

GEOMORPHOLOGY OF GROUNDWATER

UNIT 9



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Water beneath the surface (groundwater)

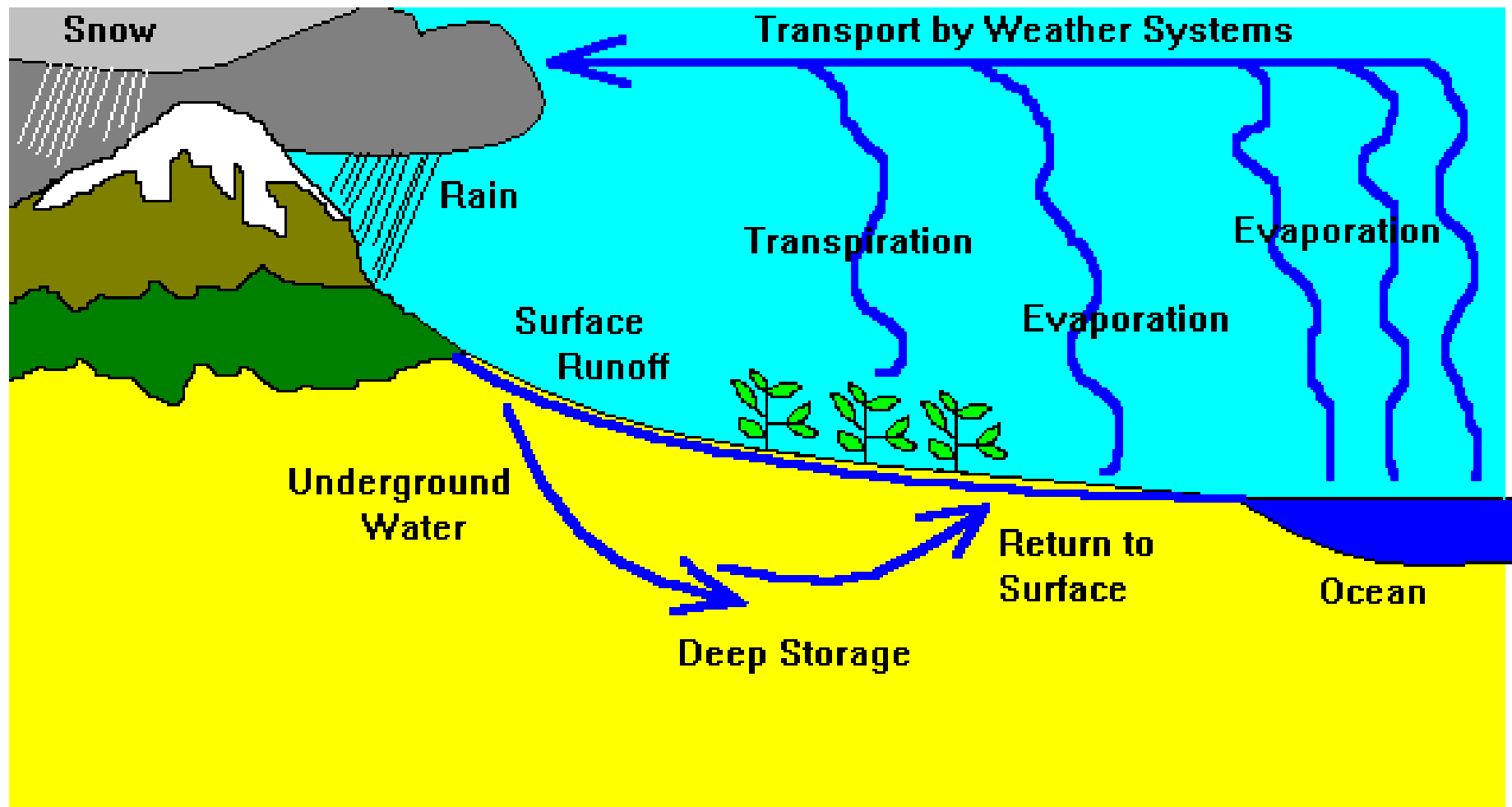
→ Largest freshwater reservoir for humans

- ❖ Groundwater fills the open spaces in rocks, sediment, and soil beneath the surface
- ❖ Groundwater is an important source for domestic, industrial, and agricultural use, but is also an important erosional and depositional Agent in subsurface, important energy source in some areas

Groundwater is about 22% of the world's fresh water
comes from precipitation percolating through
soils and sediment

streams, lakes, and snowmelt also contribute

Groundwater and the Hydrologic Cycle



How water reaching the subsurface

What Properties of Earth's Materials allow them to absorb Water?

