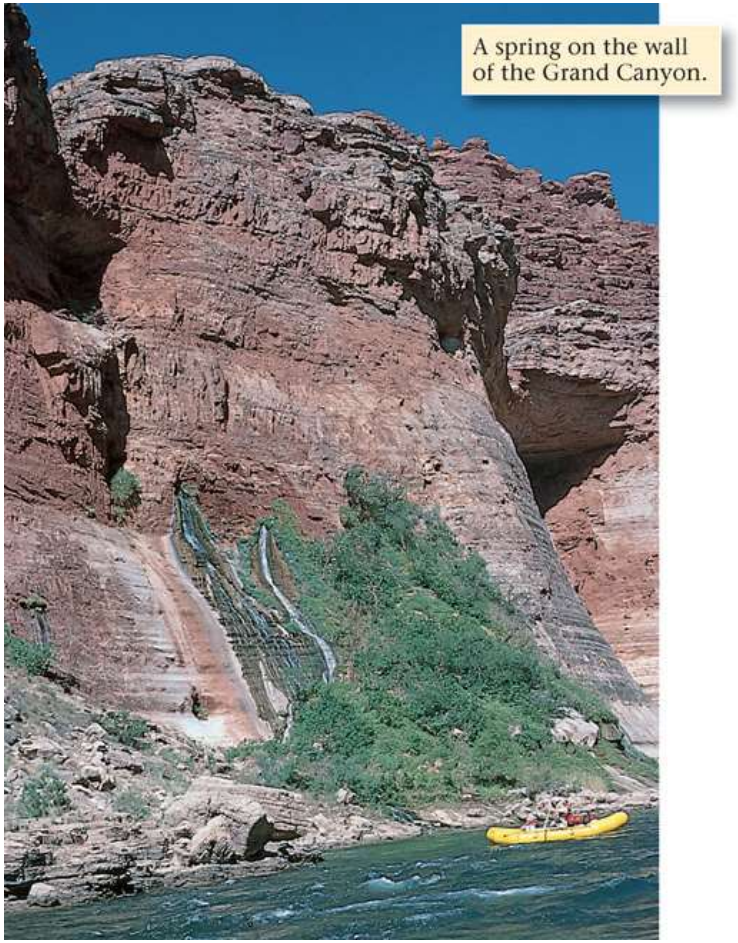
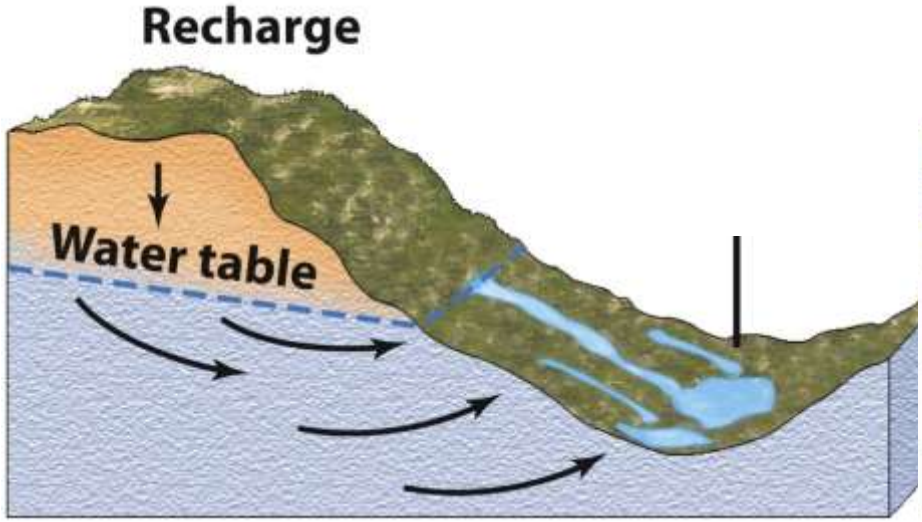


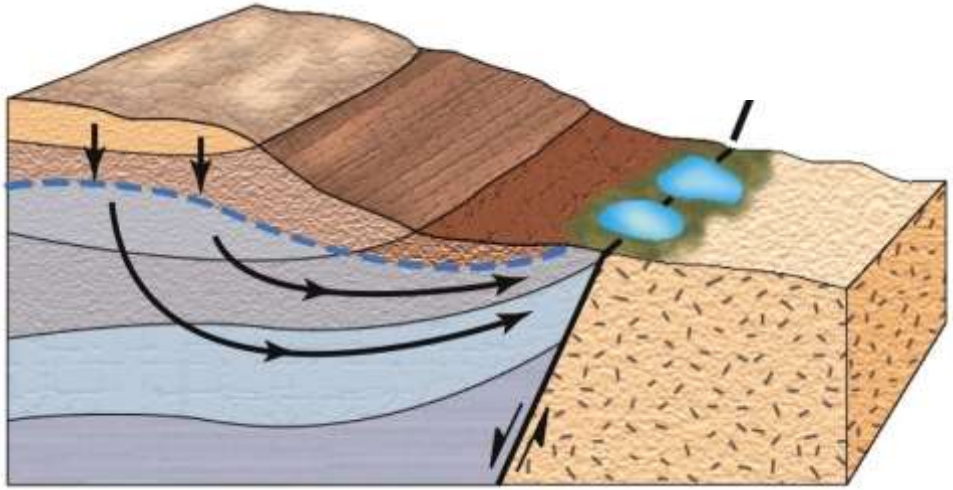

# Tapping Groundwater

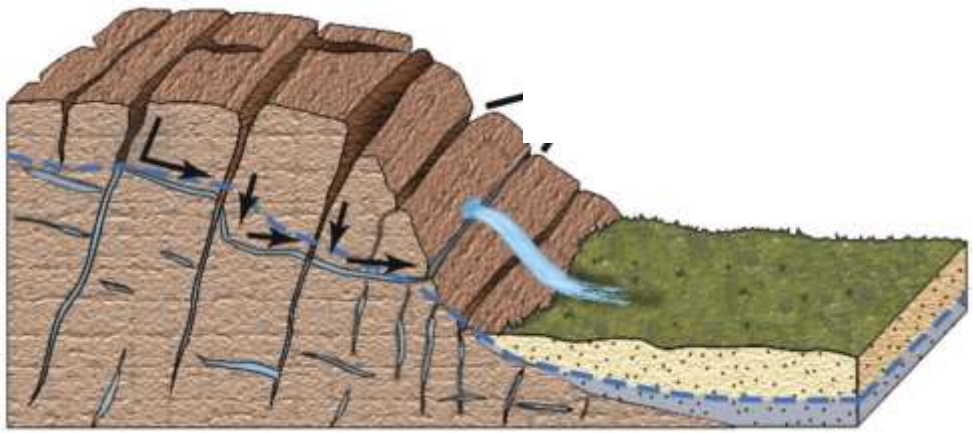
- Springs are locations of natural groundwater discharge
  - Springs are marked by…
    - Hydrophilic vegetation
    - Perennial wetlands
    - Saturated soils
    - Non-freezing ground
    - Streamflow

