Groundwater

- **Water filling open spaces in rock, sediment, and soil beneath the surface is called groundwater. This natural resource is as important to human endeavors as surface water.**
- **Groundwater is an especially important resource in semiarid regions and played a pivotal role in westward expansion of the U.S. in the 19th century.**
- **Many legal battles have resulted from claims and counterclaims of groundwater ownership.**
- **In addition to being a source of freshwater, groundwater is an important erosional agent as well as an alternative energy source (geothermal energy).**

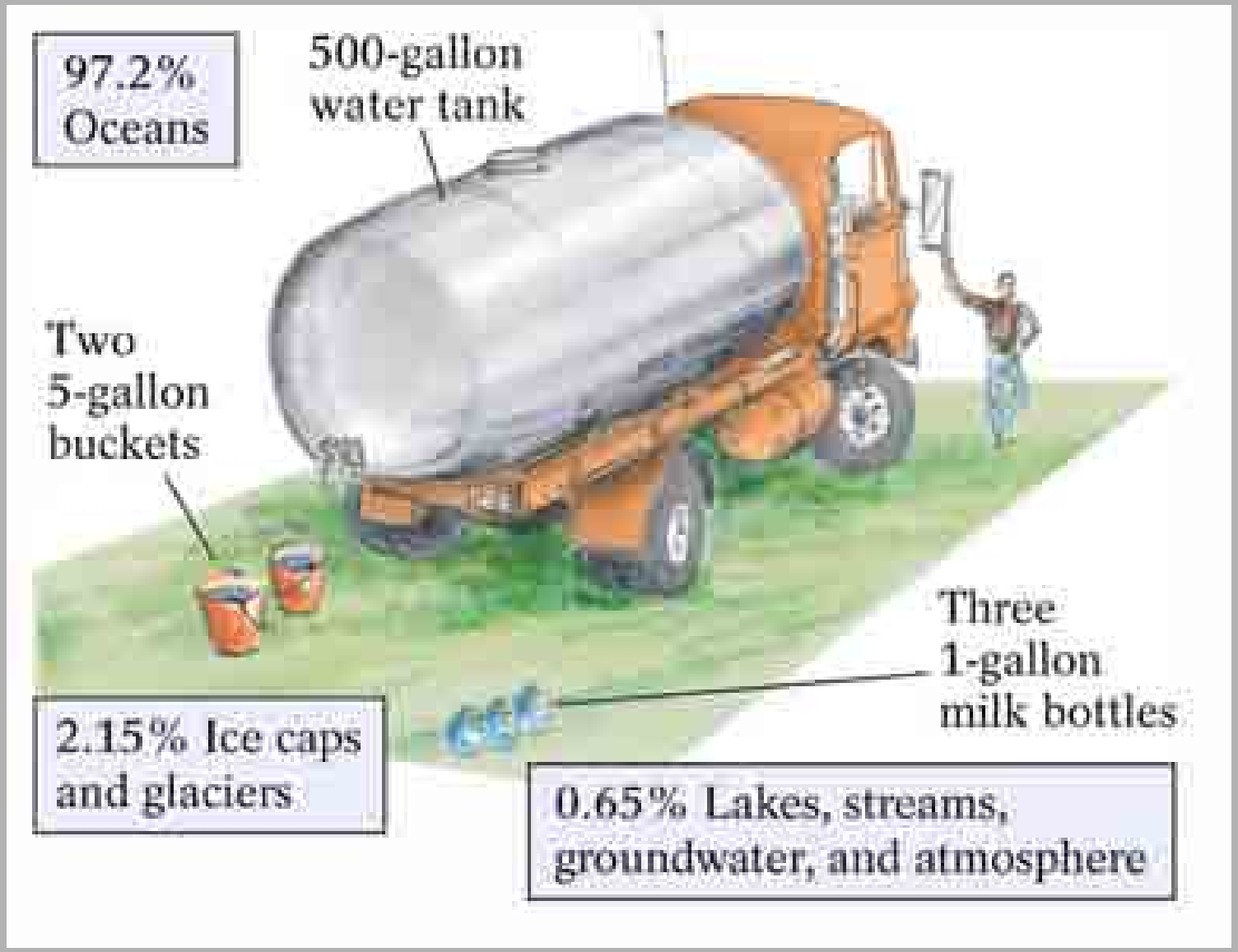
Why Study Groundwater?

- **Agricultural, industrial, and domestic demands for freshwater is at an all time high.**
- **Demands for groundwater have depleted supplies in many areas and led to ground subsidence and saltwater intrusion. In other areas pollution from landfills, toxic waste, and agriculture has made portions of the groundwater supply unsafe.**
- **As global population and industrialization expand, so will the demand for clean, safe groundwater. To assure the needs of future generations are meet, people must become aware of the value and vulnerability of our groundwater resources.**

Groundwater & the Hydrologic Cycle

- **Groundwater is one of the several reservoirs of the hydrologic cycle.**
- **Groundwater comprises ~8.4 million km^3 of the world's supply of freshwater.**
- **Water enters the groundwater reservoir via several pathways: ground infiltration of precipitation as well as infiltration from streams, lakes, swamps, artificial recharge ponds and water treatment systems.**
- **Movement of groundwater through the tiny pores of soil, sediment, and rock filters out many impurities such as disease-causing microorganisms and pollutants.**

Water in the hydrosphere



Chernicoff & Whitney (2002)

Groundwater

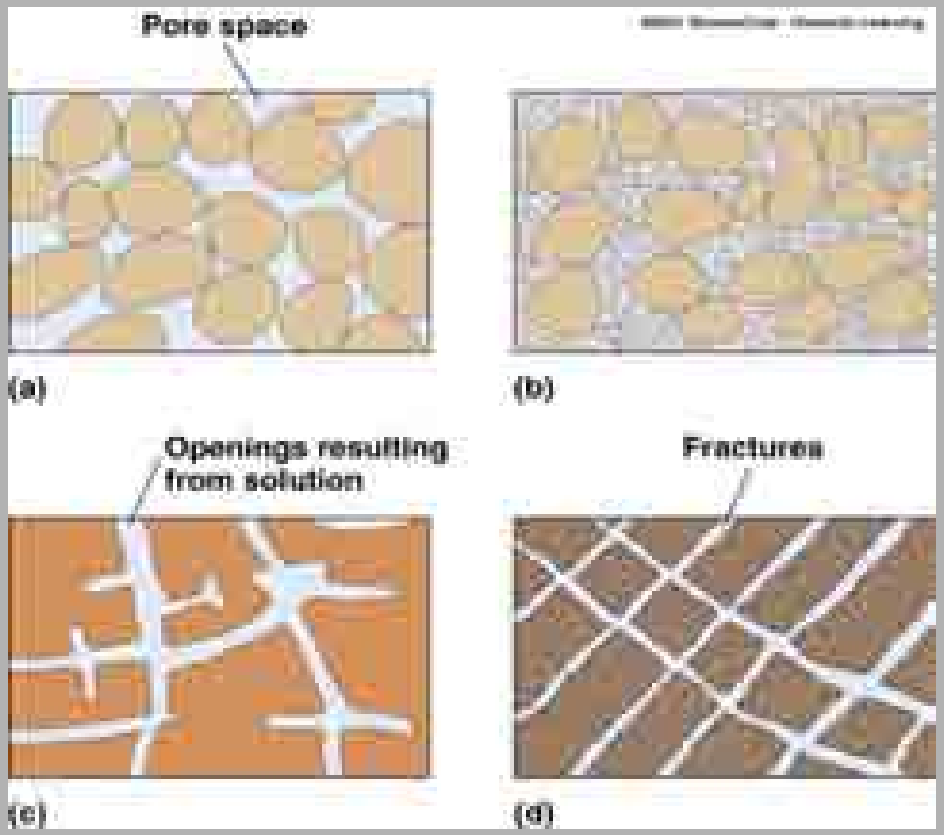
- **98%** of the earth's unfrozen fresh water exists as groundwater
- **40%** of the public water supply in the US is derived from groundwater
- 34 of the largest 100 cities in the US depend entirely on groundwater, a reflection of the fact that it is the cheapest source of municipal water

Marshak (2002)

Some definitions

- **Porosity – proportion of void space within or between mineral grains**
- **Permeability – measure of how readily a fluid passes through the material (hydraulic conductivity)**
- **Aquitard – a rock that may store water but in which water flow is slowed**
- **Aquiclude – a rock that is impermeable, an extreme aquitard. This term is not commonly used today**

Porosity



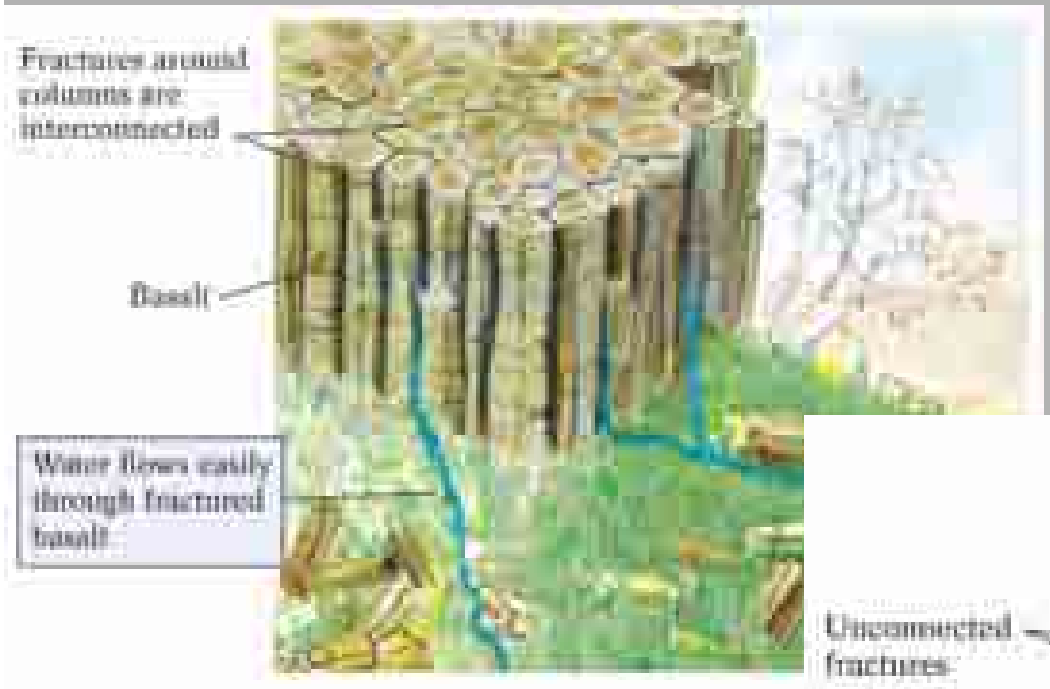
Wicander and Monroe (2002)

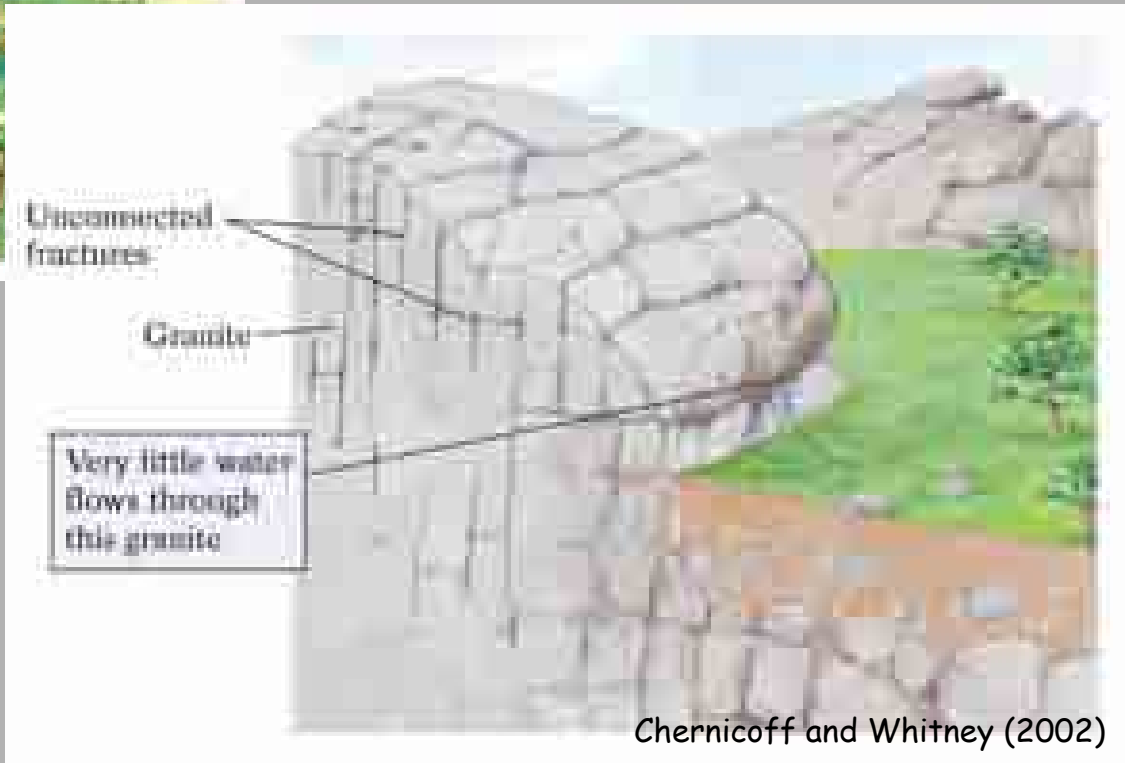
- **Porosity is the percentage of the material's total volume that is pore space and determines the amount of groundwater a material can hold.**
- **Types of porosity are:**
  - **intergranular**
  - **solution**
  - **fracture**
- **Sorting affects the volume of intergranular porosity. Well-sorted deposits have greater porosity**

Permeability

- **Permeability is the capacity of a material to transmit fluids.**
- **Permeability depends on pore size and interconnectedness.**

What is interconnectedness?

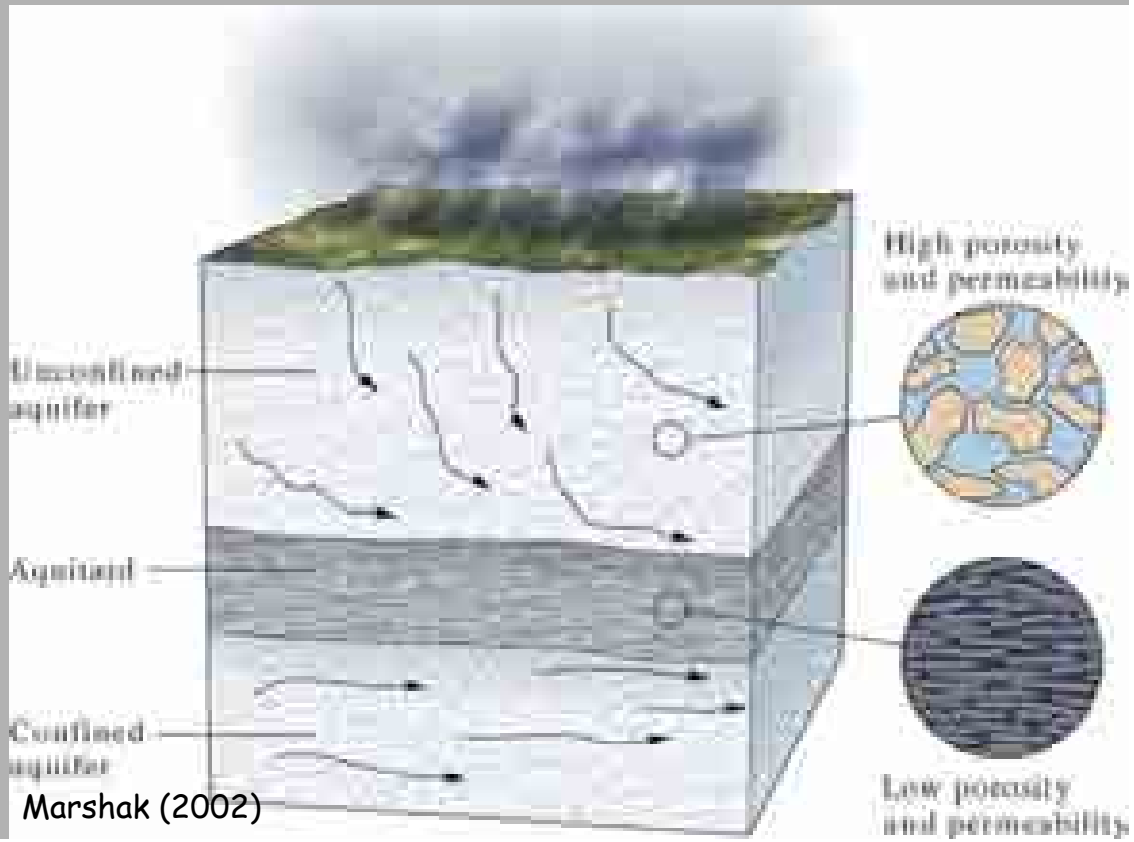




Chernicoff and Whitney (2002)