→ It is depend on the porosity and permeability of the rock

Porosity

- Percentage of pore spaces in compare to its volume rock
- Determines how much groundwater can be stored

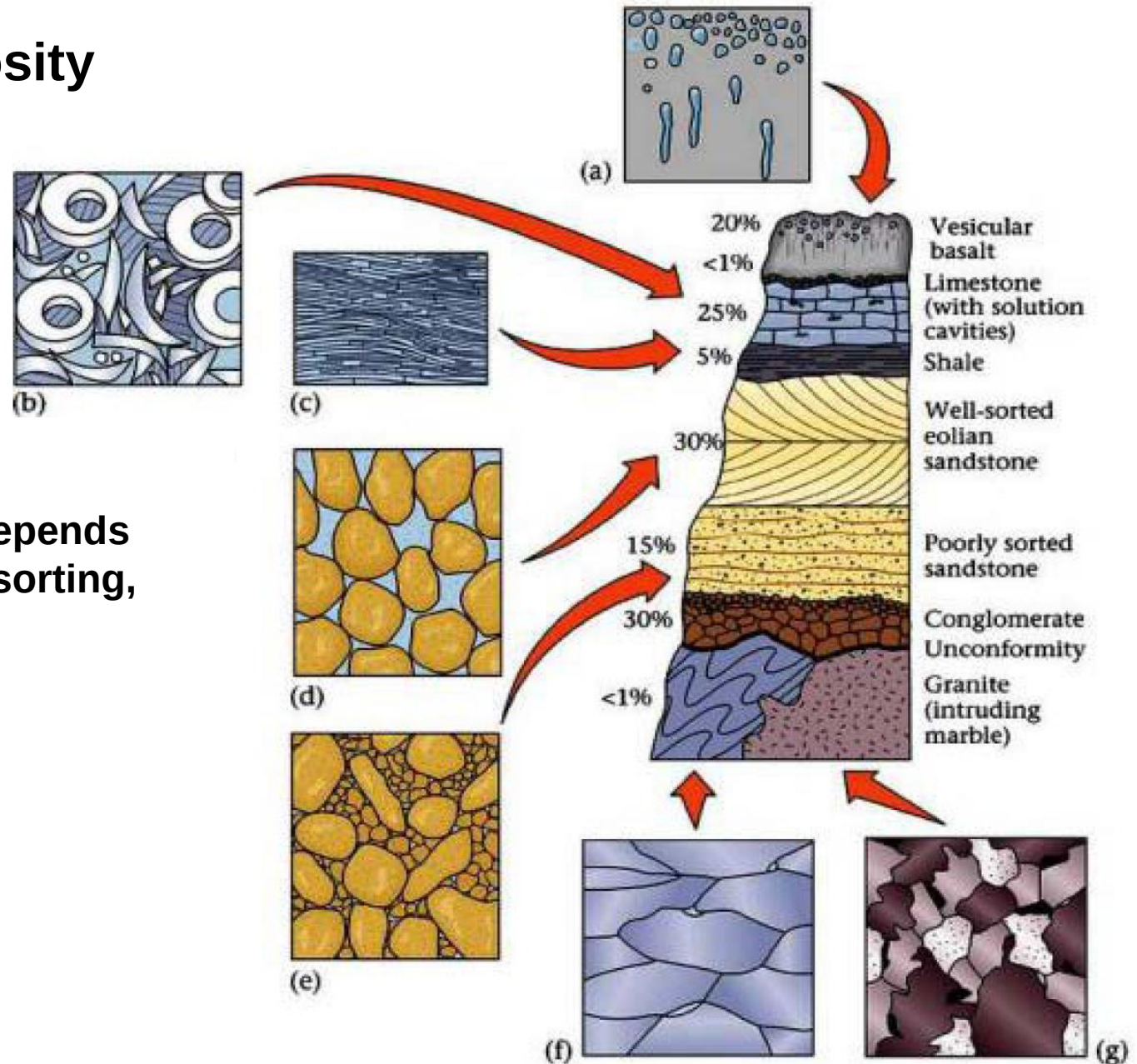
Permeability

- Ability to transmit water through connected pore spaces

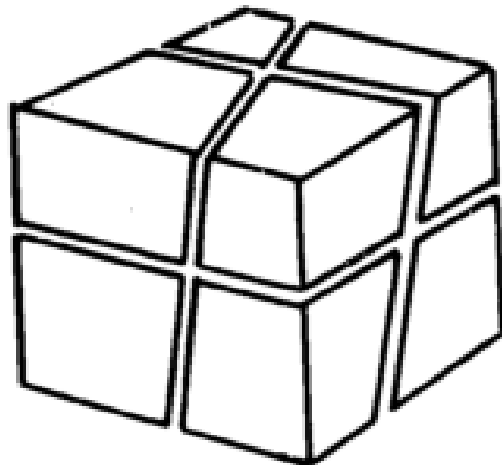
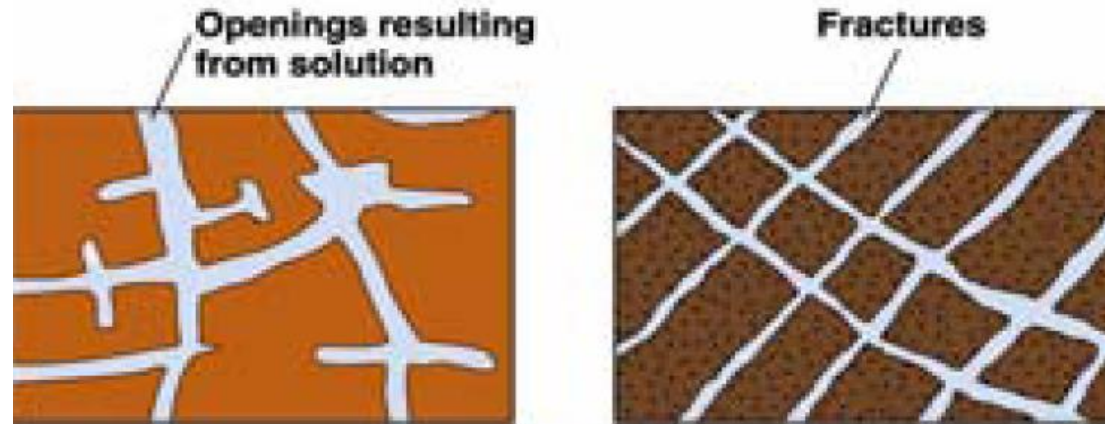