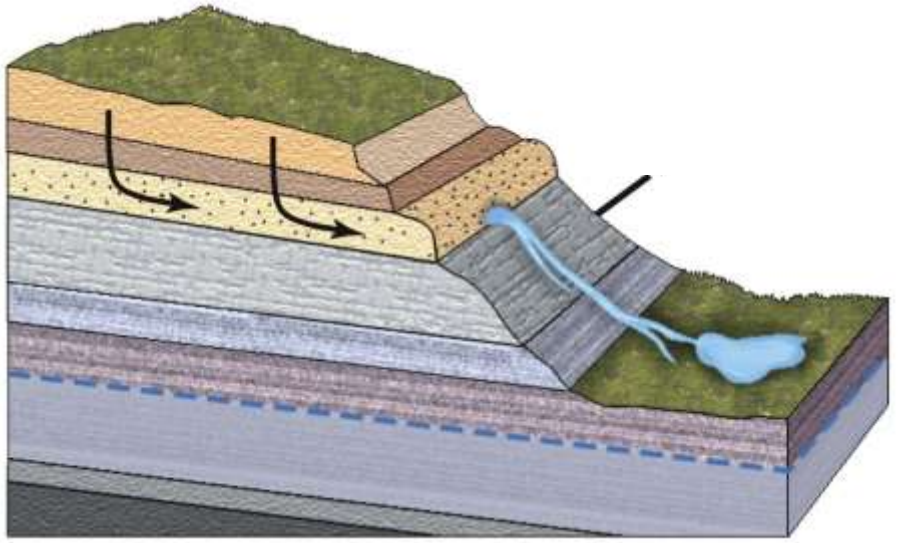


# Tapping Groundwater







# Group Question

What information would you need to determine where a good place to build a well might be?

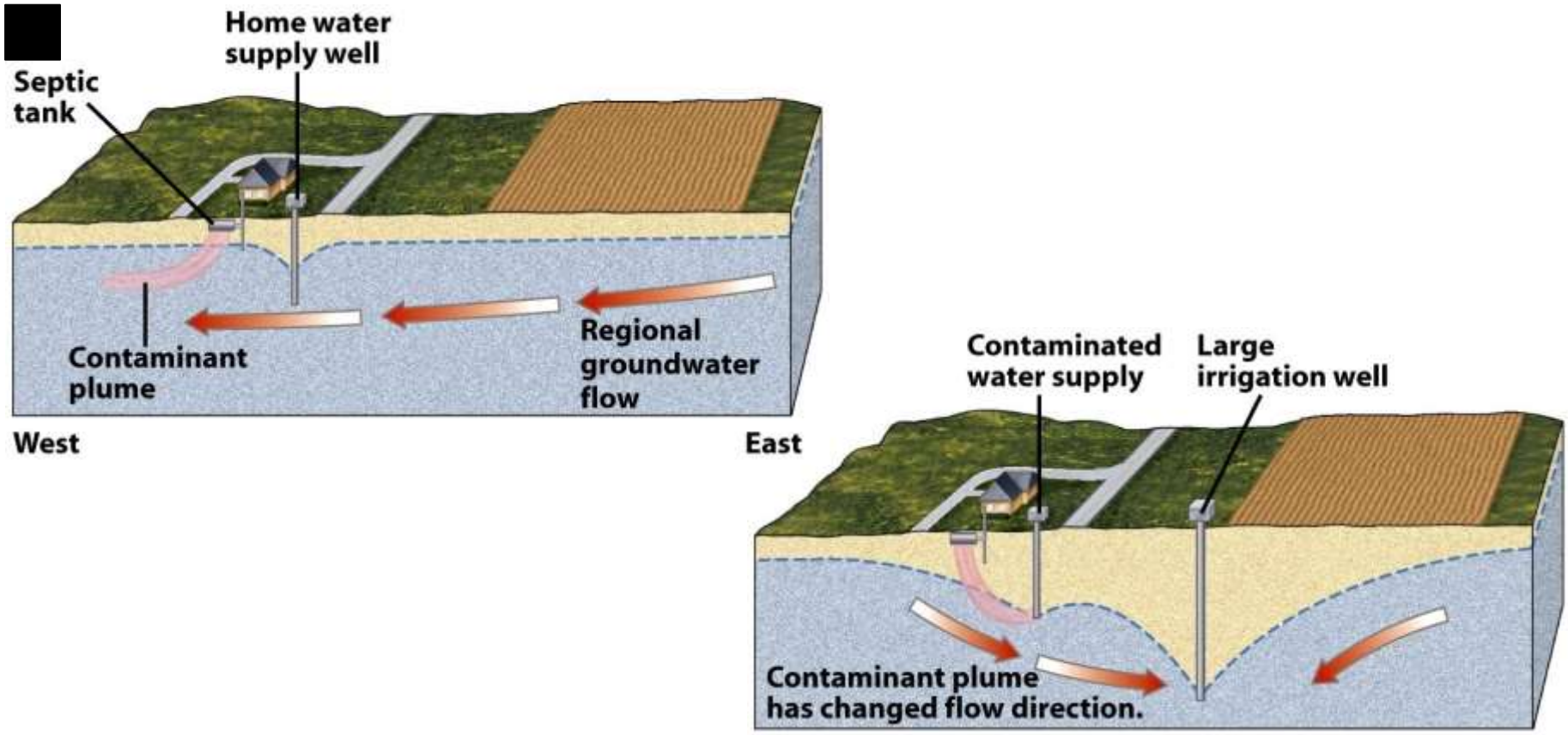
# Groundwater Problems

- Groundwater is an important natural resource
  - It accounts for 95% of all the liquid freshwater on Earth
  - It supplies a substantial portion of drinking-water needs
  - Groundwater is threatened by…
    - Mismanagement
    - Overuse
    - Pollution