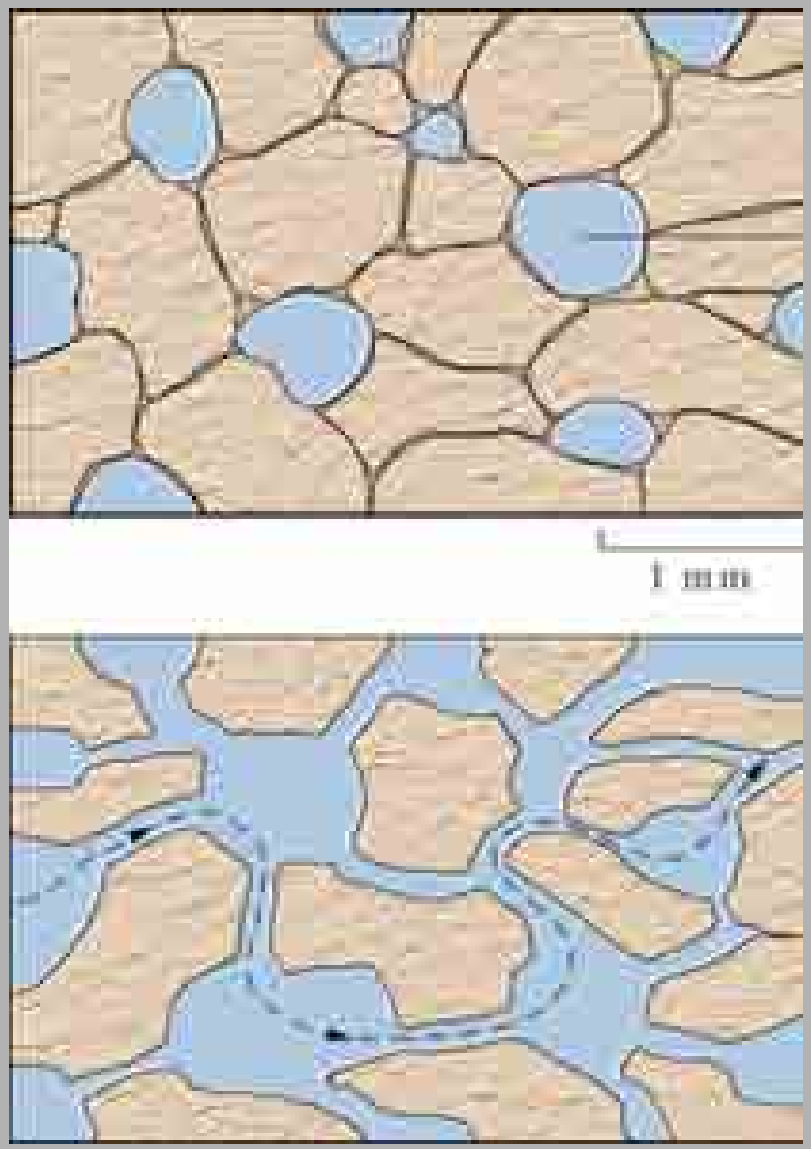
Permeability

- **A permeable layer transporting groundwater is an aquifer. Sand and gravel deposits, fractured granite, and limestone with solution cavities are good aquifers.**
- **Impermeable materials that prevent groundwater movement are known as aquicludes. Shale and unfractured igneous and metamorphic rocks are examples of aquicludes.**
- **Porosity and permeability together control groundwater movement and recoverability.**



Marshak (2002)

Porosity and permeability

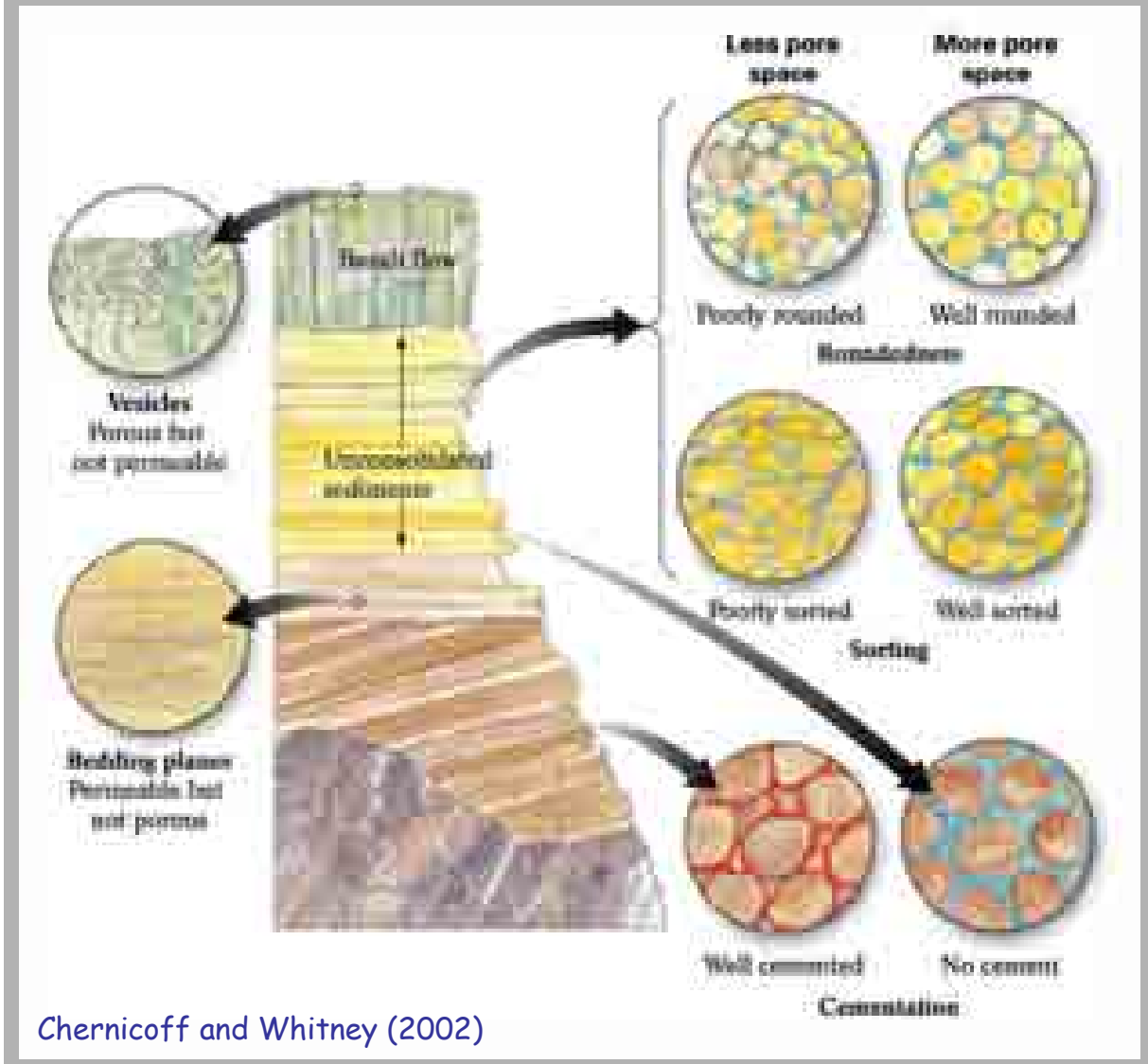


Marshak (2002)

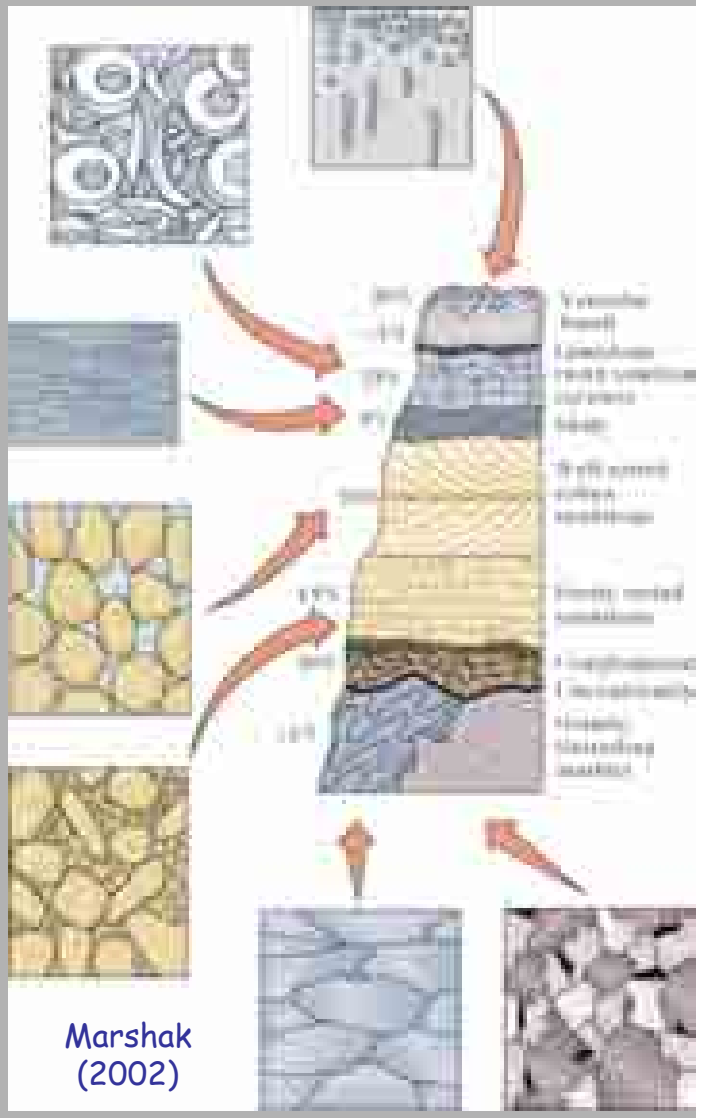
Porosity and permeability

MATERIALS	POROSITY
Unconsolidated Sediment	
Soil	55%
Gravel	20-40%
Sand	25-50%
Silt	35-50%
Clay	50-70%
Rocks	
Sandstone	5-30%
Shale	0-10%
Solution activity in limestone and dolostone	10-30%
Fractured basalt	5-40%
Fractured granite	10%

Porosity of sedimentary rocks.

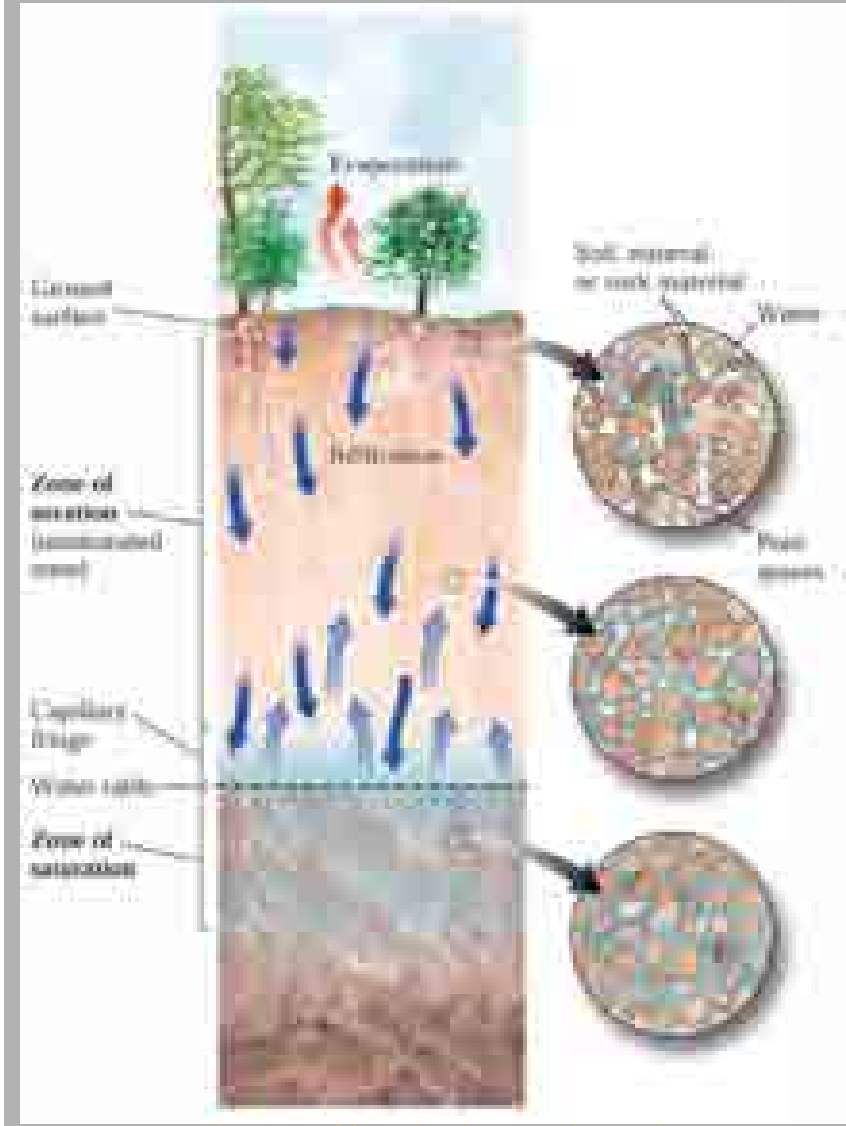


Chernicoff and Whitney (2002)



Marshak (2002)

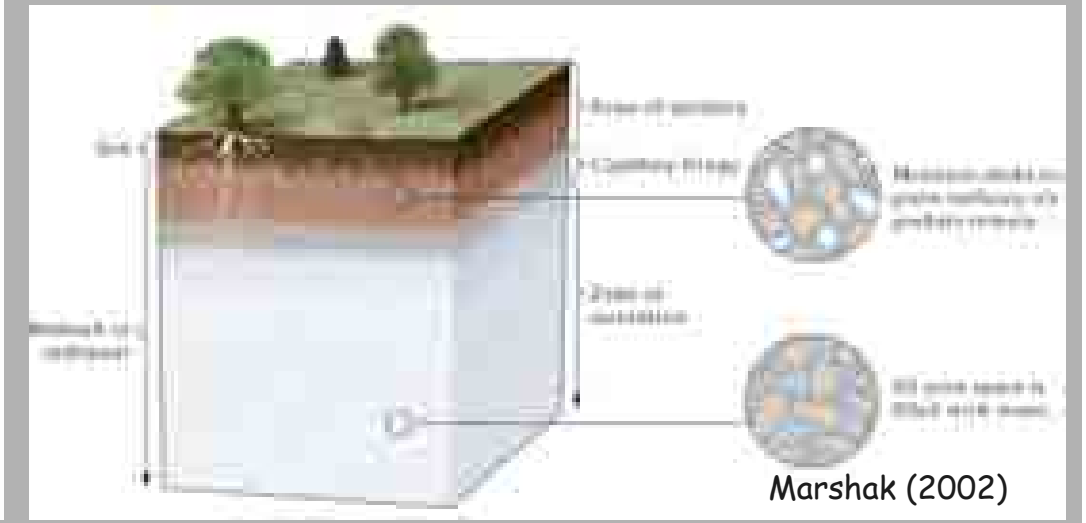
Surface distribution of water.



Chernicoff and Whitney (2002)

The elevation of the water table is a subdued replica of the land surface; higher beneath hills and lowest beneath valleys. Surface tension produces the capillary fringe. The small amount of water adhering to particles in the zone of aeration is known as suspended water.