Porosity

❖ Primary porosity

Primary porosity depends on the rock types, sorting,

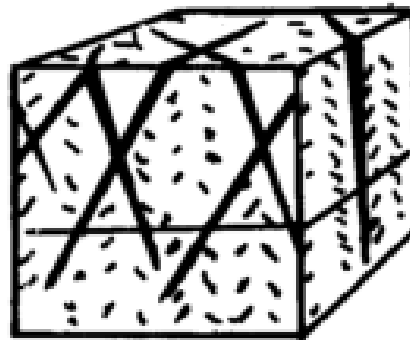


Secondary porosity

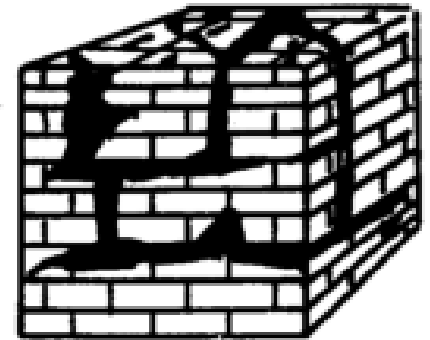


Fractured rock

Secondary Openings



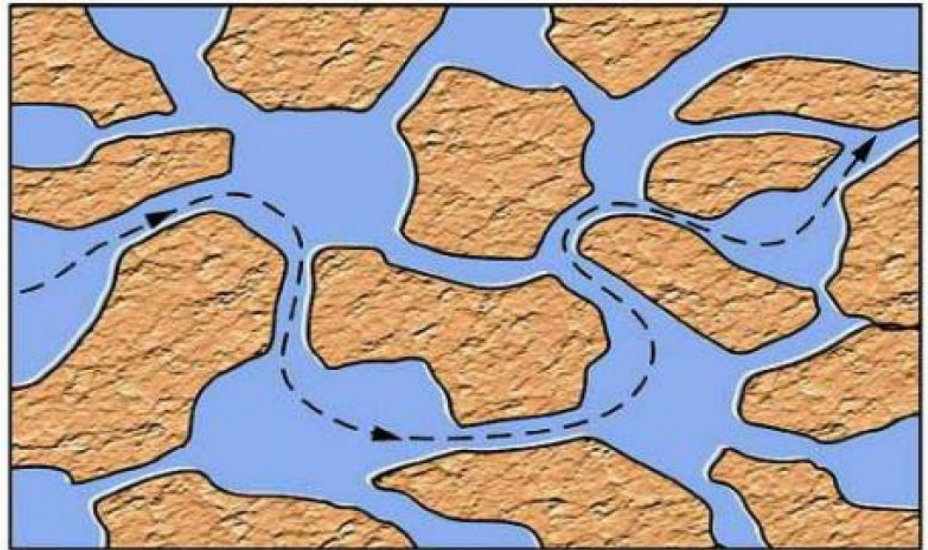
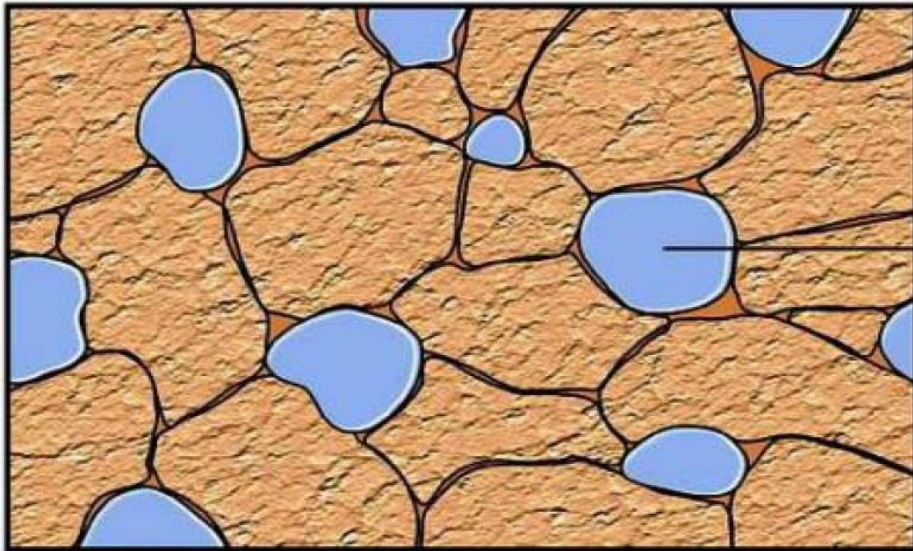
Fractures in granite