# Groundwater Depletion

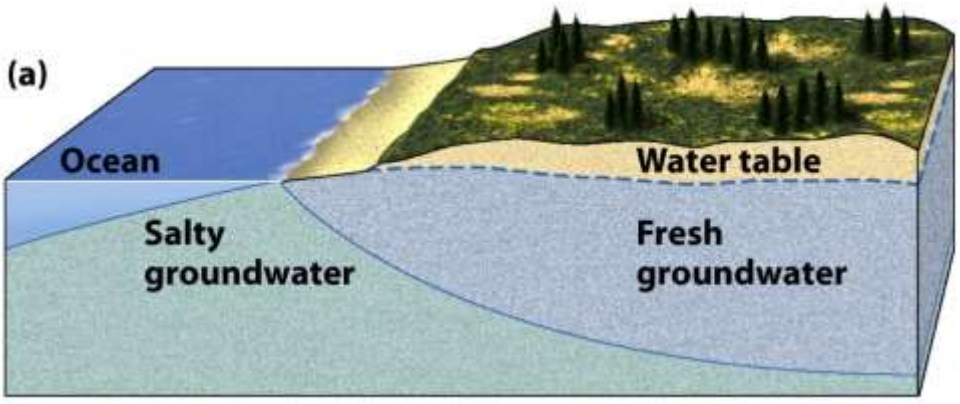
# Groundwater Depletion

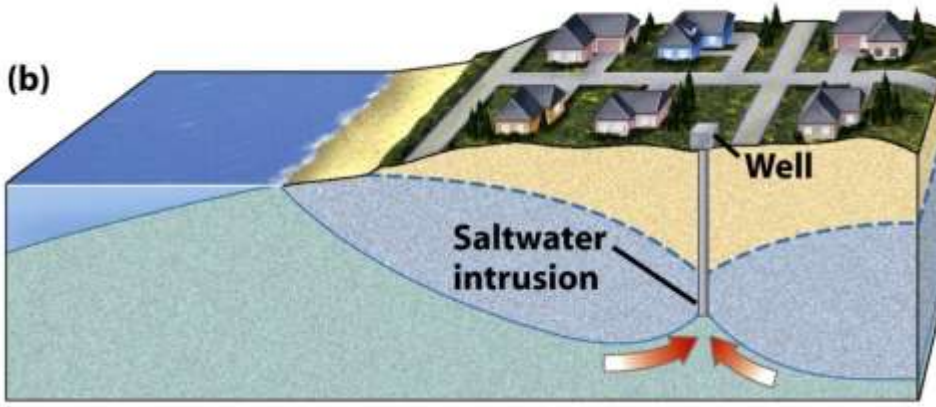
- Cones of depression are capable of reversing flow
- An expanding cone may capture pollutants



# Groundwater Depletion

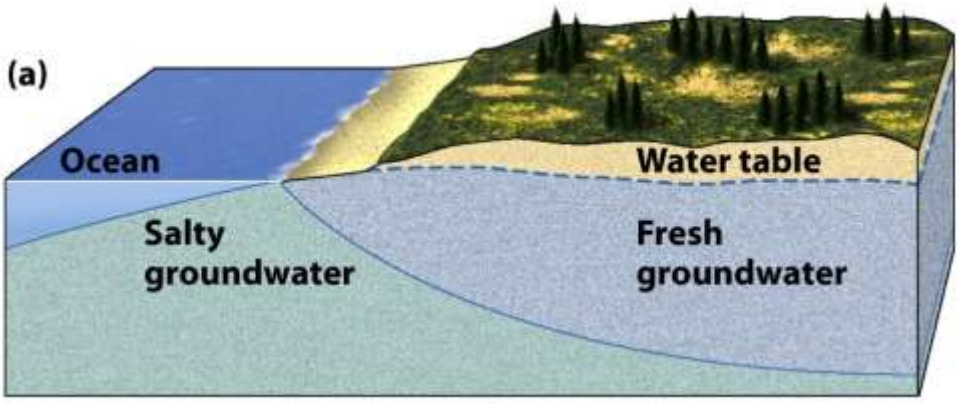
- Saltwater intrusion renders the water undrinkable