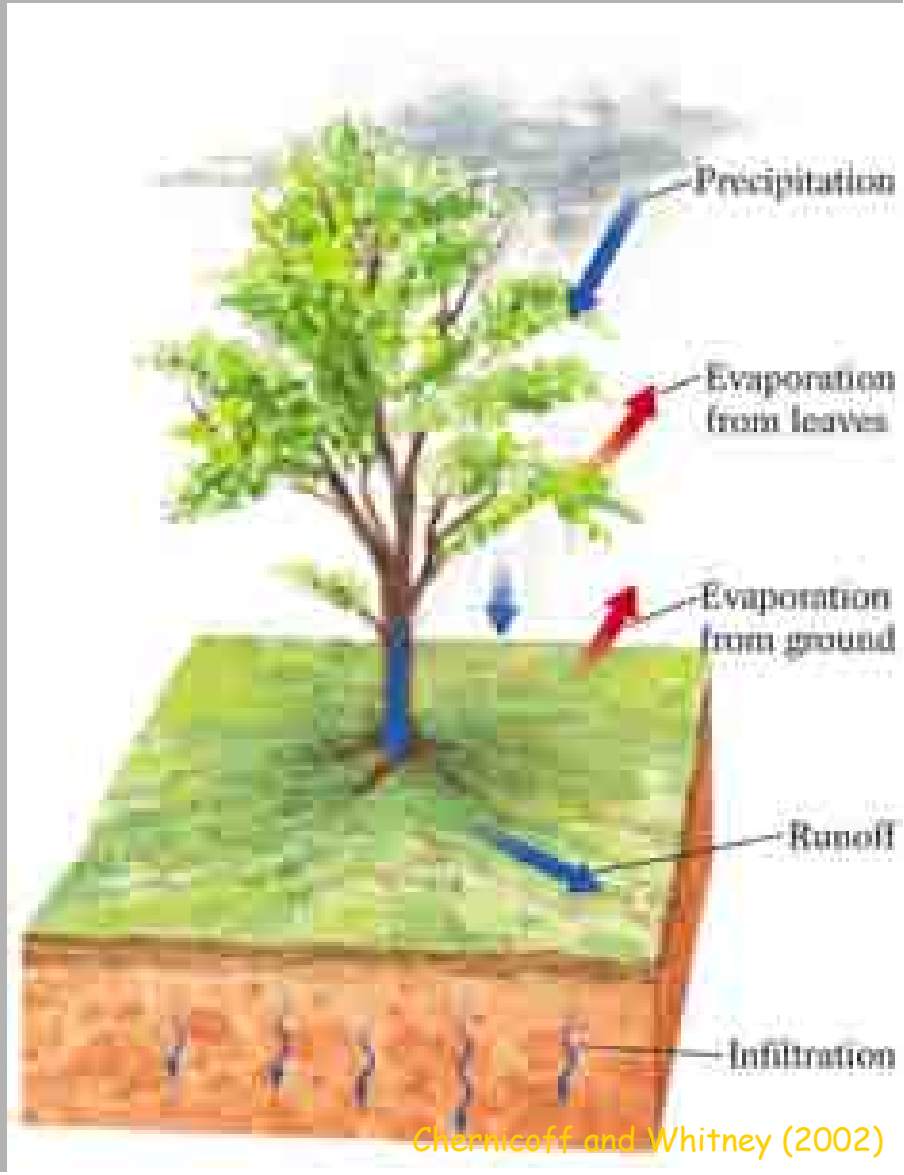
Excellent diagram: pg 401 text



Marshak (2002)

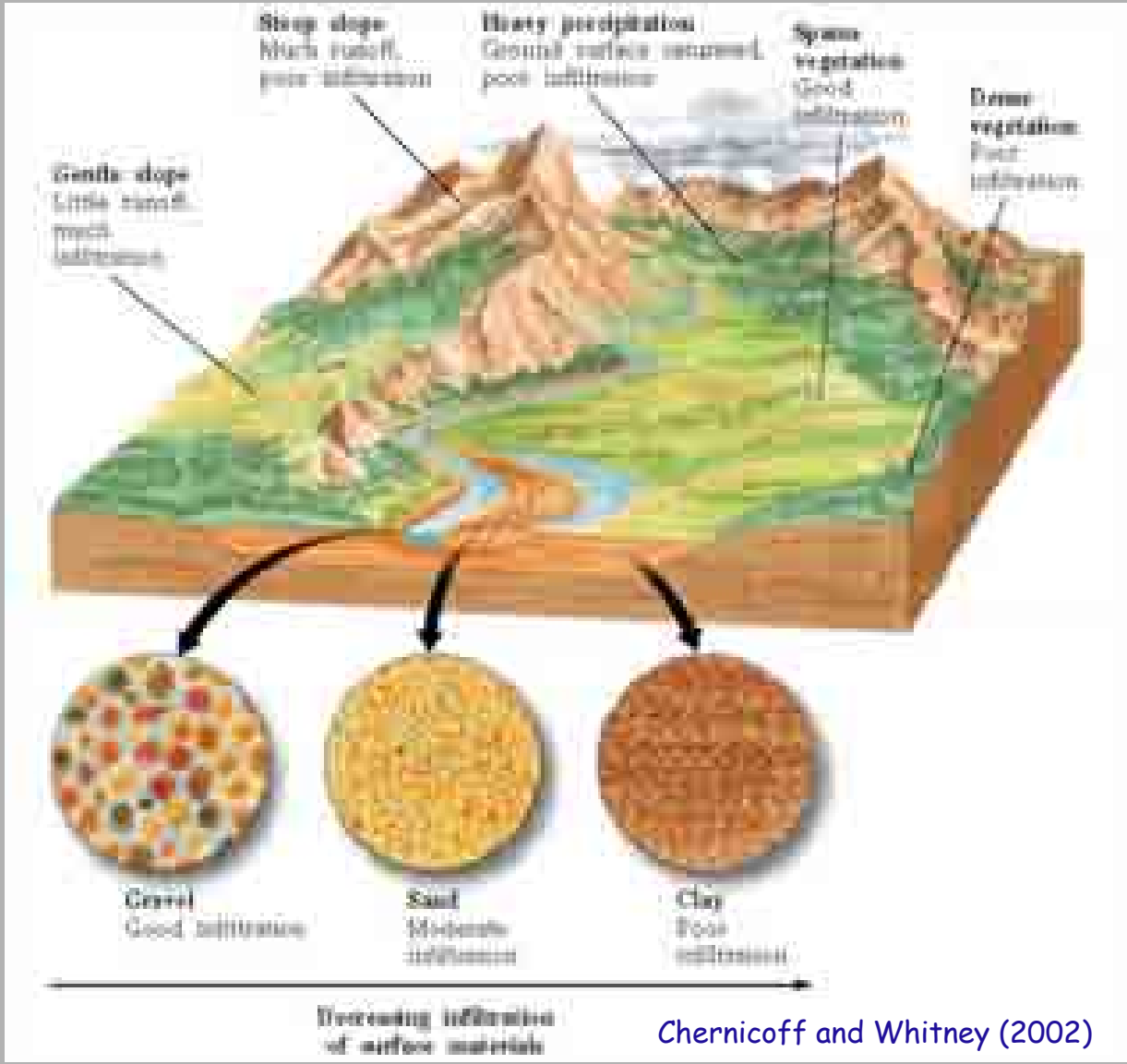
Moisture through trees

- Only the water that infiltrates the soil that will contribute to groundwater



Chernicoff and Whitney (2002)

Factors affecting infiltration.



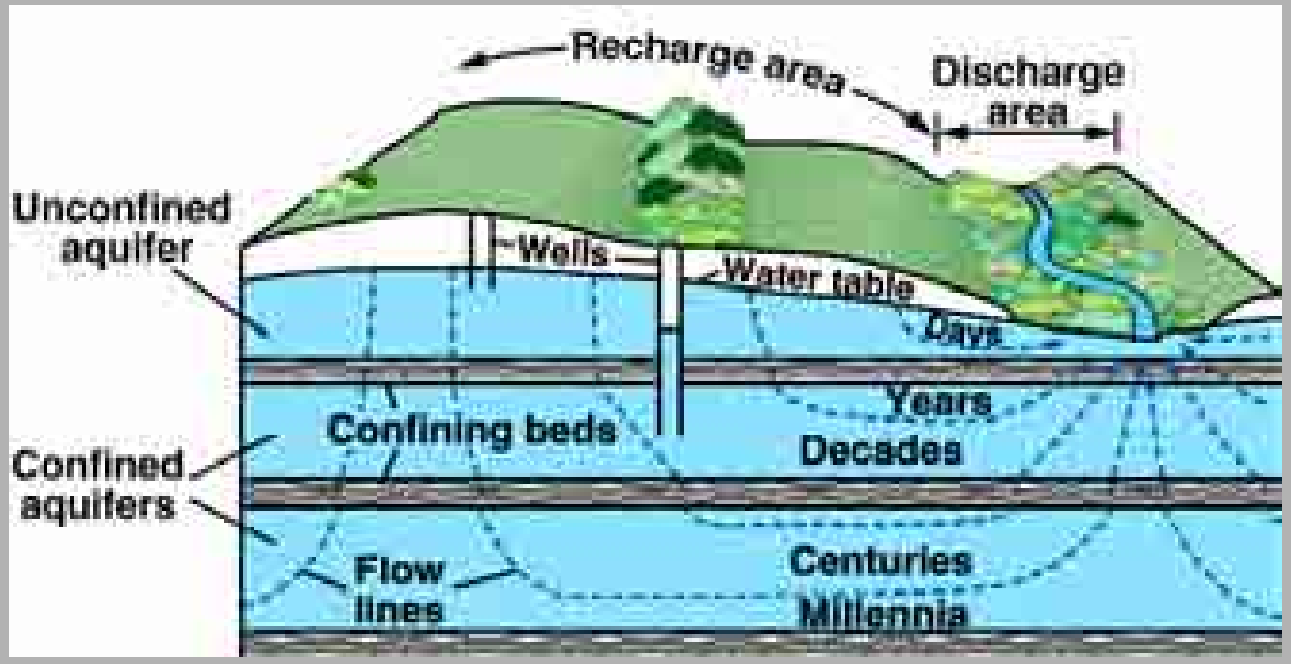
Chernicoff and Whitney (2002)

Aquifers: pg 407 text

- A saturated body of rock or soil that transmits economically significant quantities of groundwater.
- The most IMPORTANT property of an aquifer is it's HYDRAULIC CONDUCTIVITY, for it is the rate at which water can move to the screen of a pumping well to replace the water pumped out that determines the yield of a well.
- Hydraulic conductivity: the ease at which water or fluid will move through pore spaces or fractures
- Either confined or unconfined aquifers

Aquifers (pg 407 text)

- Unconfined aquifers are formations that are exposed to atmospheric pressure changes. They may be recharged by infiltration over the whole area underlain by the aquifer. These often occur in surficial deposits of sand and gravel.
- Confined aquifers are bounded above and below by low permeability rocks. These act as water conduits. The difference in water pressure between the top and bottom of the aquifer is known as the hydraulic head



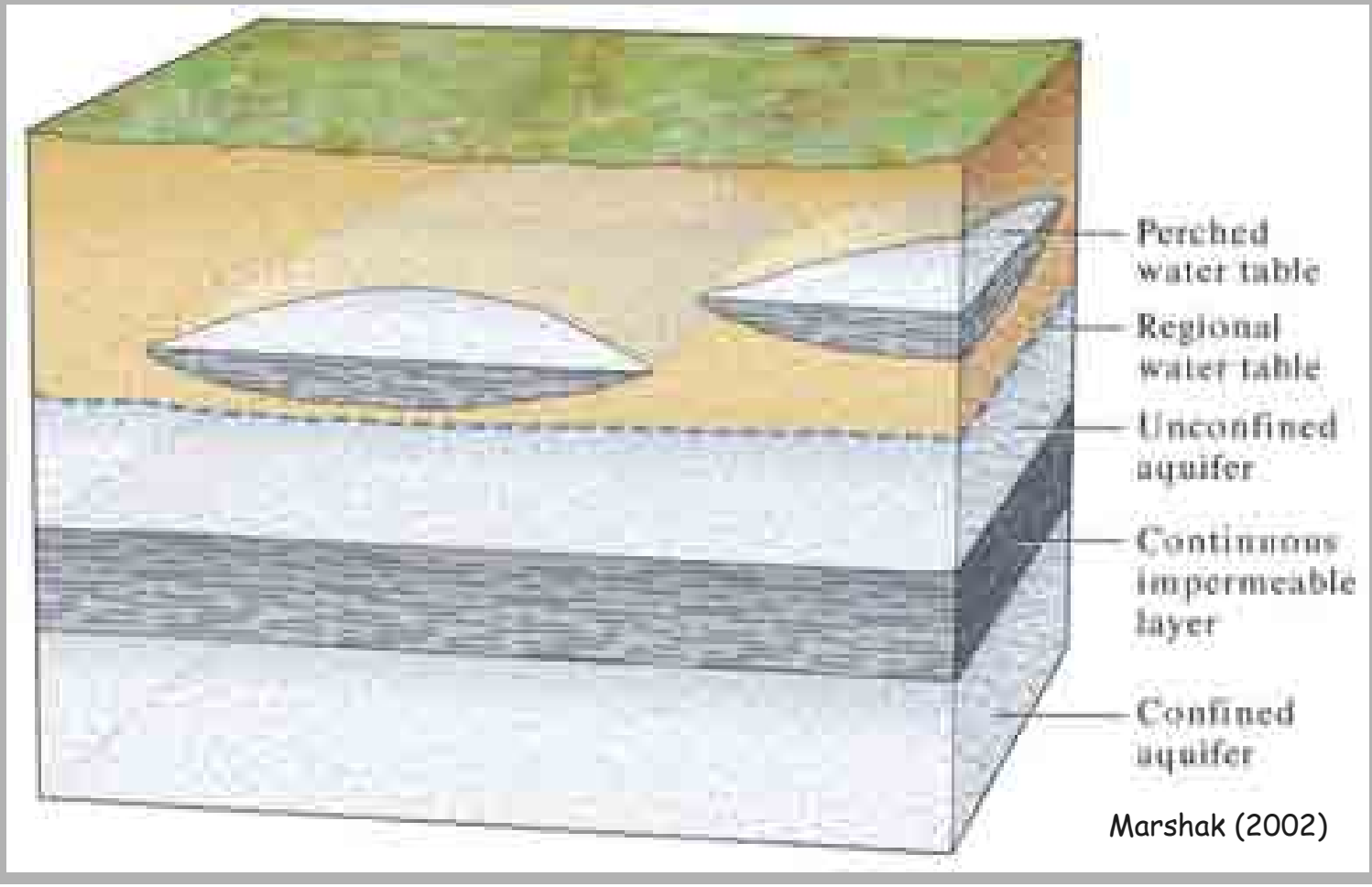
Plummer et al. (1997)

Residence time

- the amount of time that groundwater is present in an aquifer as it moves from the recharge area to the discharge area.
- In unconfined aquifers: days
- In confined aquifers: up to millions of years (in deep sedimentary basins)
- Figure 11.18 pg 411 text.

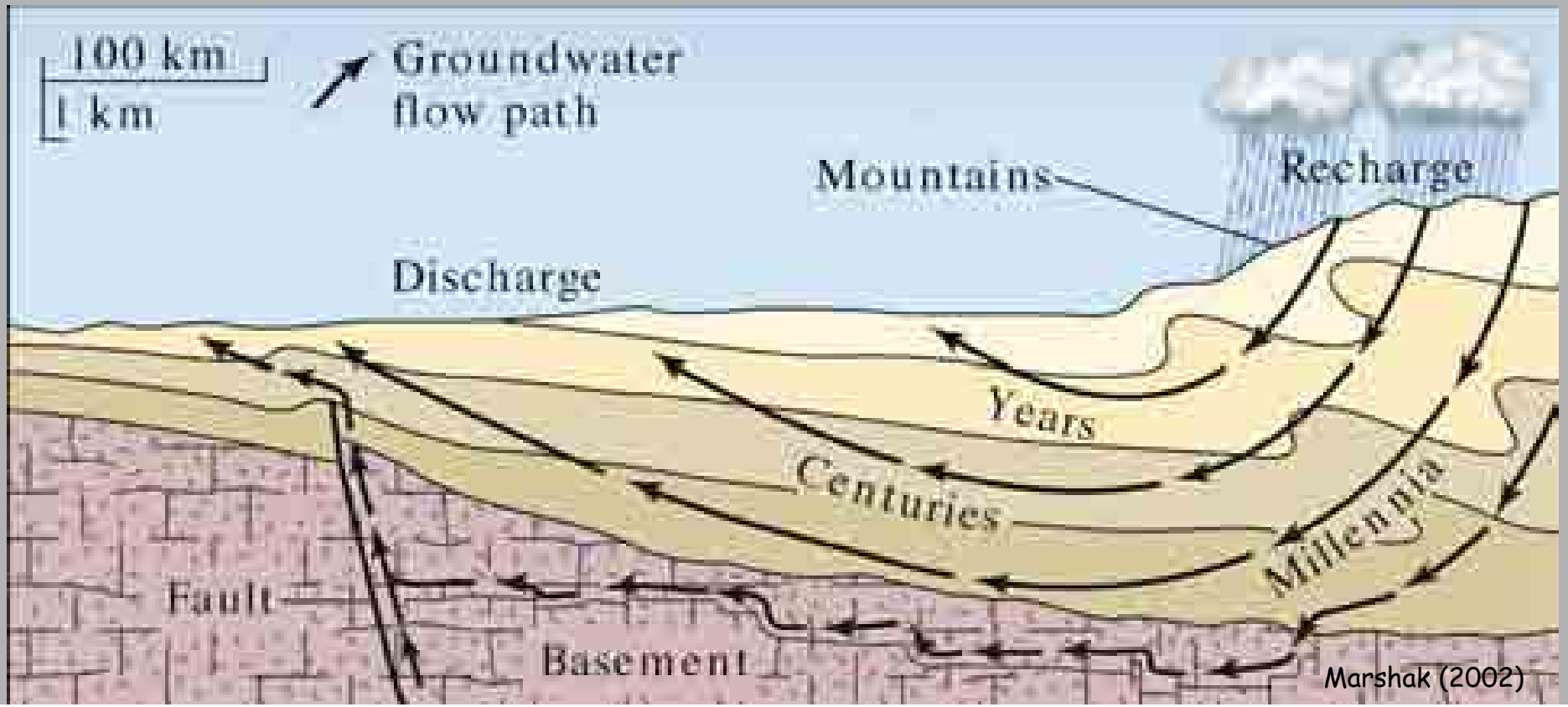
Aquifers - complications

Perched water tables – false indications of the depth to the water table and the quantities available