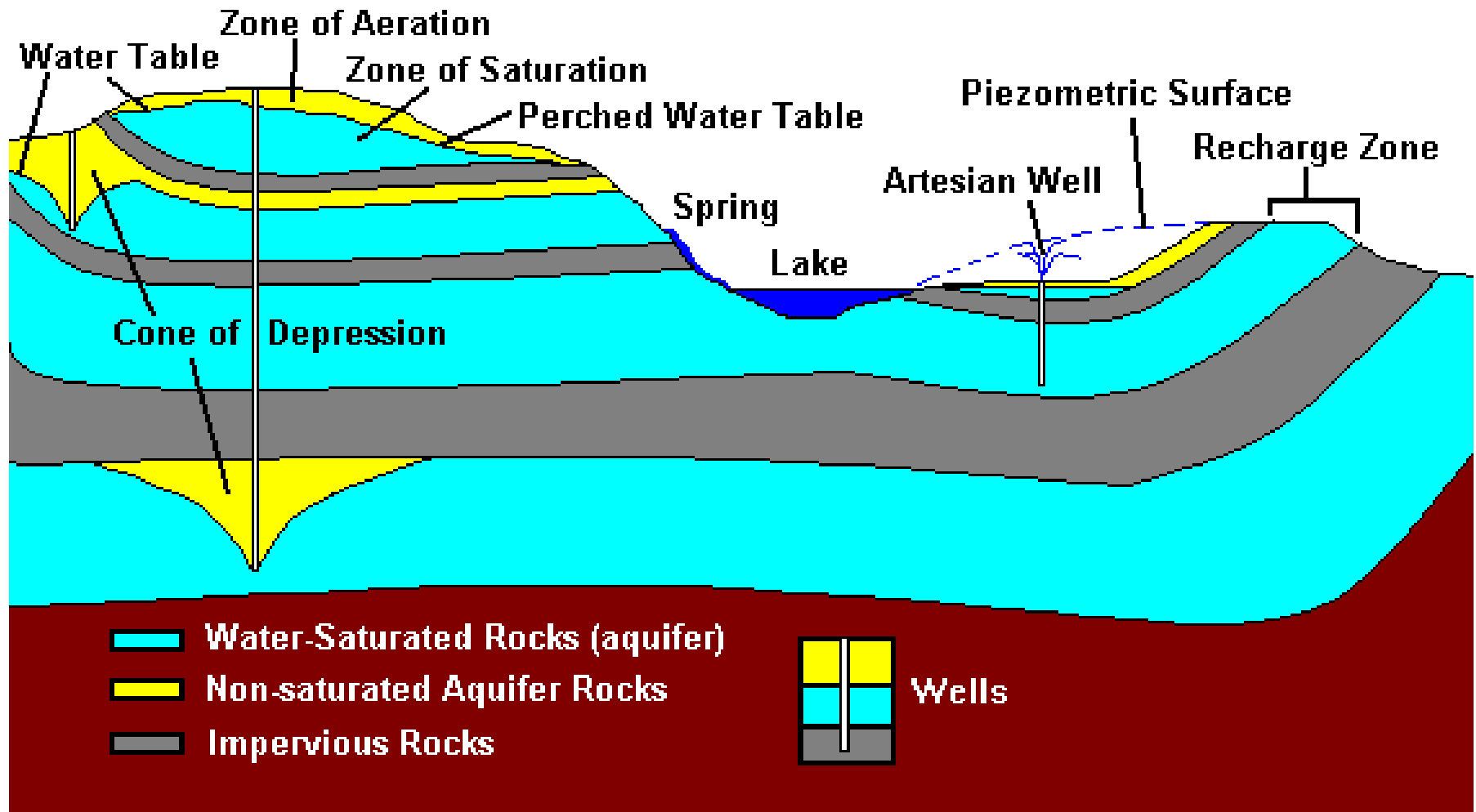
Caverns in limestone

Permeability