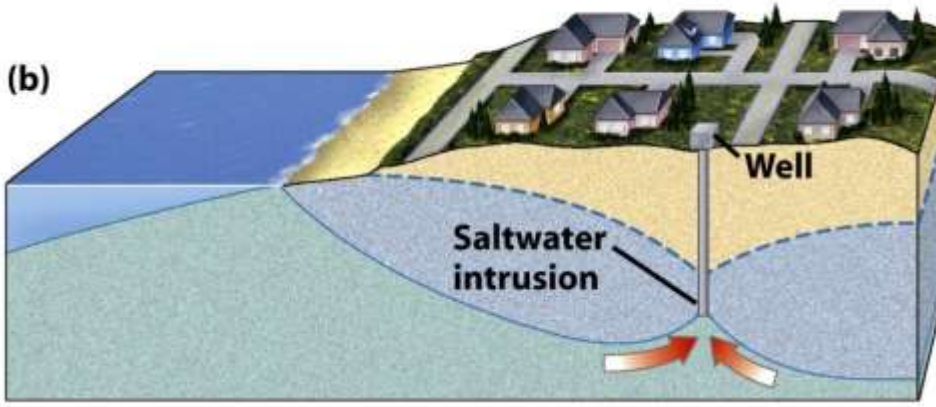


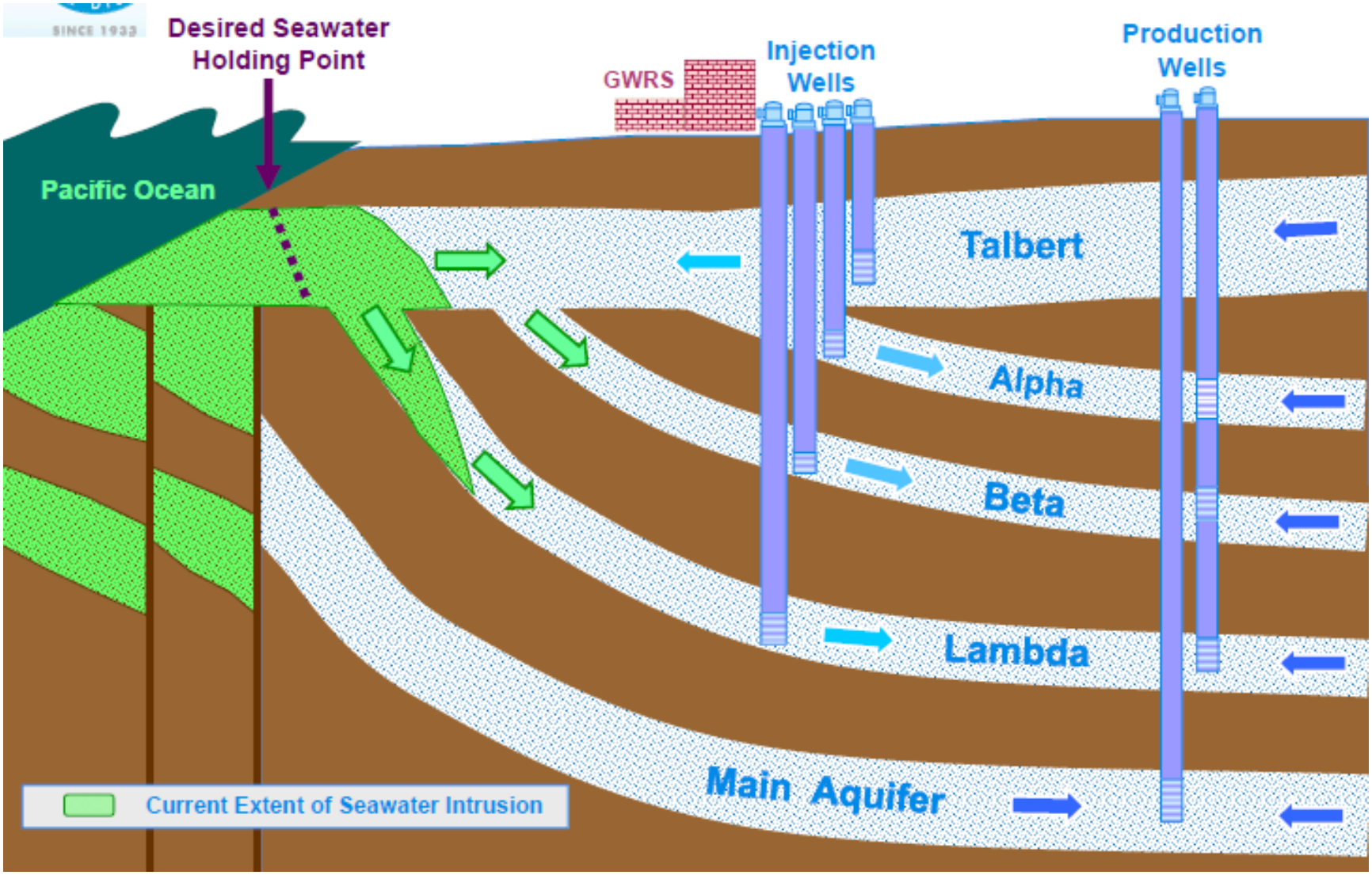
# Group Question

- How could you stop your salt water supply from being contaminated by saltwater intrusion?