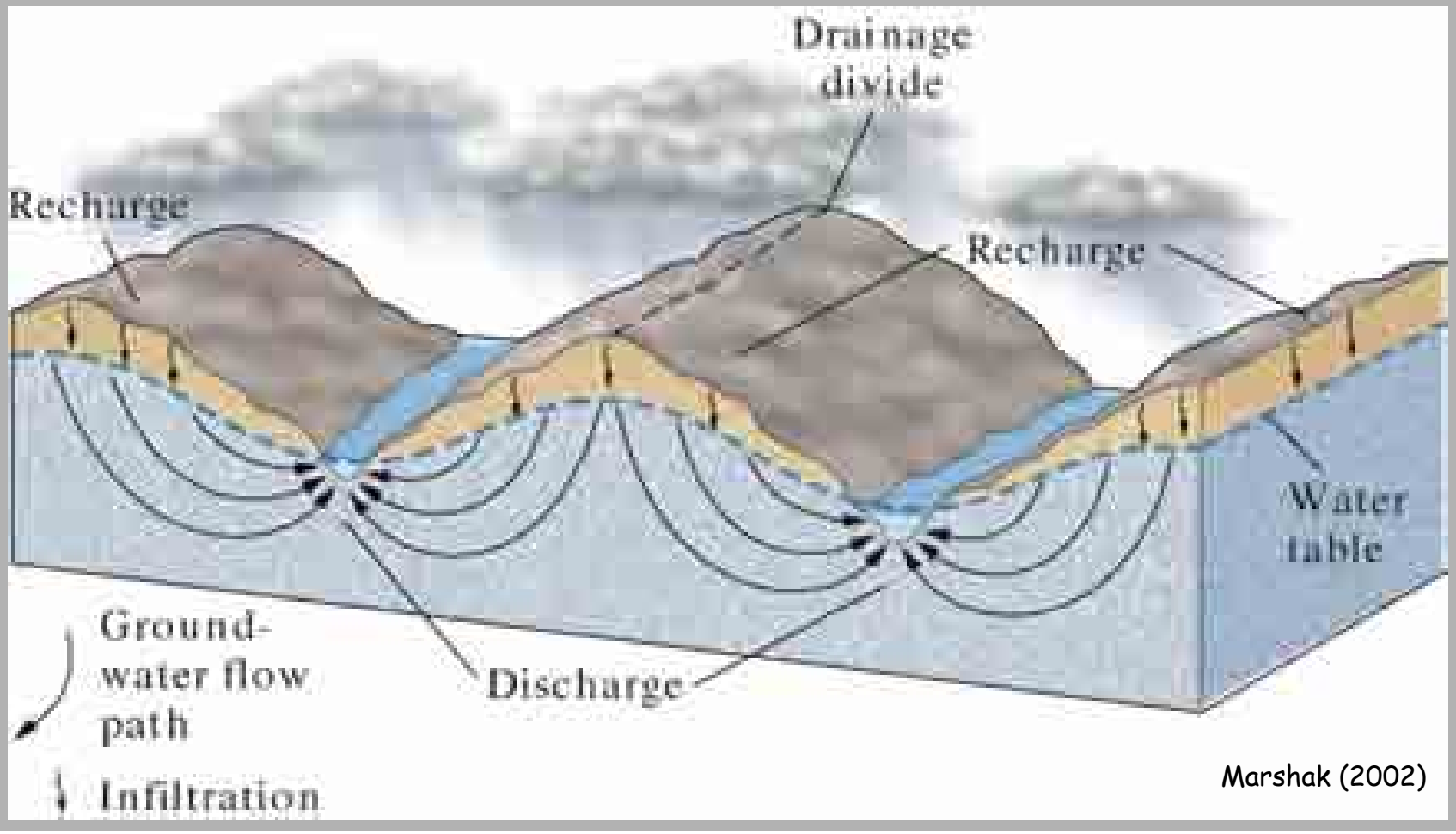
Aquifers

- Need to know flow paths and recharge zones in order to calculate how much water can be safely extracted. For example high extraction rates close to the recharge area are more likely to be a problem than if they occur further down the flow path.



Groundwater extraction

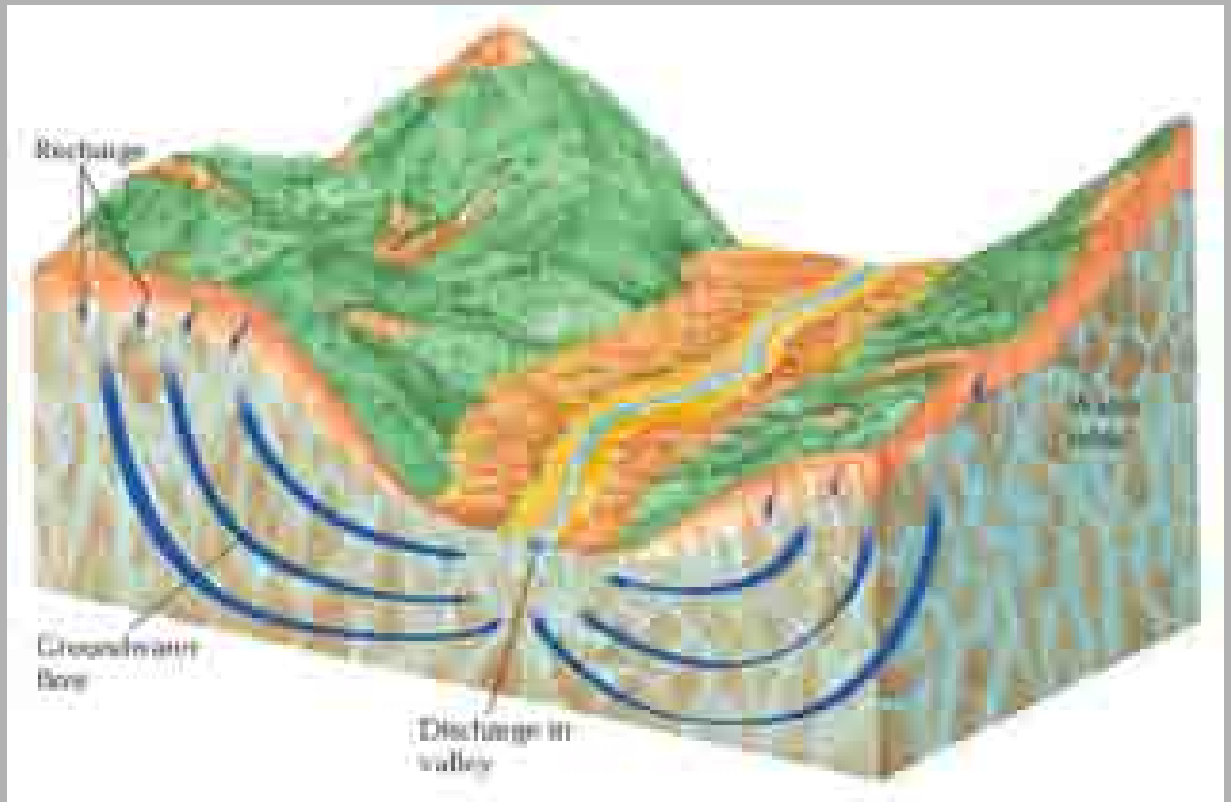
The sustained yield is the amount of water an aquifer can yield on a day-to-day basis over a long period of time without depleting the resource



Marshak (2002)

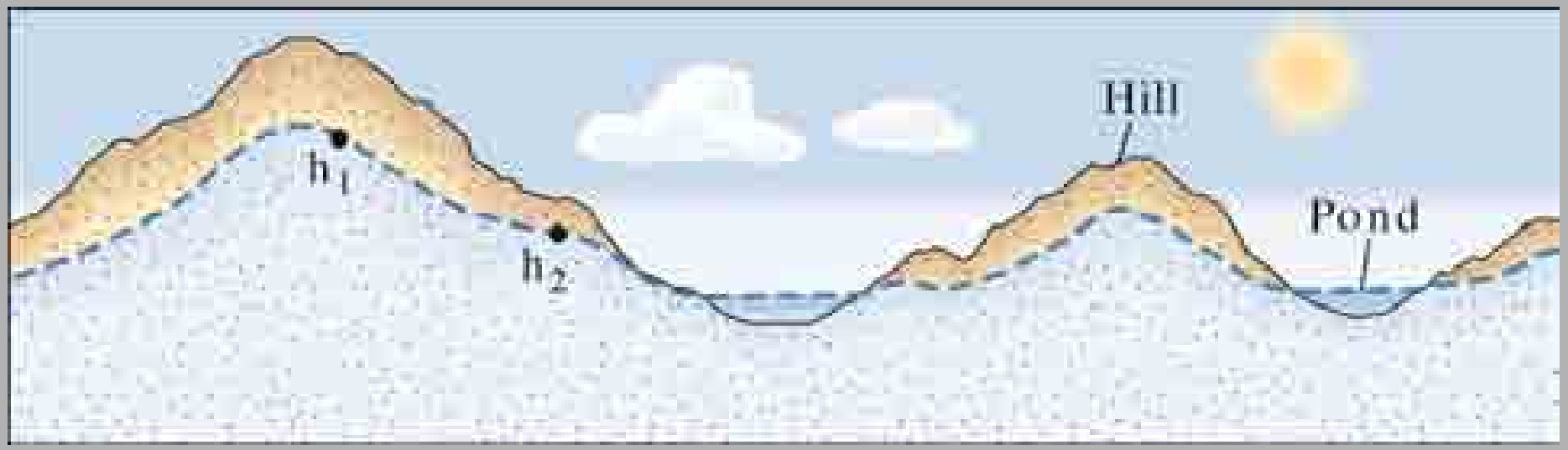
How Does Groundwater Move?

Groundwater flow is driven by gravity as is surface water flow. **Movement through the zone of saturation is from areas of high pressure (beneath hills) to areas of low pressure (rivers and swamps).**

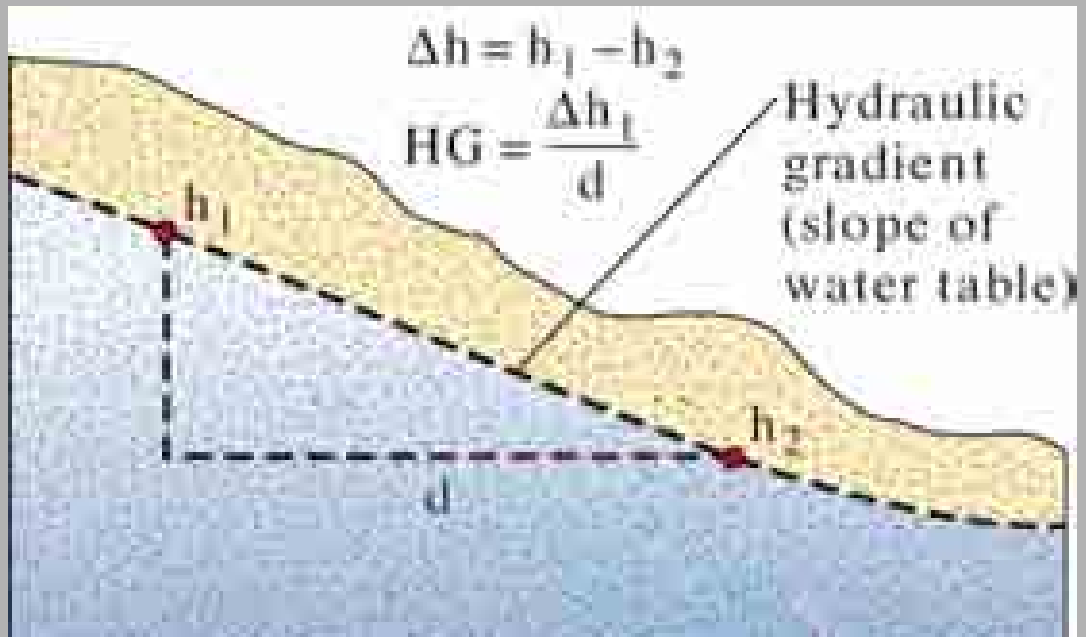


Chernicoff and Whitney (2002)

Groundwater distribution (pg 397 text)

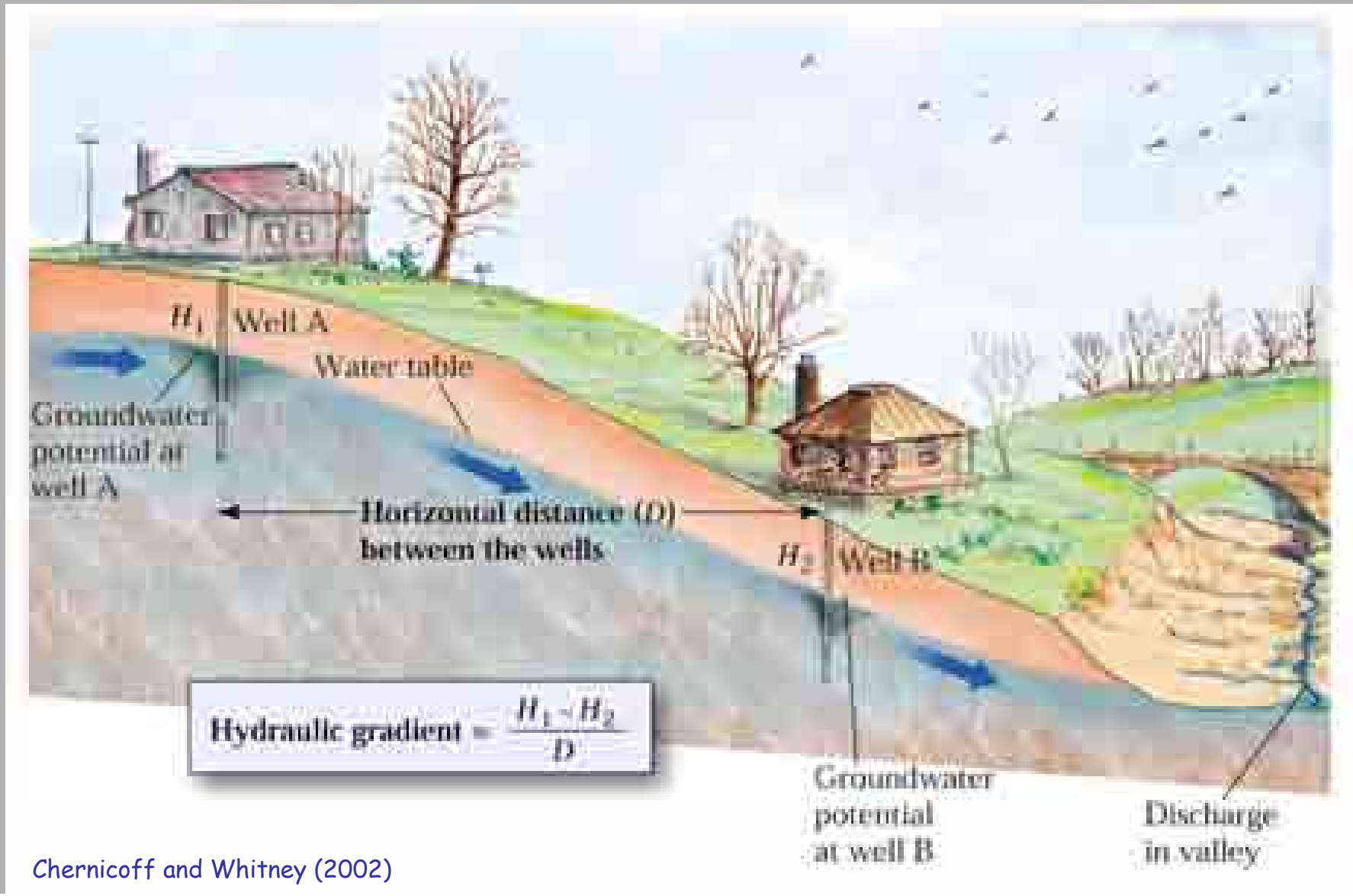


h = hydraulic head (a fancy term for water level…)



Marshak (2002)

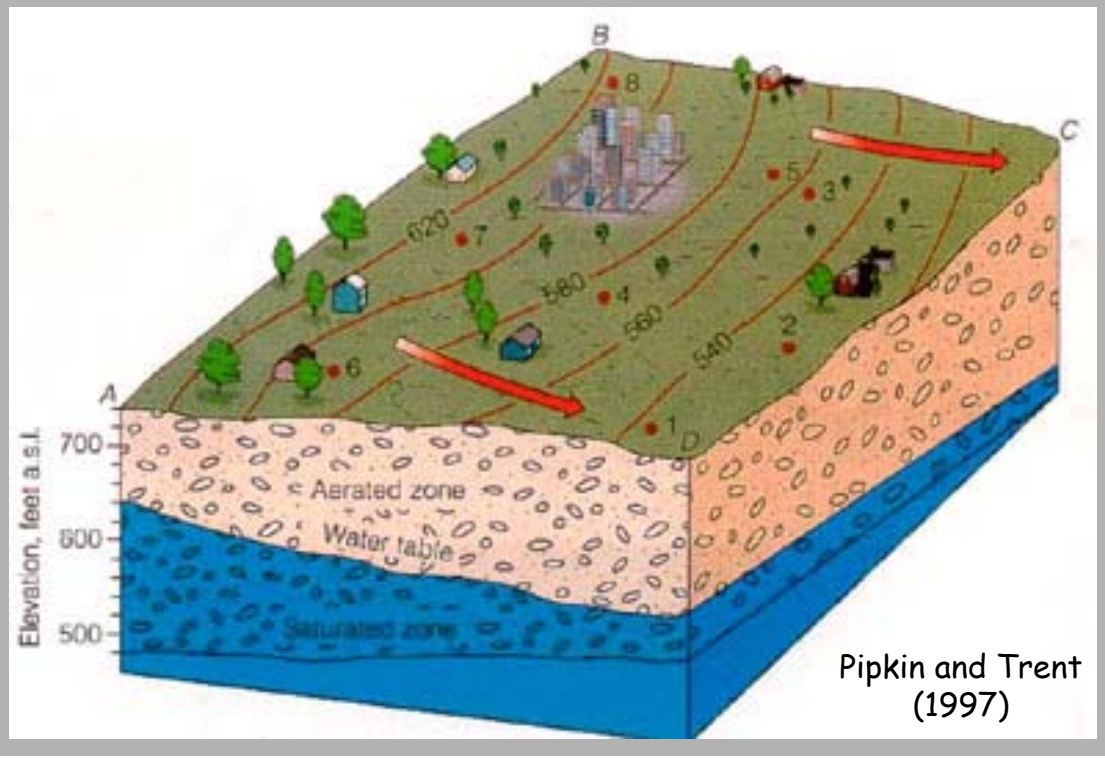
Hydraulic (energy) gradient



Chernicoff and Whitney (2002)