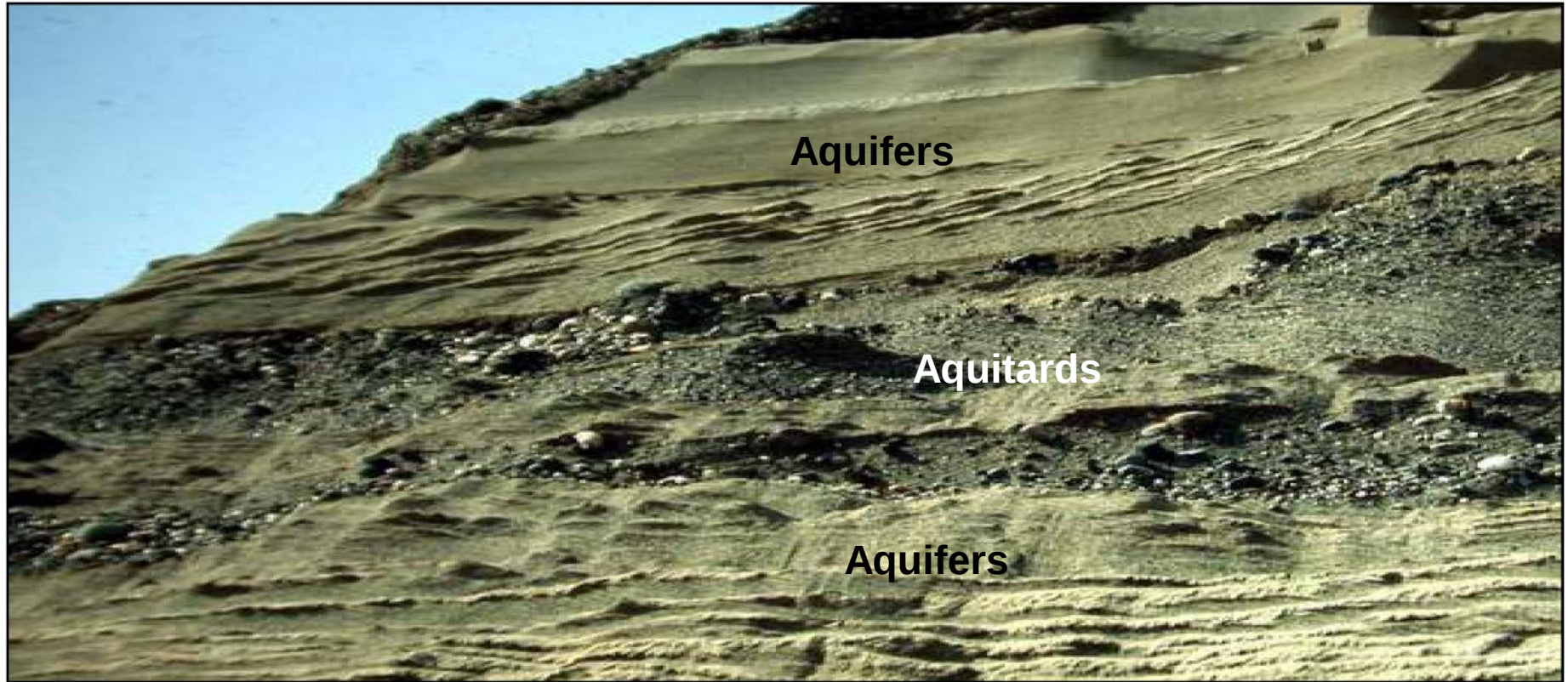
- Ability to transmit water through connected pore spaces