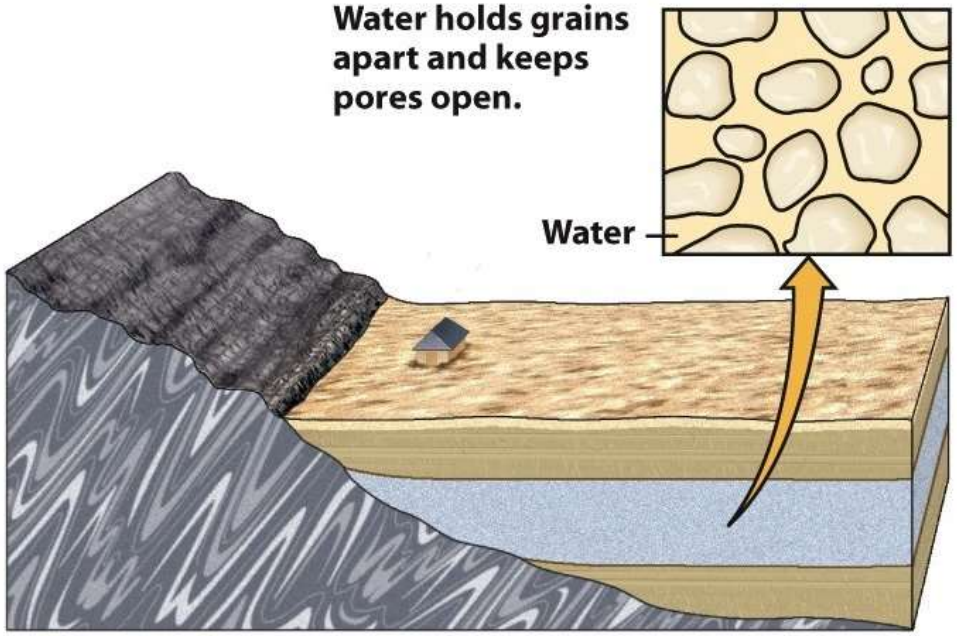



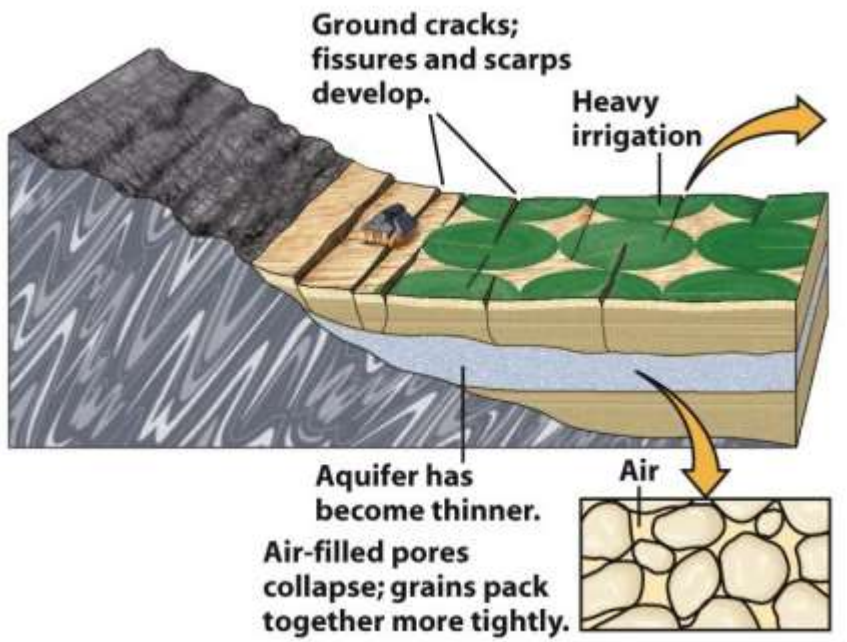
# Case Study: Orange County (and California)



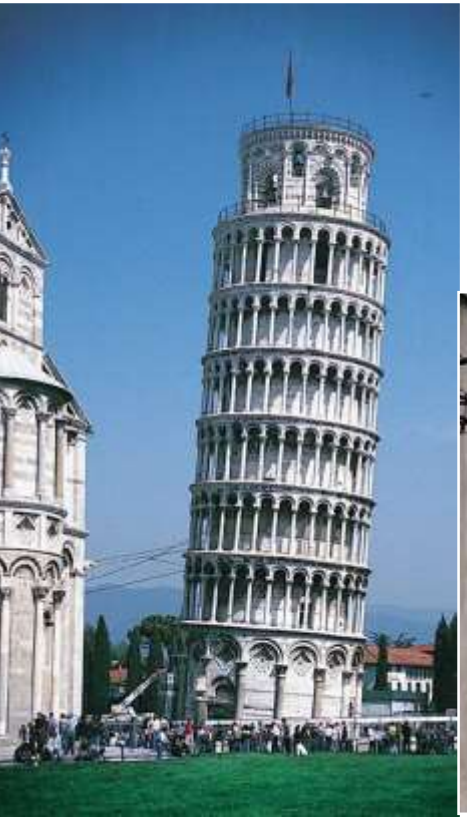
# Groundwater Depletion

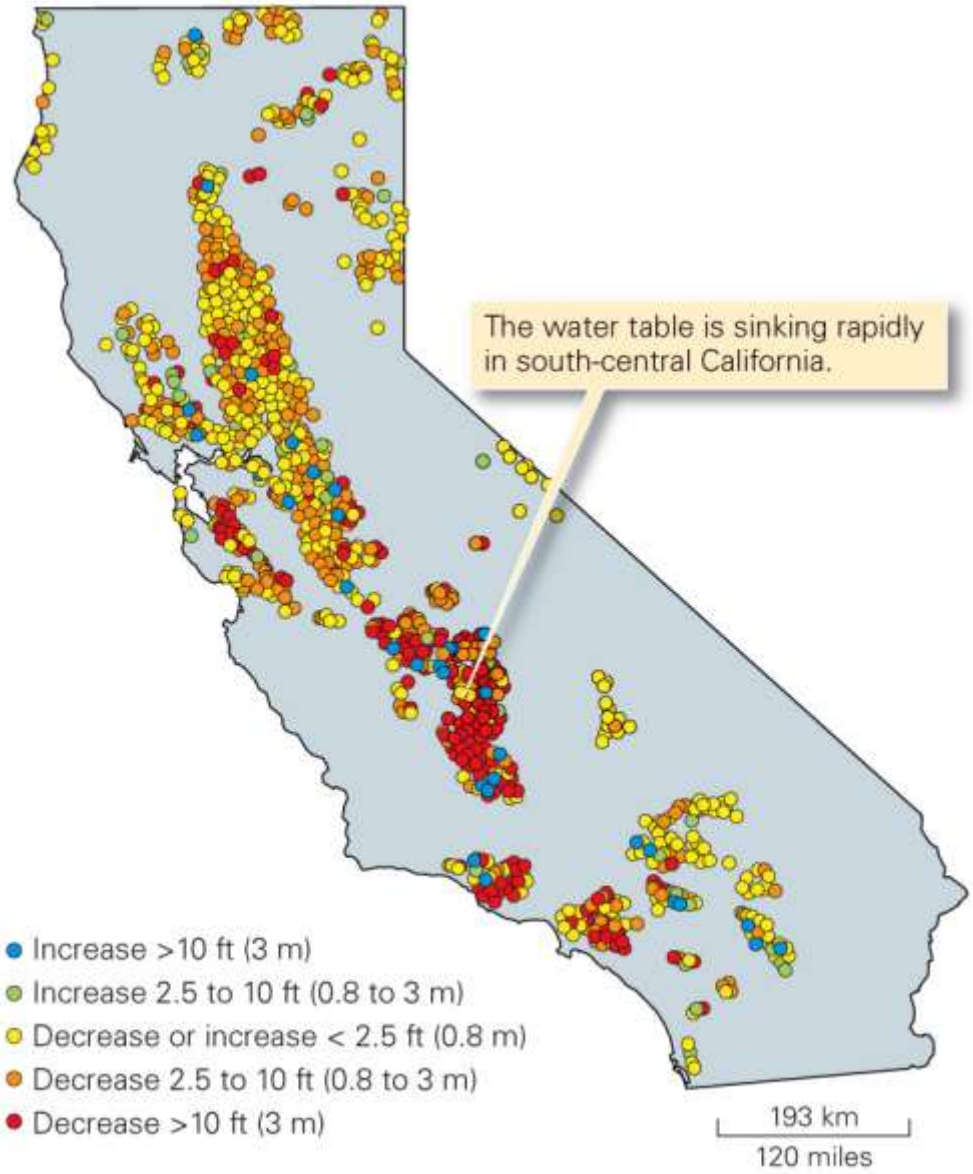
- Water in pore space acts to hold grains apart
- When groundwater is removed…
  - Sediment grains compress; pores collapse
  - The land surface cracks and sinks
- Subsidence is mostly irreversible