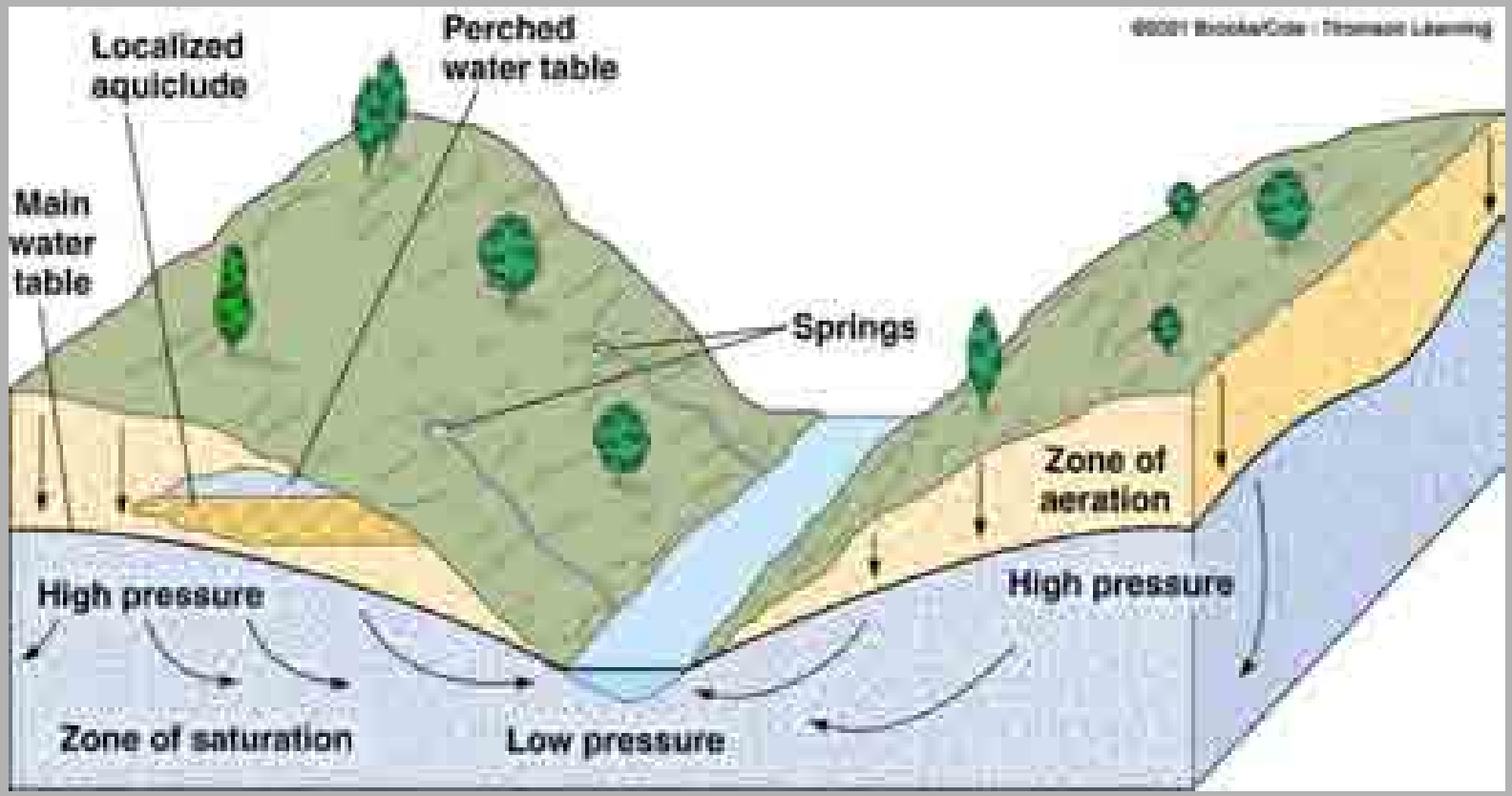
Potentiometric contours

- Well data is used to measure the depth to the water table
- Arrows indicate flow directions



Discharge

Discharge refers to the removal of water and takes place where groundwater flows into streams, lakes, swamps, and springs, or is withdrawn at water wells



Wicander and Monroe (2002)

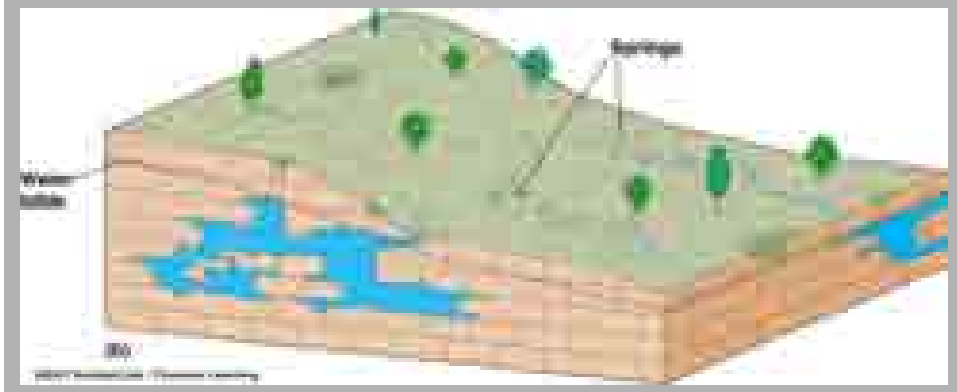
Recharge

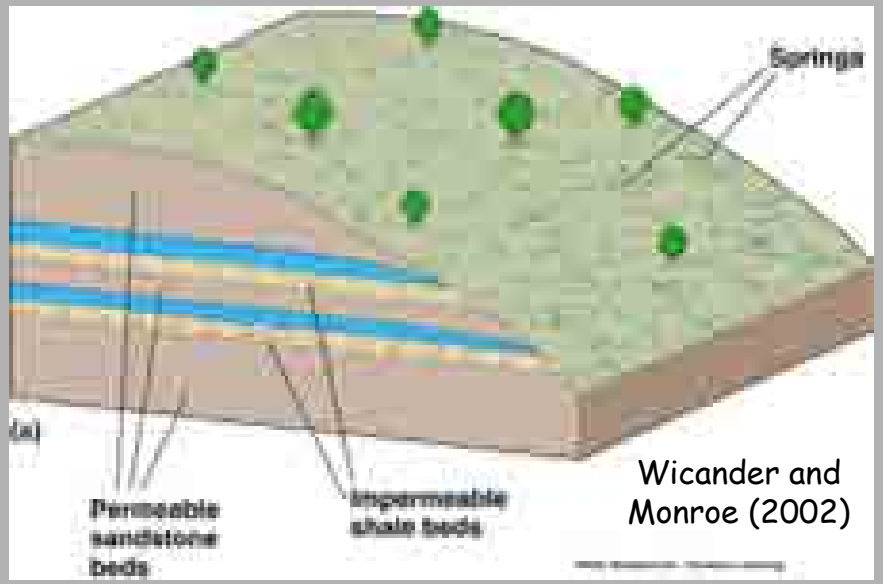
- Recharge is the addition of water by infiltration of precipitation, snow melt, stream water, or water from artificial recharge ponds or water treatment systems.
- The water table rises or falls based on the ratio of recharge to discharge.

Wicander and Monroe (2002)

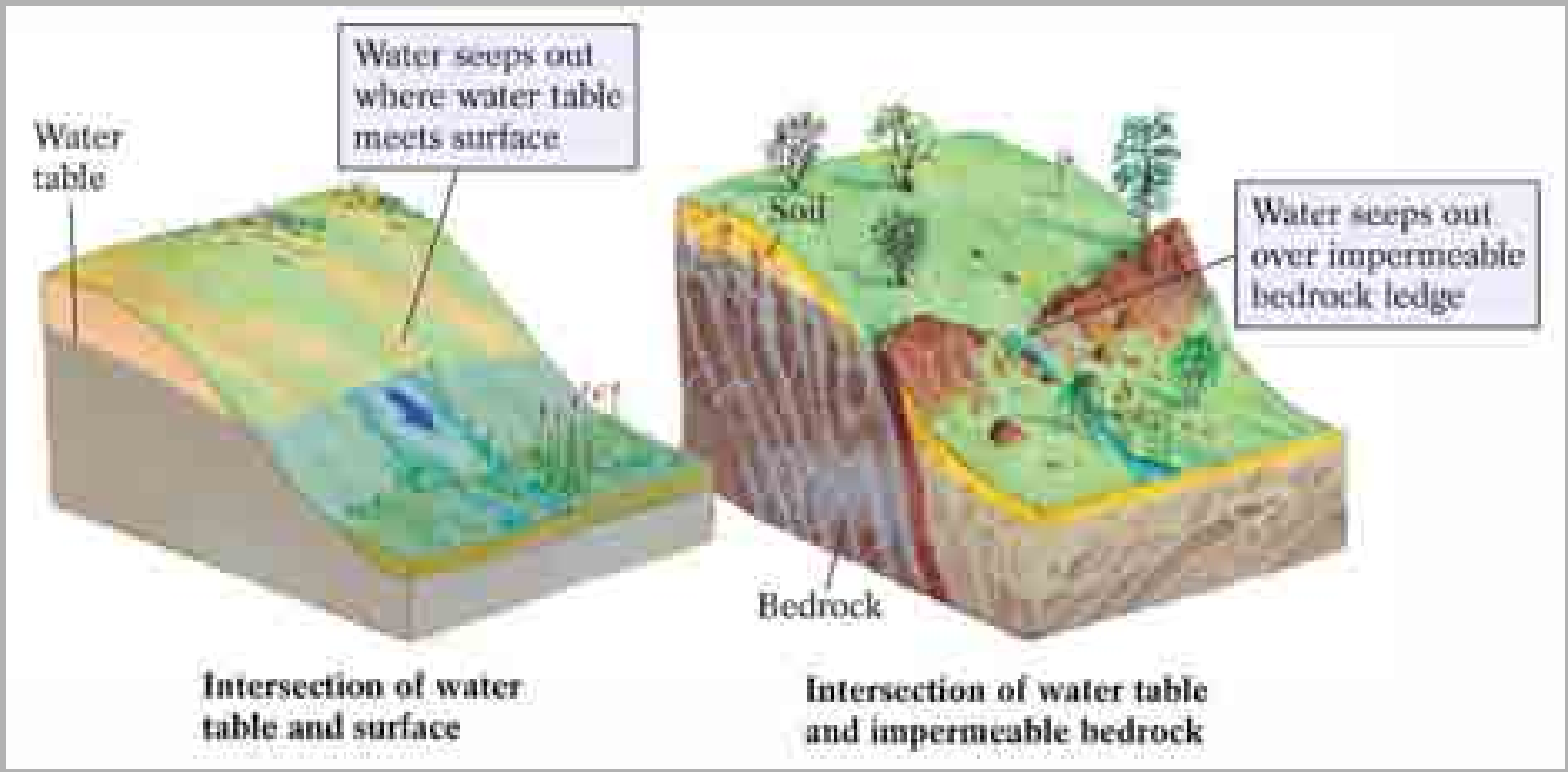
Springs

- Springs are formed when groundwater flows laterally to intersect the land surface and is discharged
- Springs form where solution cavities, fractures, or perched water tables intersect the ground surface.





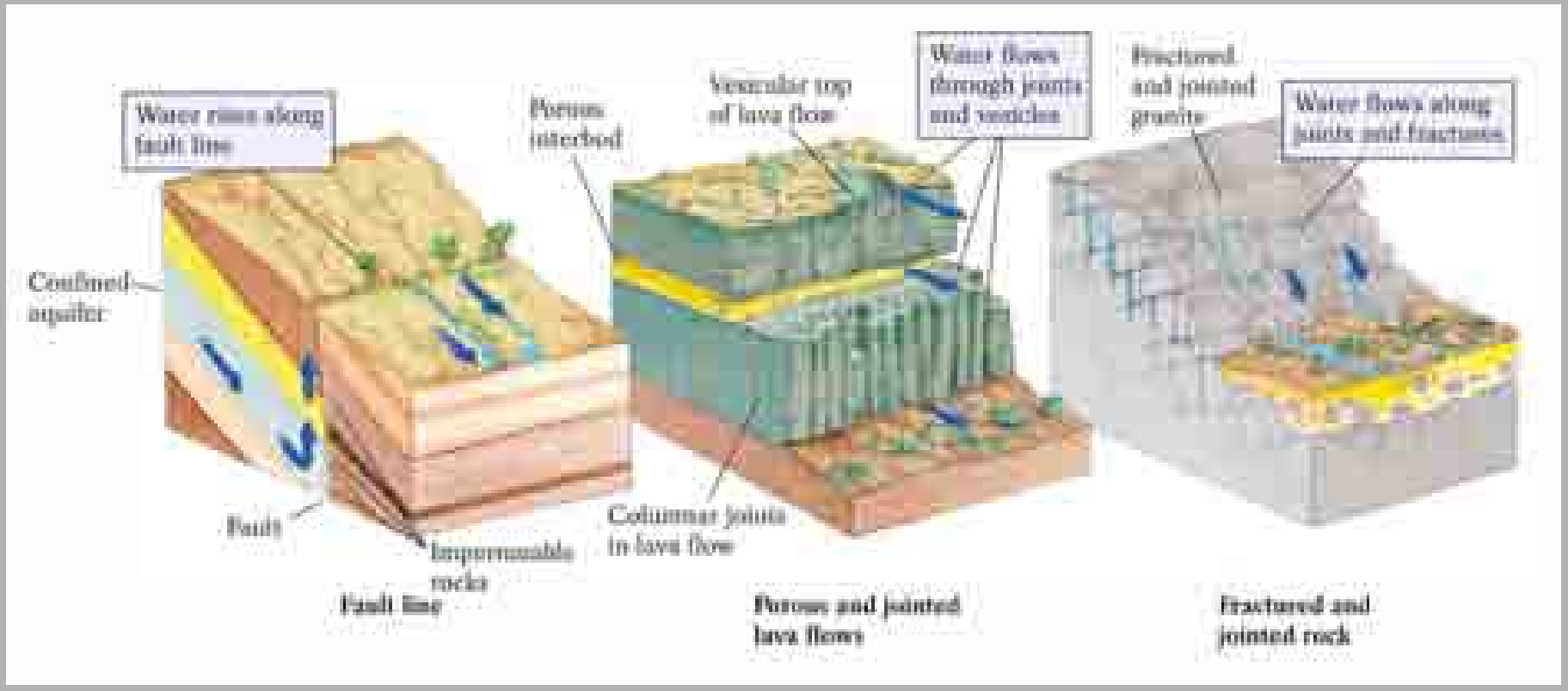
Natural Springs



Chernicoff and Whitney (2002)

Natural Springs (continued)

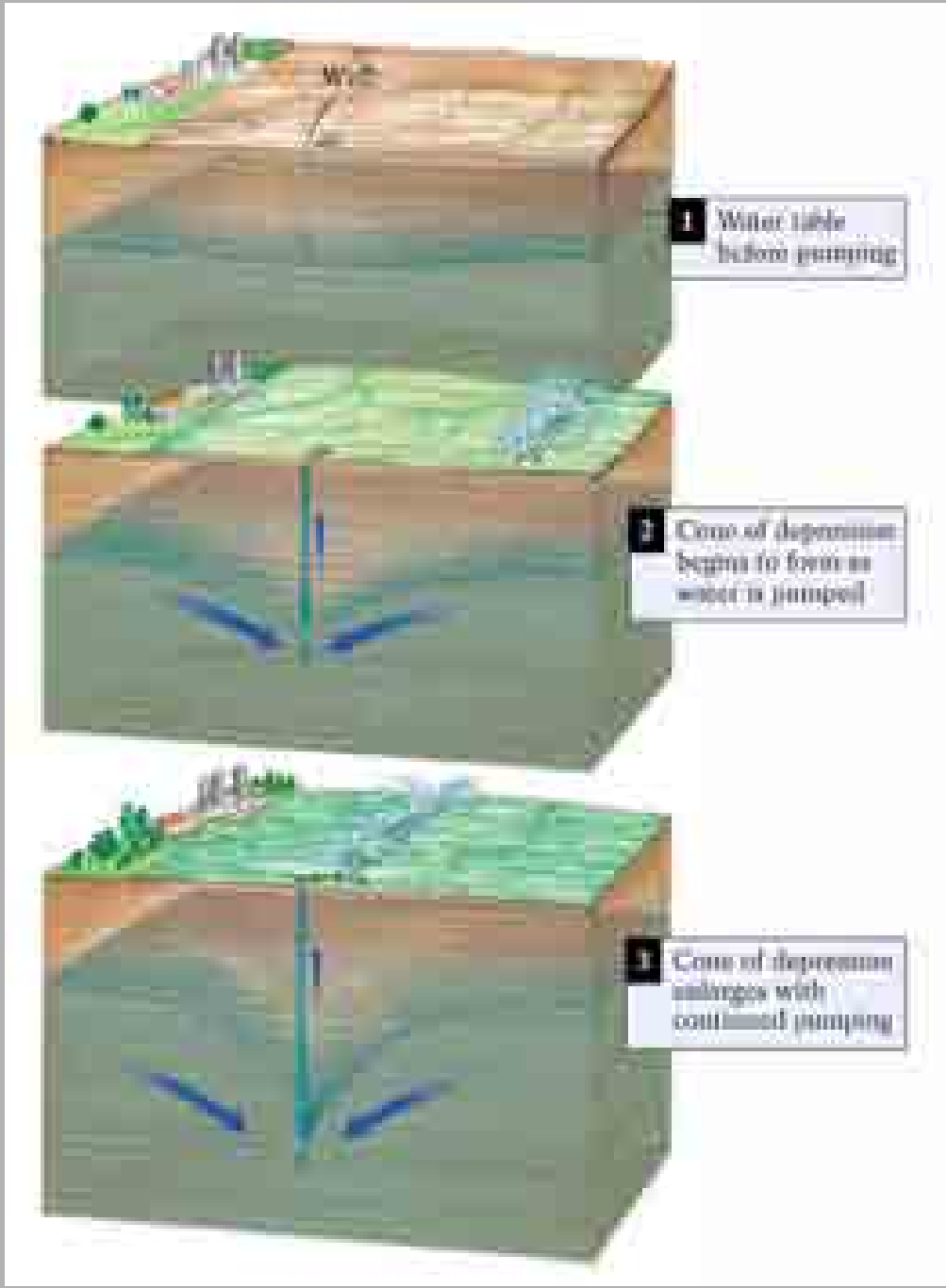
A similar diagram is on page 406 of your text.