Aquifers

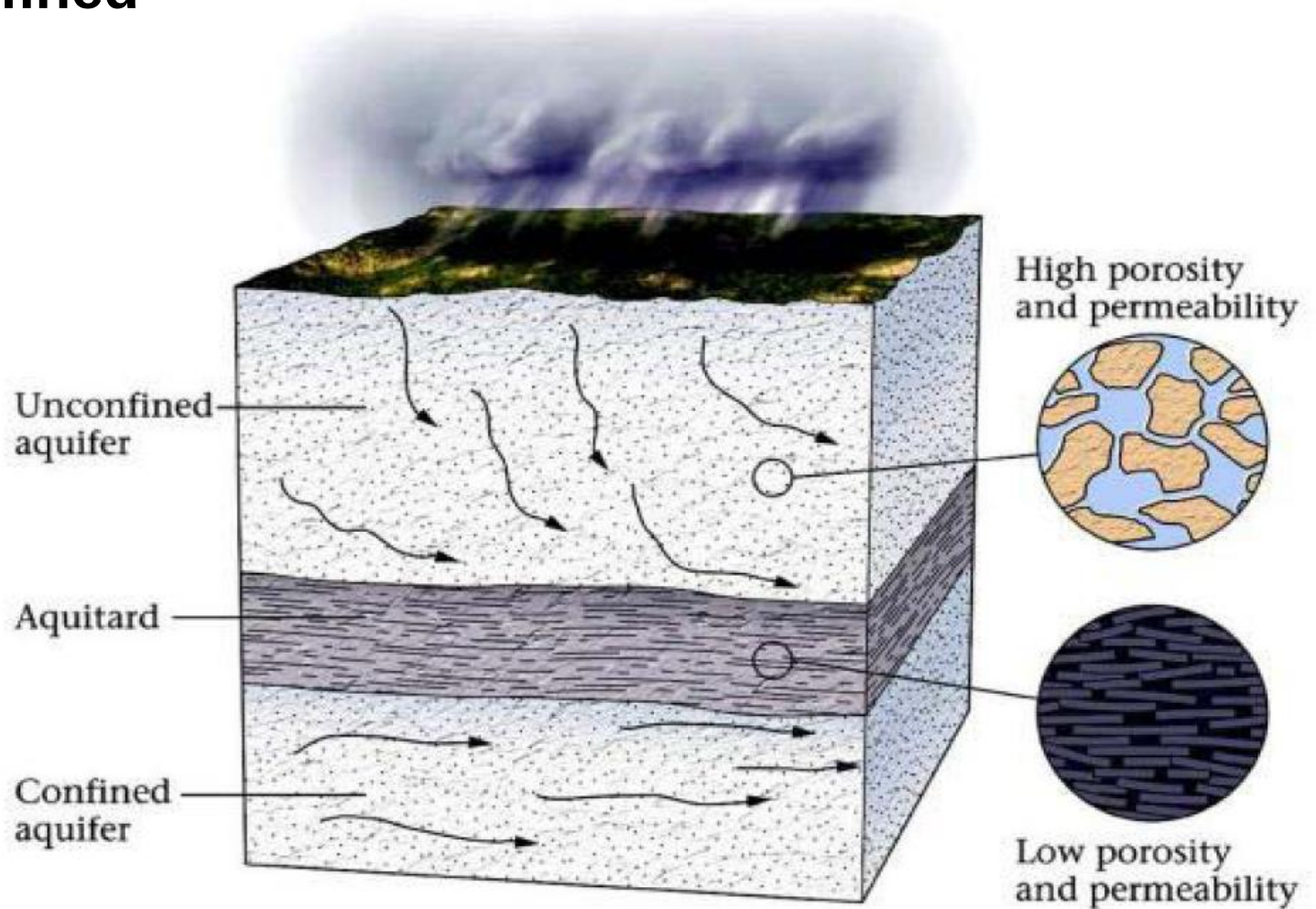


Aquifers and Aquitards



Aquifers - types

- ☐ Unconfined
- ☐ Confined



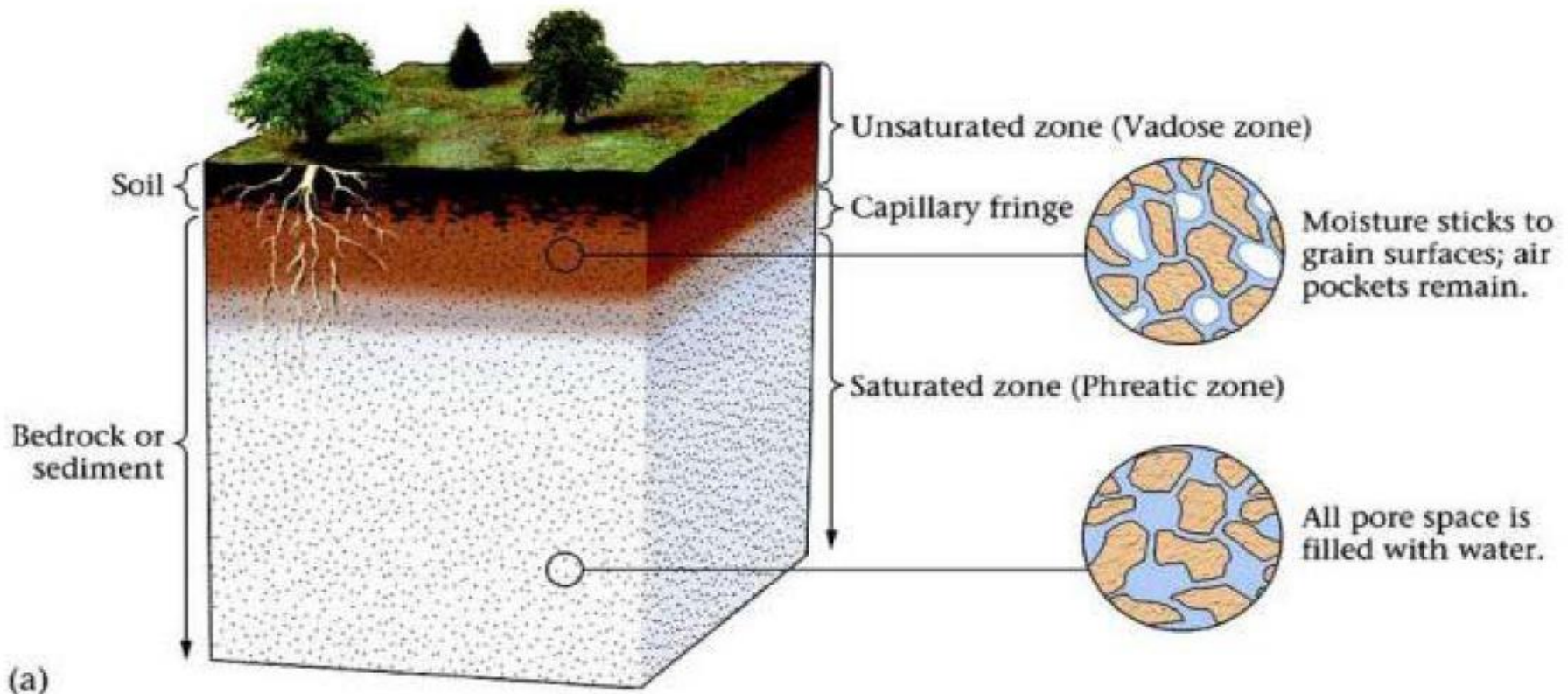