# Groundwater Depletion



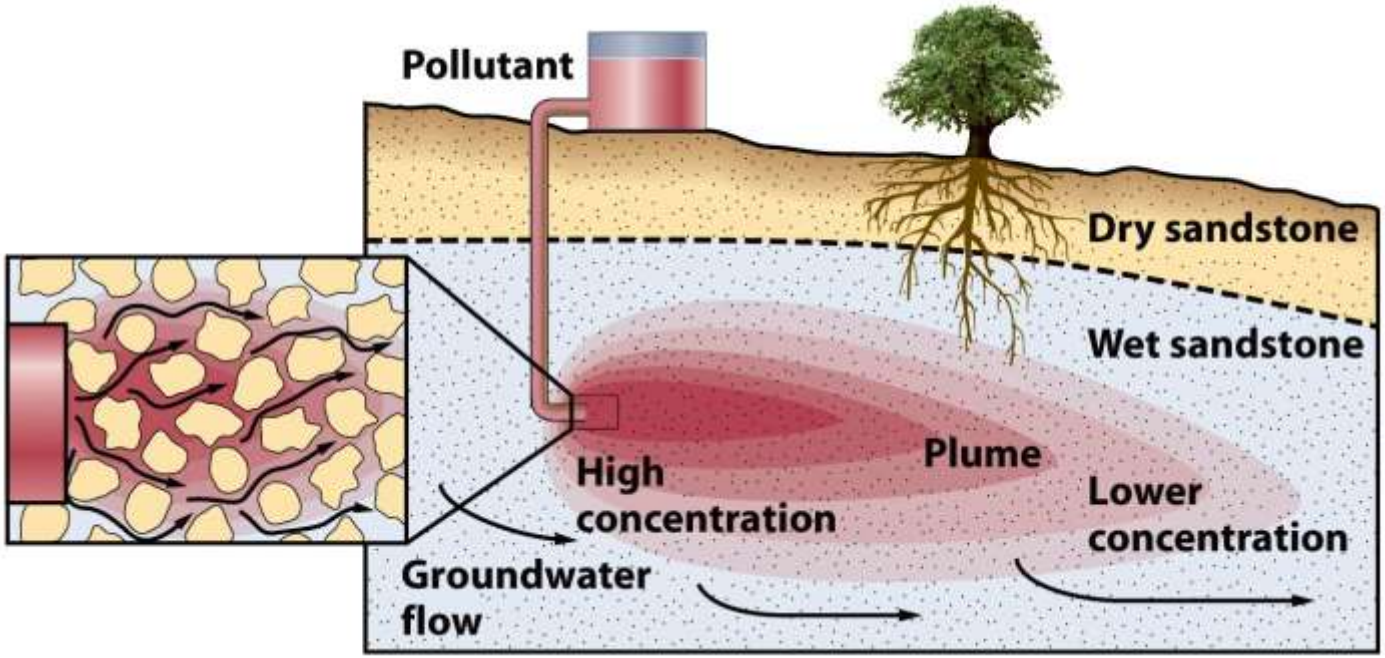


# Groundwater Quality

- Groundwater is often of high-quality
  - Filtering effect removes particulates
  - Clay minerals can absorb certain dissolved ions
- Natural groundwater may contain unwanted substances
  - Hardness
  - Dissolved iron, manganese, and hydrogen sulfide gas
  - Dissolved arsenic

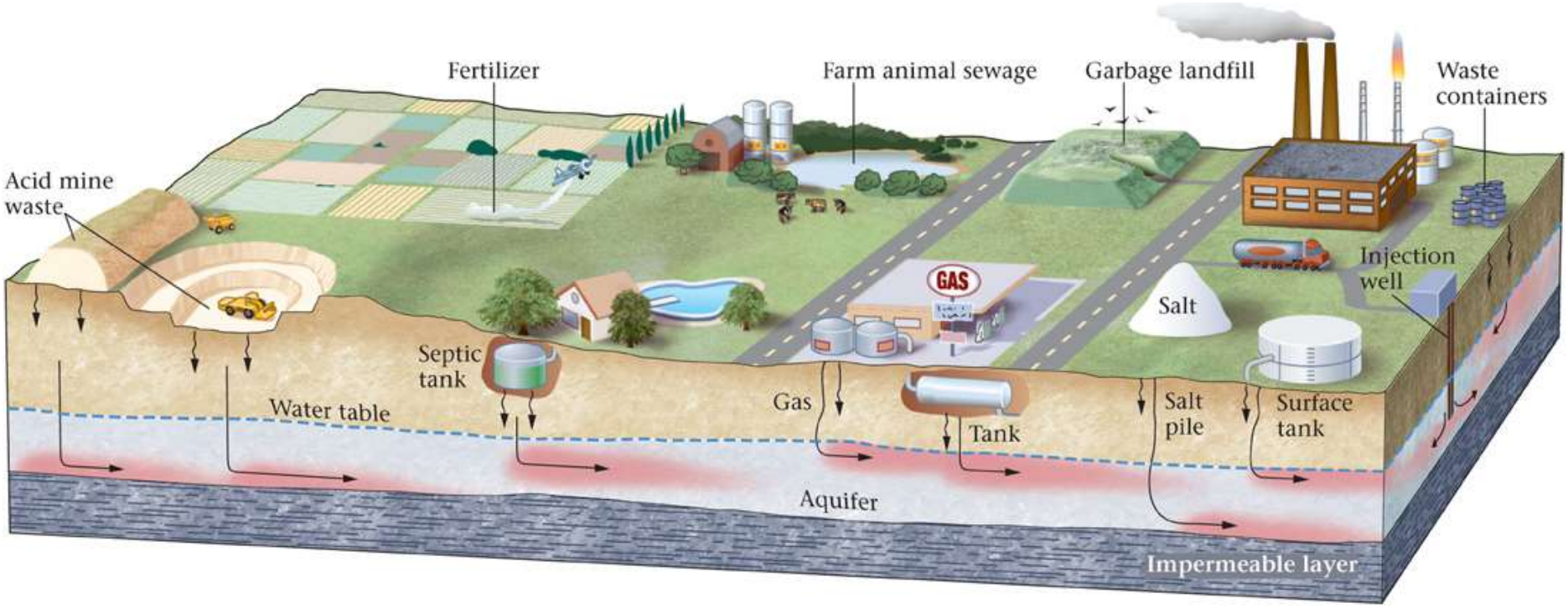
# Groundwater Contamination

- Human activities add pollutants to groundwater flow
  - Dissolved and pure organic and inorganic compounds
  - Dissolved metals
  - Pathogenic microbes
- Groundwater transports pollutants away from a source