Chernicoff and Whitney (2002)

Water Wells

Water wells are openings, either dug or drilled, that connect the zone of saturation with Earth's surface. Water flows into the well cavity, filling it to the level of the water table. In the vicinity of a well, the water table is lowered, forming a cone of depression if water withdrawal exceeds the rate of inflow.

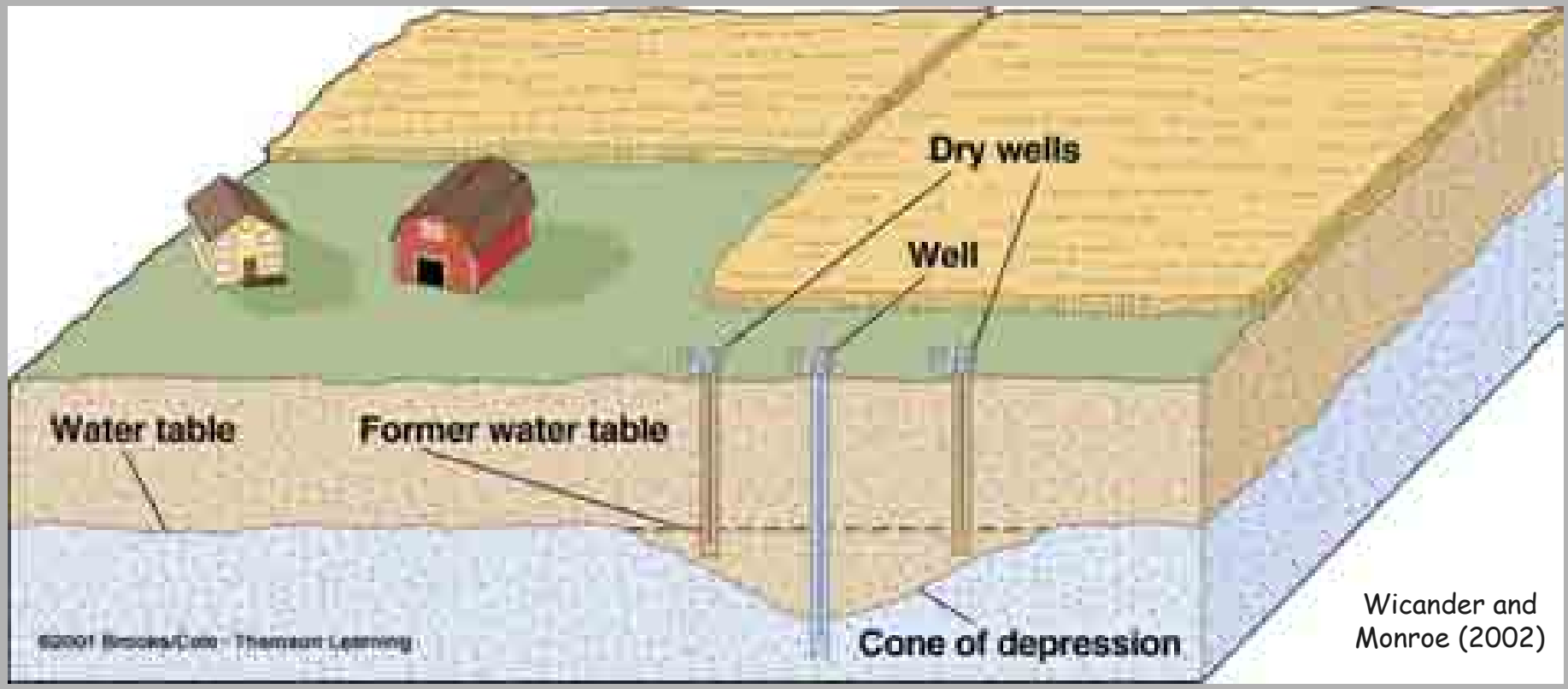


Chernicoff and Whitney (2002)

Water wells

(Cone of depression, pg 412-413 text)

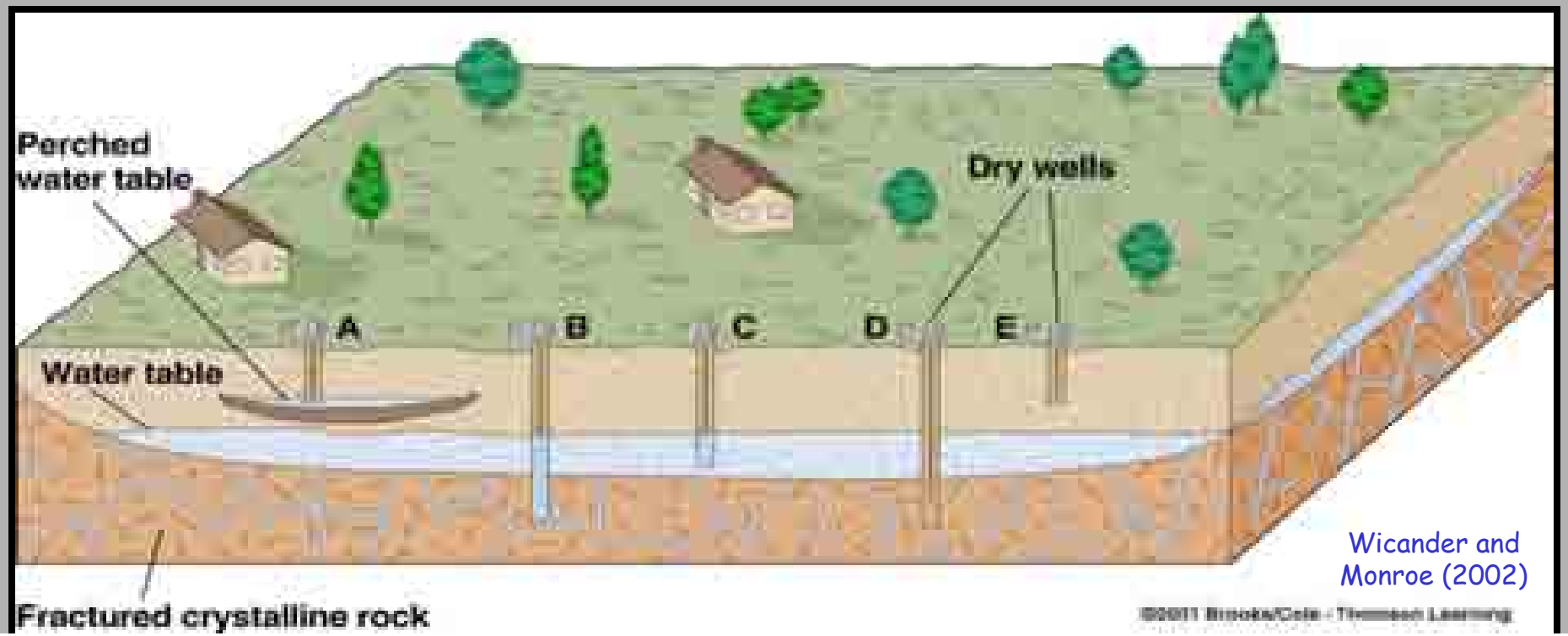
If groundwater withdrawal is great, a large cone of depression can form such that the water table is lowered sufficiently to cause adjacent wells to go dry.



Wicander and Monroe (2002)

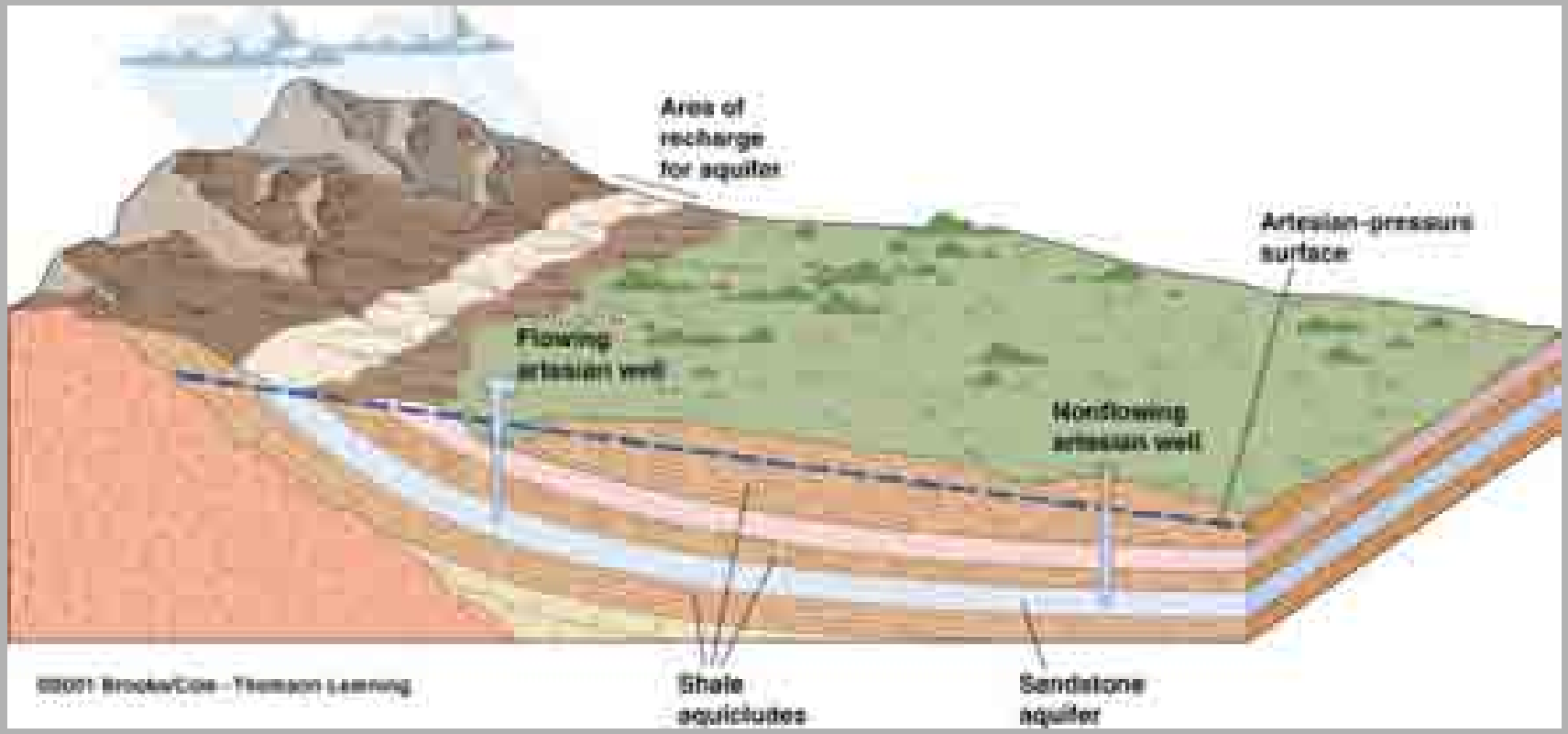
Water Wells

Many factors determine whether or not a water well will be successful. Among these factors are: distribution & type of rocks present, their porosity & permeability, fracture patterns, well depth, etc.



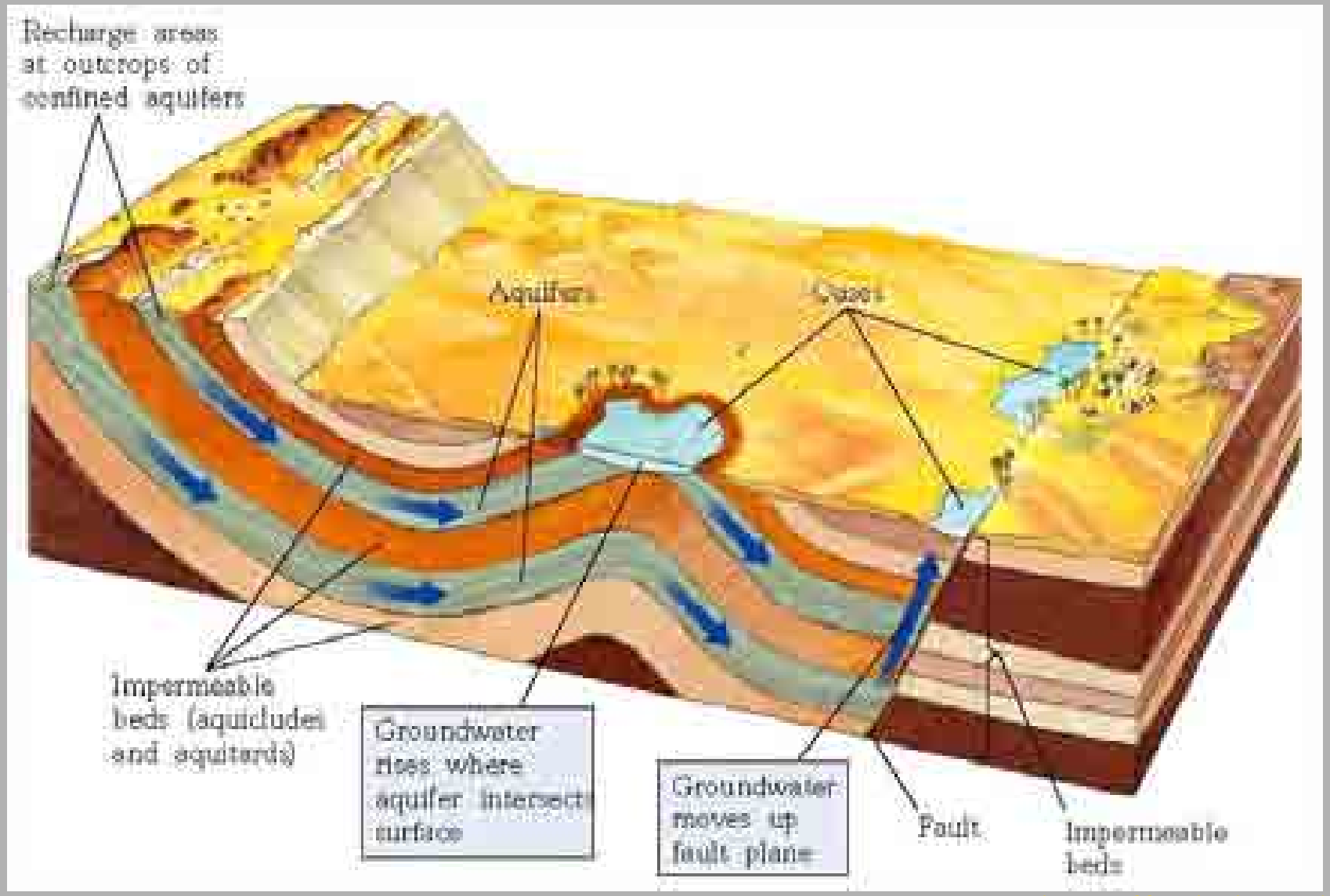
Artesian Systems

Artesian systems form where groundwater in sloping aquifers is confined by an overlying aquiclude. If recharge is sufficient to keep the aquifer filled, hydrostatic pressure builds up and allows groundwater to rise above the top of the aquifer in wells



Wicander and Monroe (2002)

Desert oases

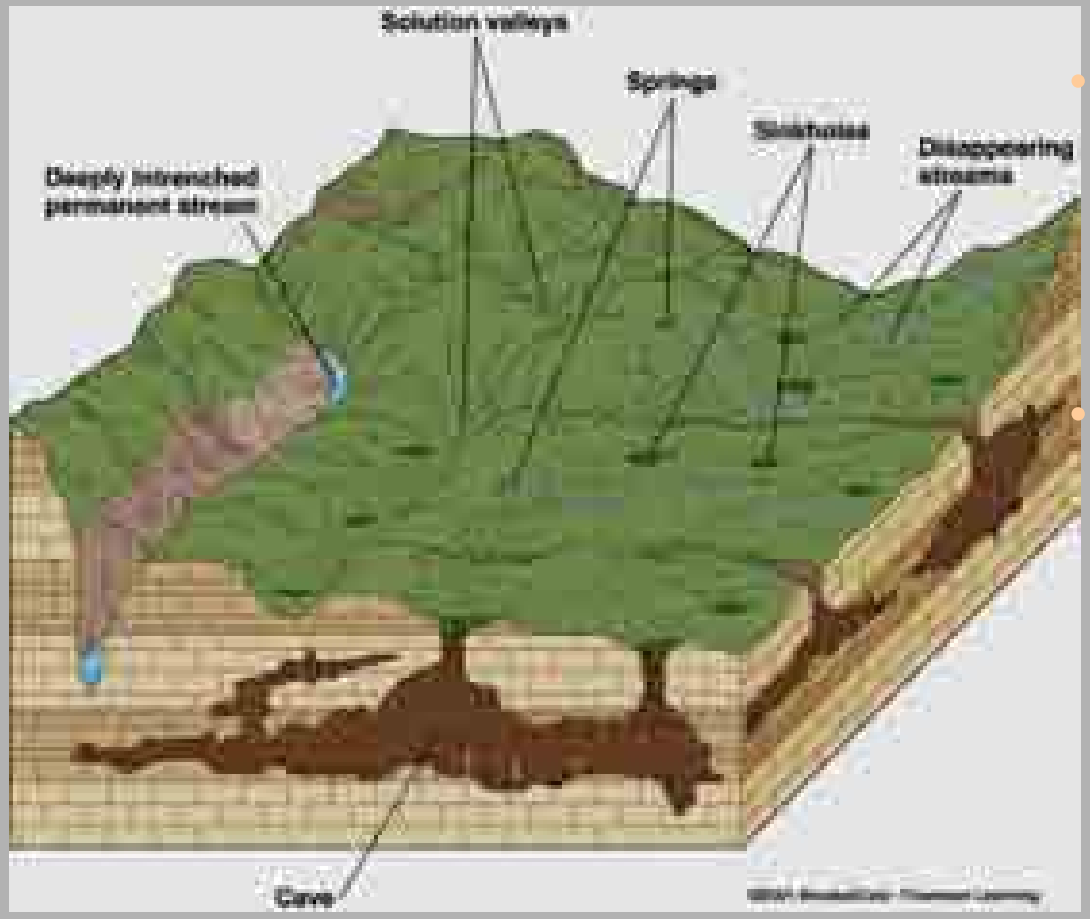


Chernicoff and Whitney (2002)

Erosion and deposition

- Rainwater seeping through Earth materials to join the groundwater system causes chemical weathering of the minerals it contacts.
- In areas underlain by soluble rocks such as limestone, groundwater is an important agent of erosion, via chemical weathering, and responsible for formation of many landscape features.
- Groundwater erosion in areas underlain by limestone produces a characteristic landscape known as karst topography.