Water Table

❖ The water table is the top of the zone of saturation.

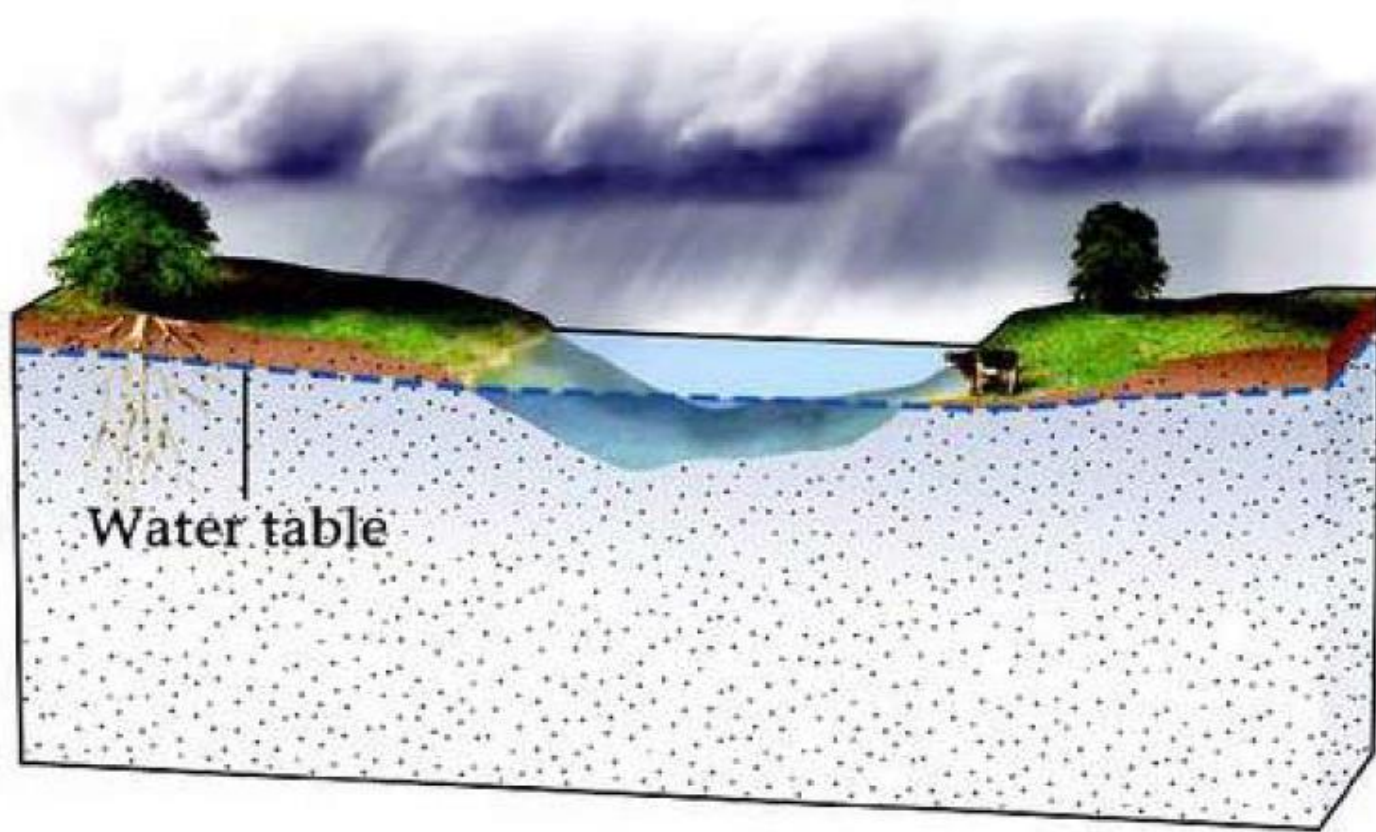
→ Vadose zone (Unsaturated zone)