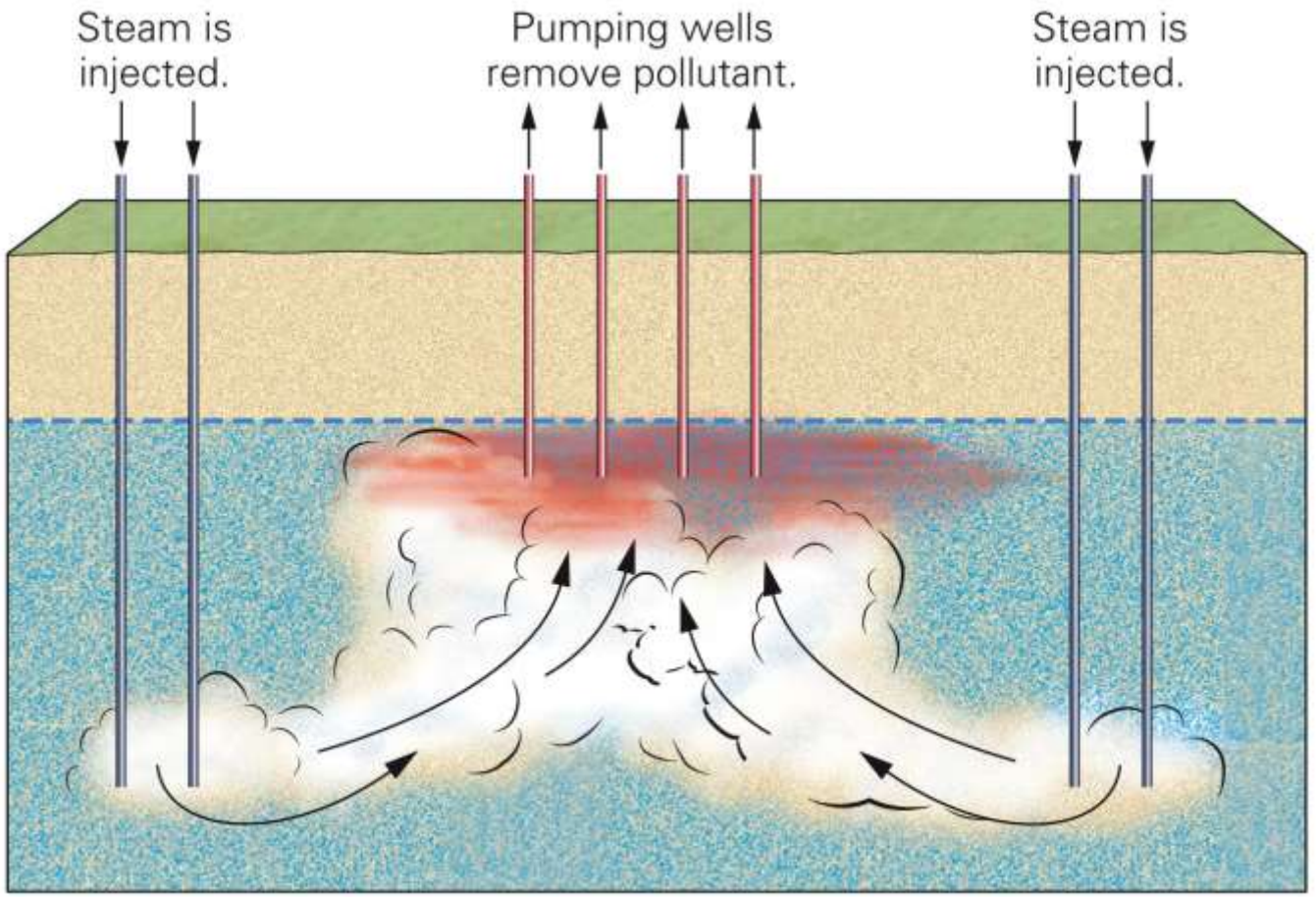



# Groundwater Contamination

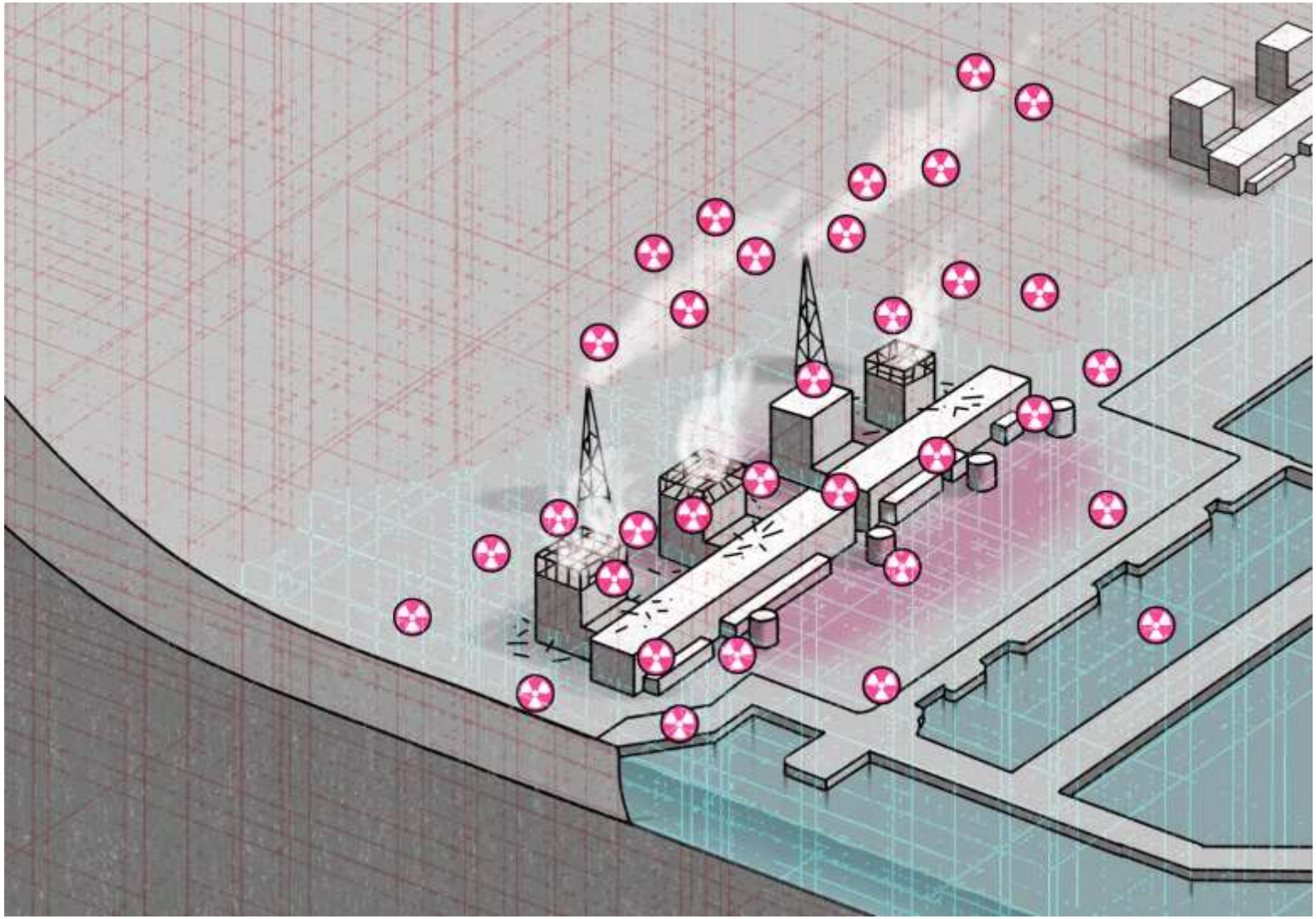
- There are many sources of groundwater contamination
- Pollution is often not recognized until damage occurs
- Groundwater cleanup is slow, expensive, and limited