Sinkholes & Karst Topography



Wicander and Monroe (2002)

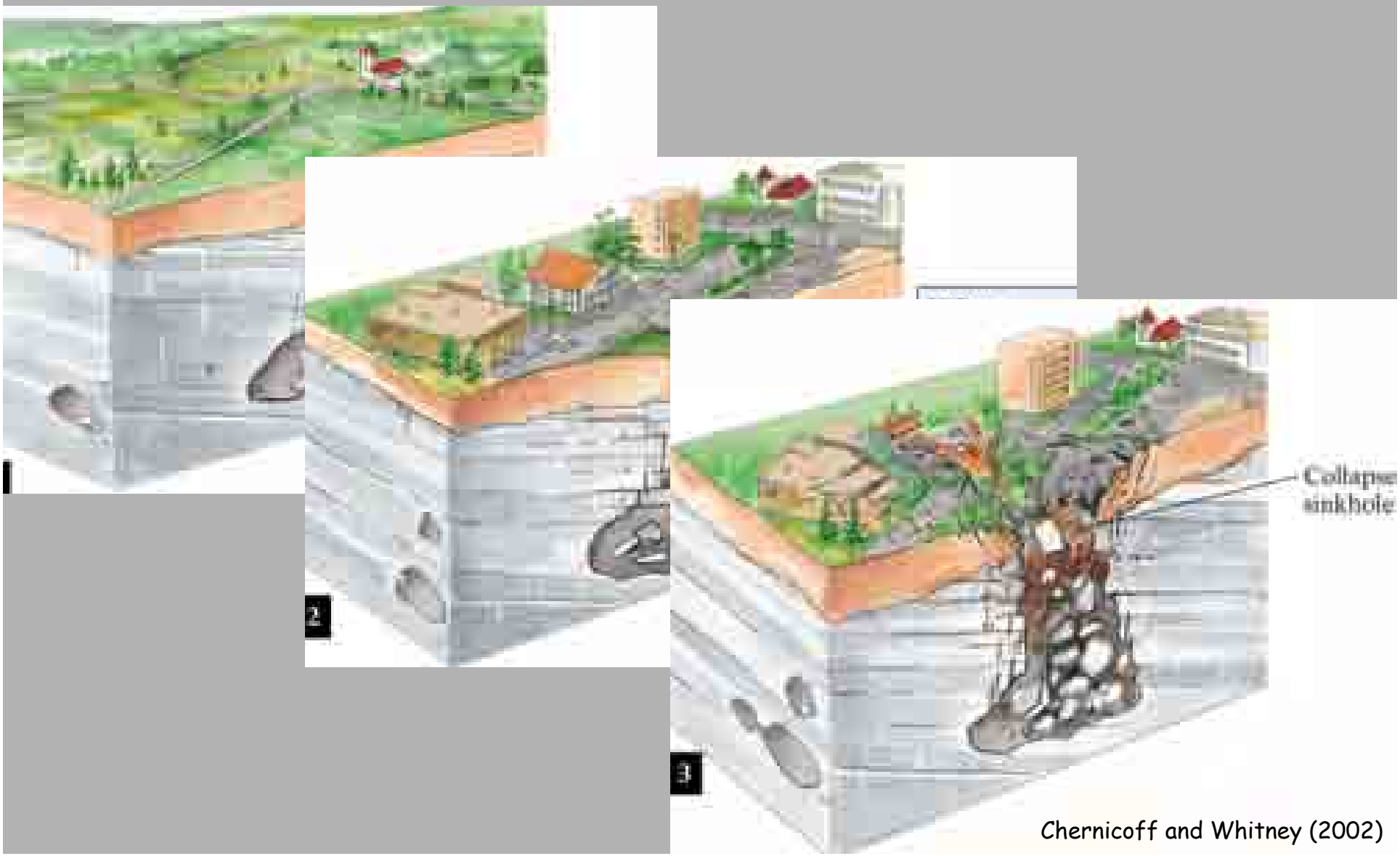
- Landscapes with karst topography are characterized by numerous sinkholes, solution valleys, disappearing streams, caves, springs.
- Karst topography forms in humid and temperate climates.

Sinkholes

- Sinkholes are depressions of various size and shape on the ground surface of regions underlain by soluble rock.
- Sinkholes can form by collapse of cave roofs and pose a serious hazard in populated areas. Sinkholes can also form from the surface downward as openings in soluble rock are progressively enlarged by seeping water.

May 8/9 1981 Winter Park, Florida. 100m wide - 35m deep. Wicander and Monroe (2002)

The origin of sinkholes



Chernicoff and Whitney (2002)

Karst Topography

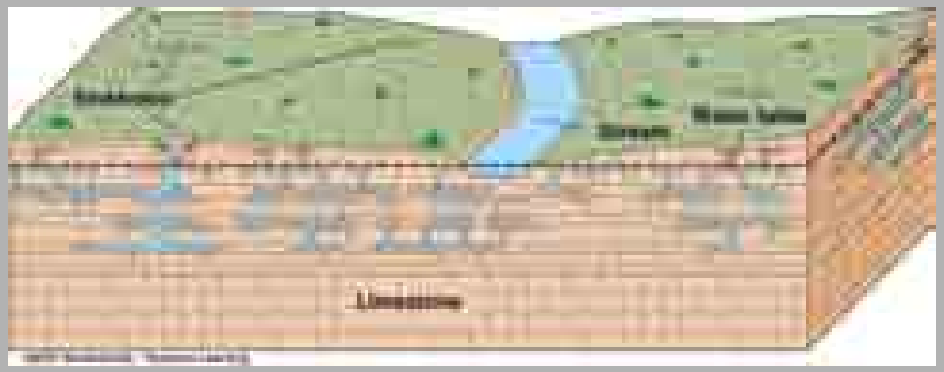
- Karst topography varies from the dramatic high-relief landscapes of China to the subdued and pock marked landscapes of Kentucky and Tennessee
- In addition to sinkholes, karst landforms include solution valleys comprised of merged sinkholes, disappearing streams which flow into sinkholes, and terra rosa, a residual, red, clayey soil formed by solution of limestone.

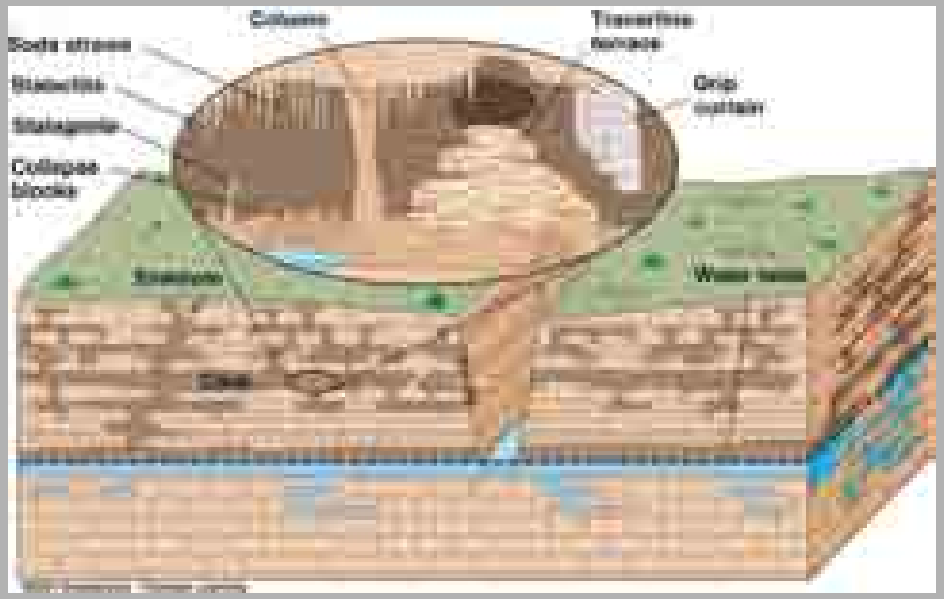
Kunming, China

Bowling Green, Kentucky

Wicander and Monroe (2002)

Caves and Cave Deposits

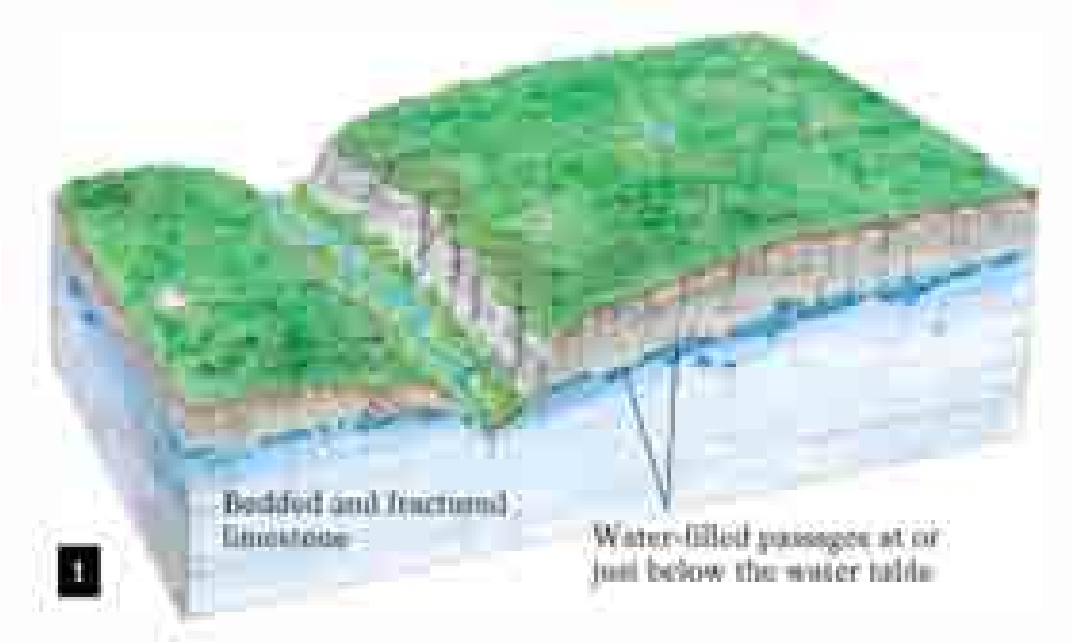


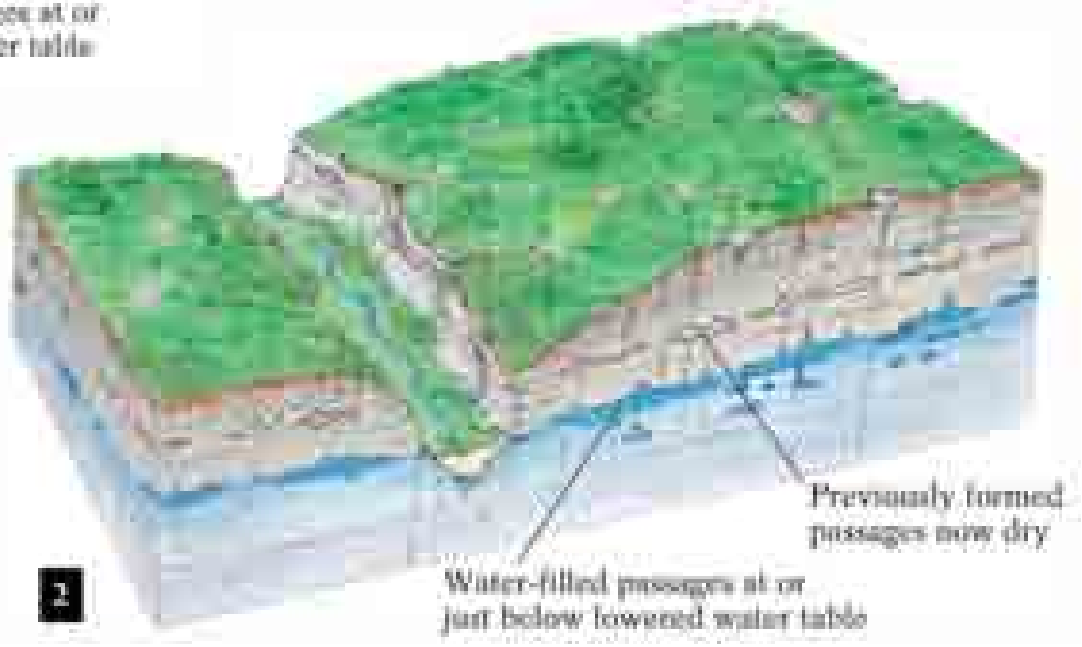


Wicander and Monroe (2002)

- A cave is a naturally formed subsurface cavity connected to the surface and large enough for a person to enter. A cavern is a very large cave or system of connected caves.
- Groundwater infiltrating the zone of aeration and flowing in the zone of saturation dissolves carbonate rock to form a system of solution cavities. A drop in the water table drains the previously formed cavities, leaving an interconnected system of caves and cavern. Water seeping into caves forms cave deposits

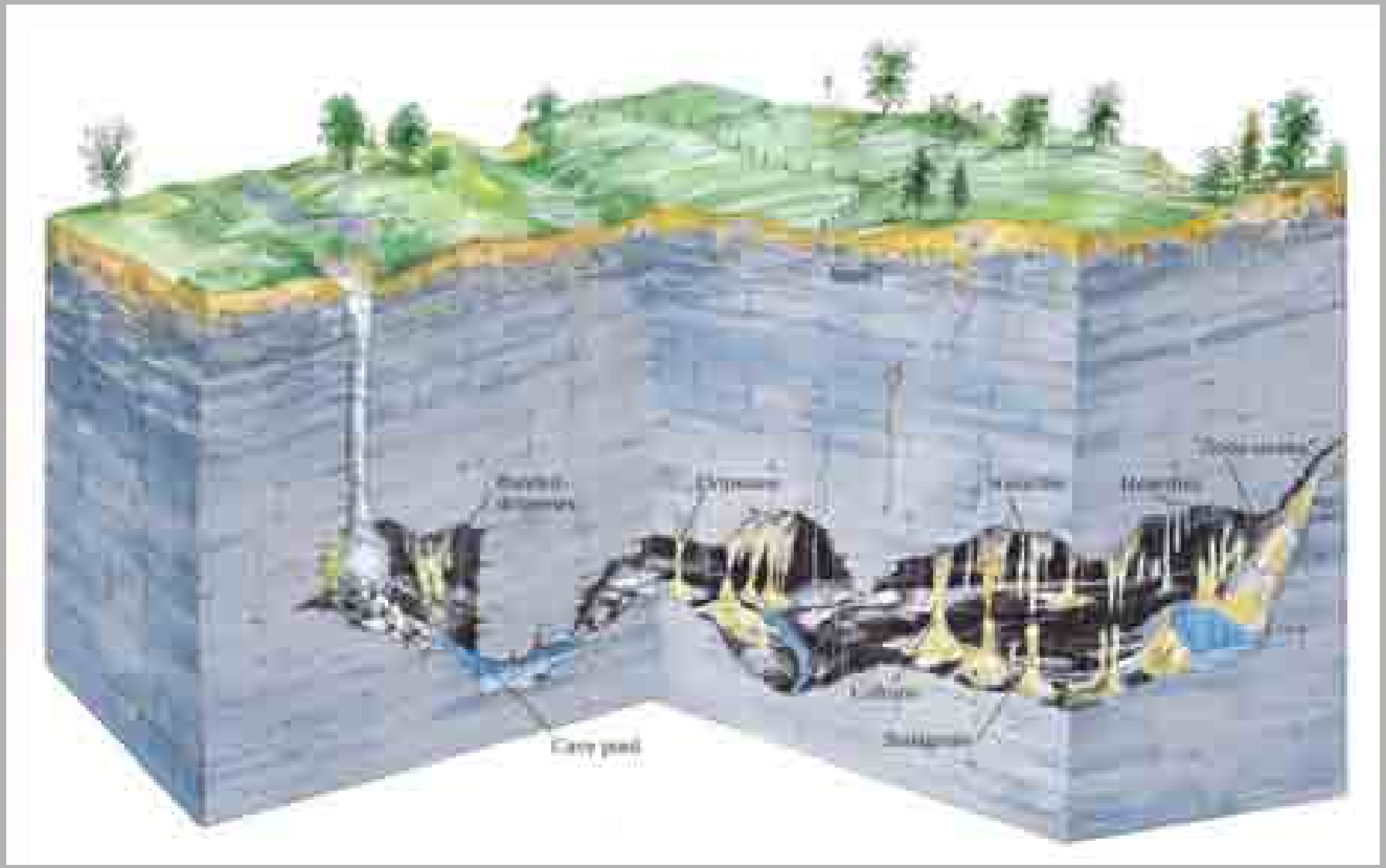
Cave formation.





Chernicoff and Whitney (2002)

Cave formations.



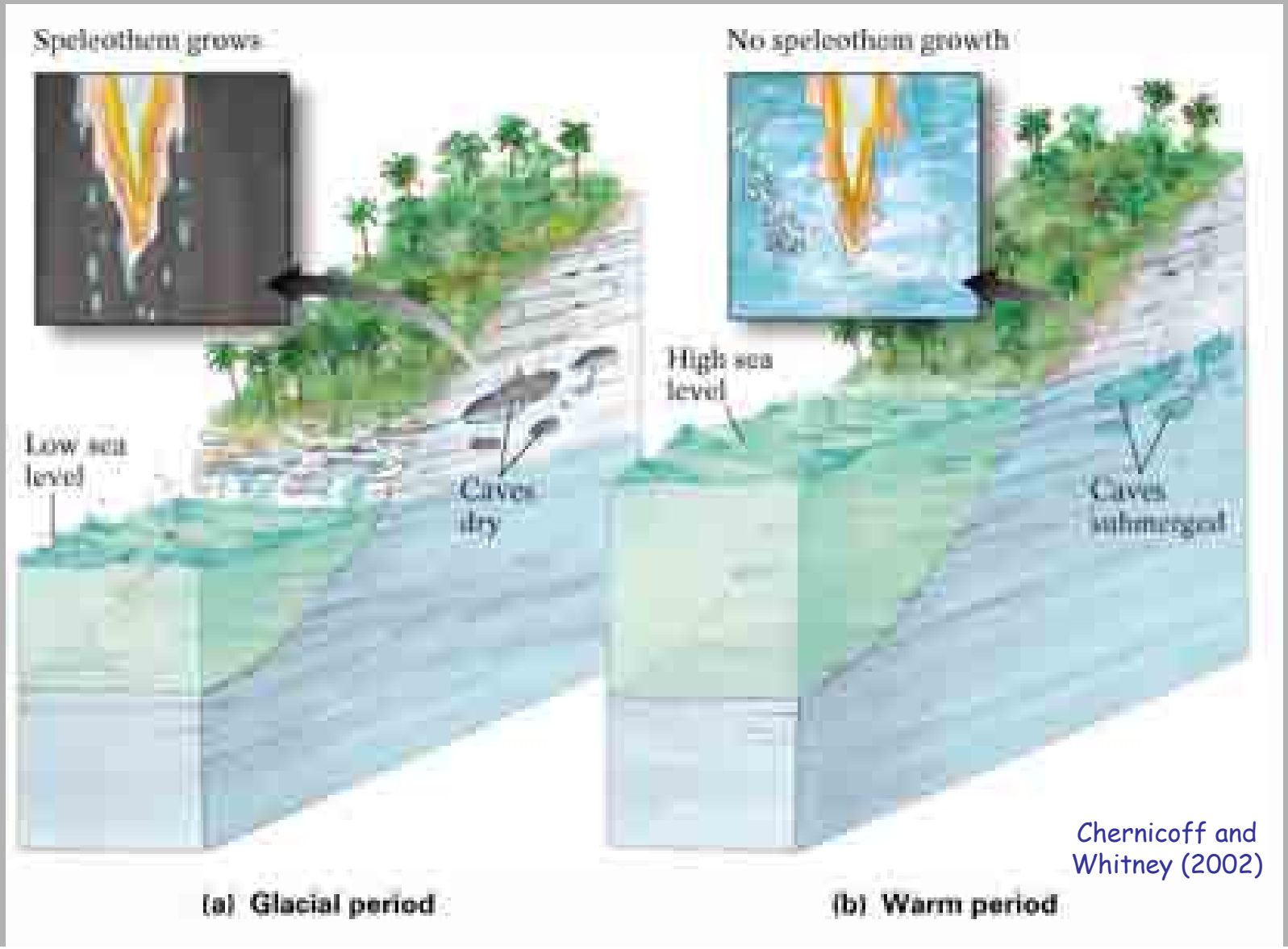
Chernicoff and Whitney (2002)

Caves and Cave deposits

As water seeps into caves, CO_2 in the water escapes and a small amount of calcite is precipitated. Almost all cave deposits form in this way and are collectively termed dripstone. Stalactites are icicle-shaped masses suspended from cave ceilings. Stalagmites are spires projecting upward from cave floors. Columns form where stalactites and stalagmites meet.

Chernicoff and Whitney (2002)

Rise and fall of the sea level.



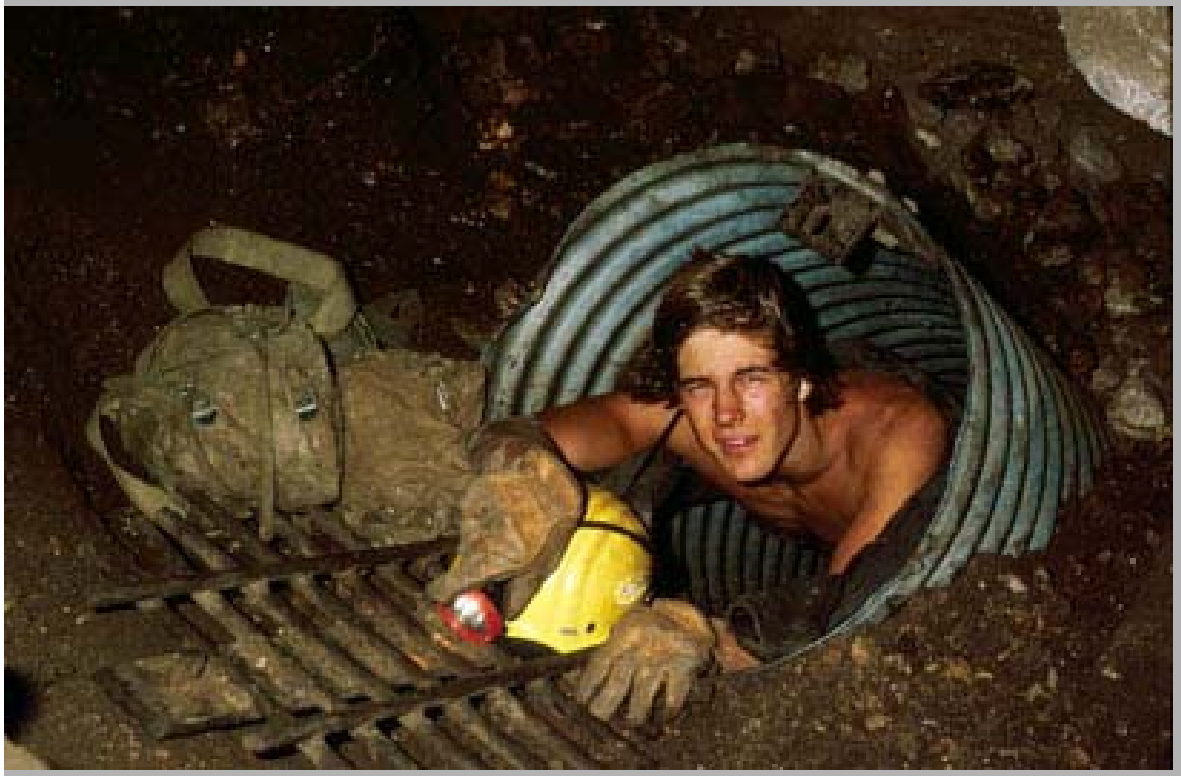
Chernicoff and Whitney (2002)

Lechuguilla Cave

- 5th longest cave in the world (196 km)
- located in the Carlsbad Caverns, New Mexico
- Check out Planet Earth (BBC)…
- access only to research and exploration
- mined in 1914 for Bat Guano (P+N)
- gypsum, sulfur deposits

Lechuguilla

Lechuguilla

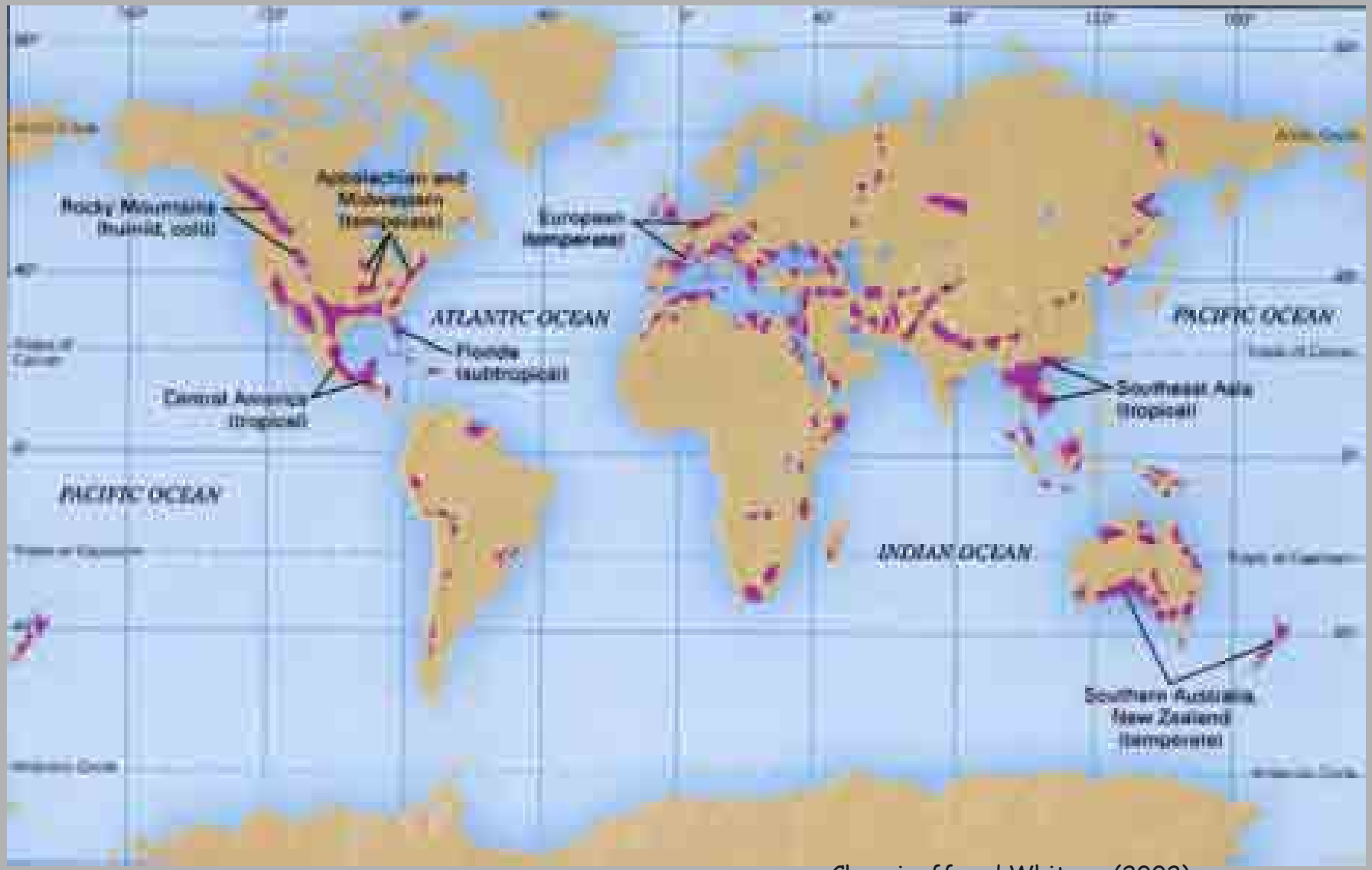


Lechuguilla

Lechuguilla

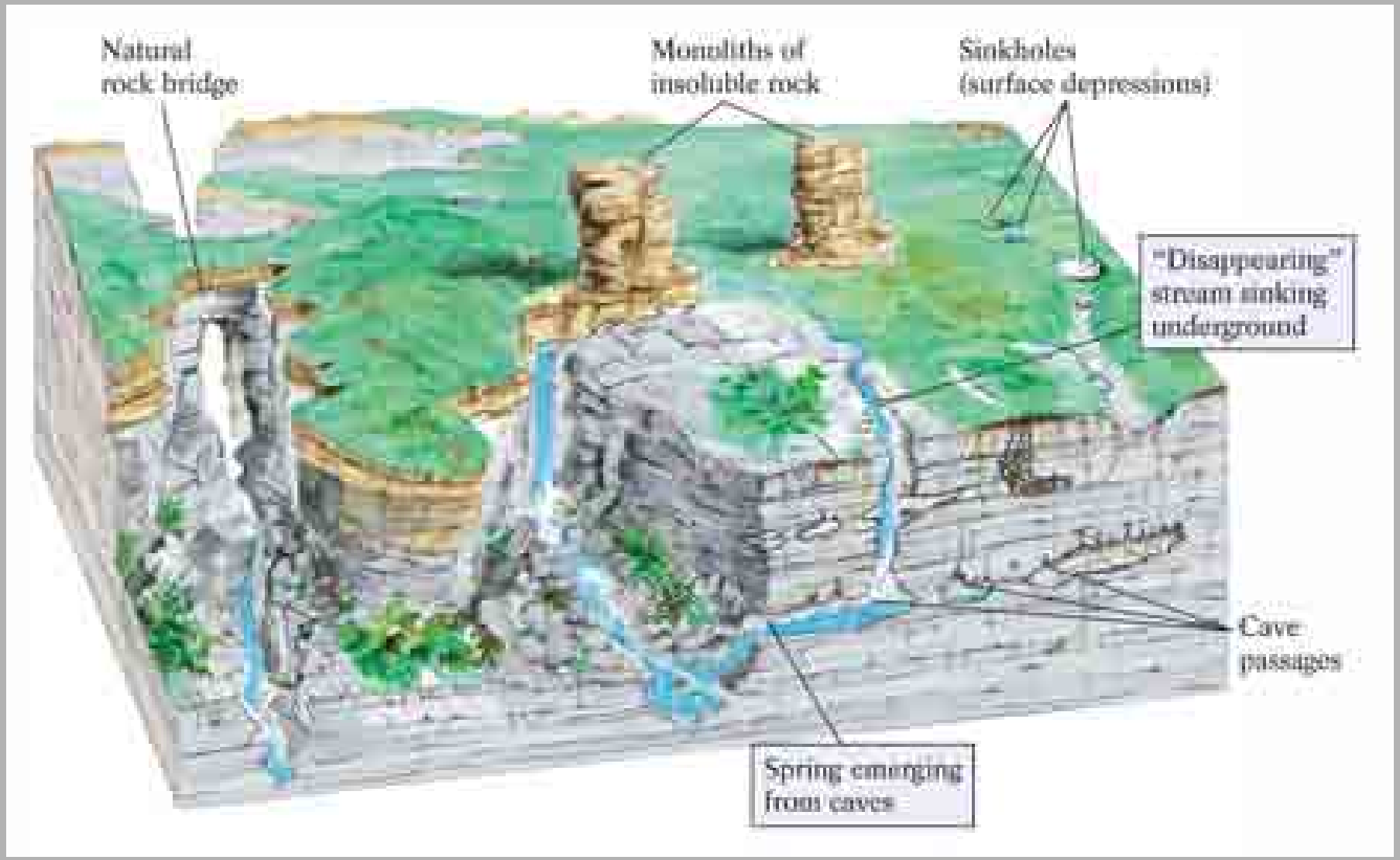
Lechuguilla

Distribution of karst landforms.



Chernicoff and Whitney (2002)

Landforms & karst topography.



Chernicoff and Whitney (2002)

Some Cave pictures from Bermuda…

All pictures are from: http://www.tamug.edu/cavebiology/Research/Bermuda/

Cave Bacon in Bermuda

Fort Scaur Cave, Bermuda / Cave bacon-beautiful

Bitumen Pitch Cave, Bermuda / Cave entrance

Andrew's Cave, Bermuda / Cave entrance

Andrew's Cave, Bermuda

Blue Hole Hill Cave, Bermuda / Mass of soda straws