# Groundwater Contamination



# Case study: Fukushima, Japan

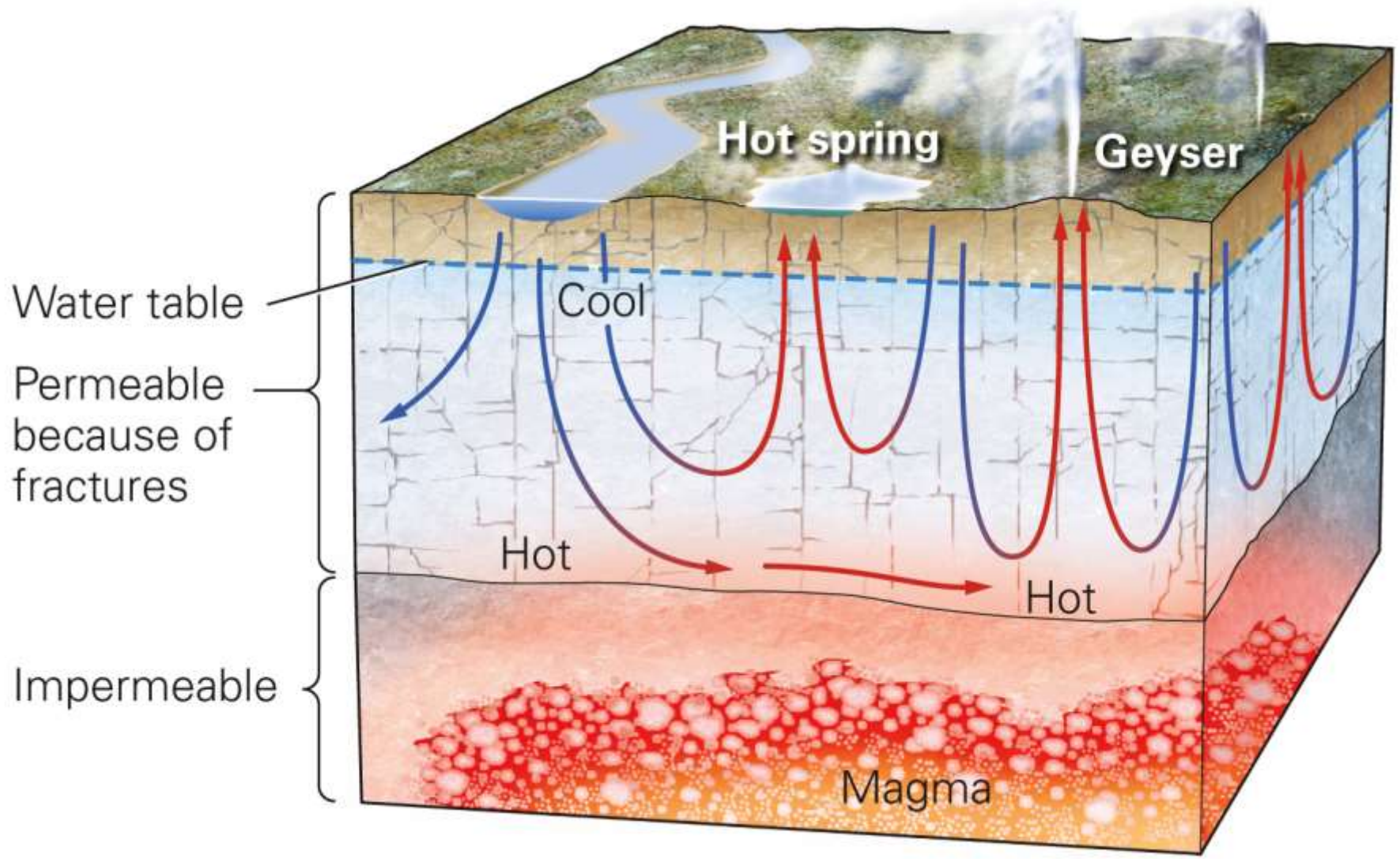


http://apps.washingtonpost.com/g/page/world/preventing-radioactive-leaks-at-fukushima-daiichi/511/

# Geysers

# Geysers

# Geysers



# Geysers

# Geysers

# Groundwater Features

# Groundwater Features

Natural Bridge, Virginia

# Groundwater Features

# Groundwater Features

Spelunker crawling in a cave

# Groundwater Features

Underground pool, Mexico

# Groundwater Features

# Groundwater Features

## Sinkholes