→ The capillary fringe

→ Phreatic zone (Saturated zone)

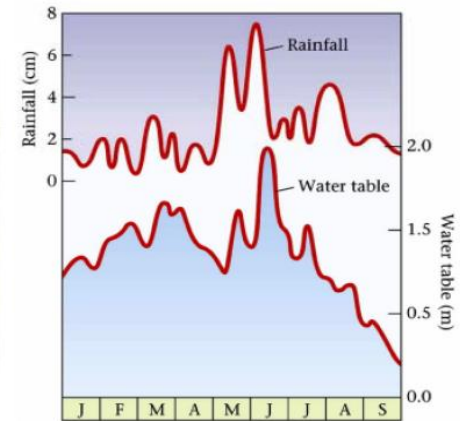
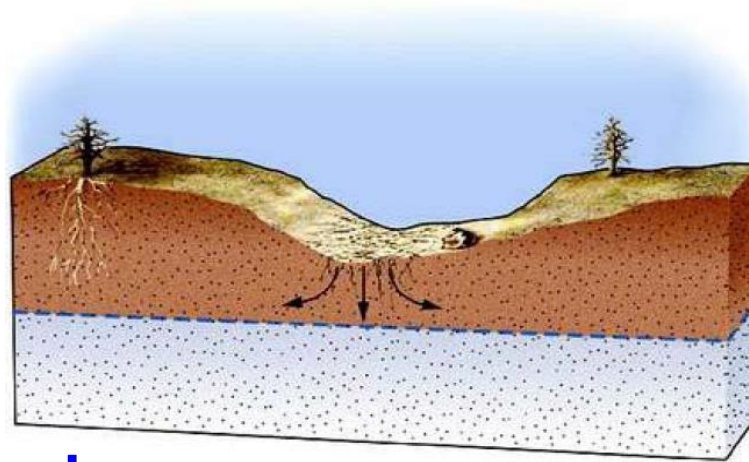


- The depth to the water table is variable
- Perennial surface water exposes the water table



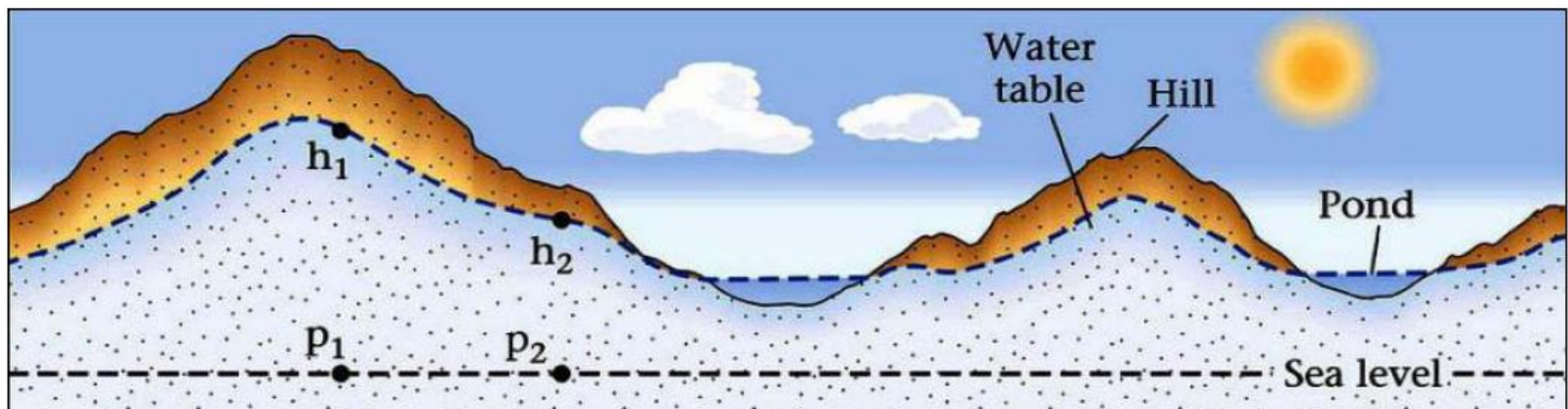
Water table position changes with rainfall

❖ Ponds go dry if the water table falls below the bottom.

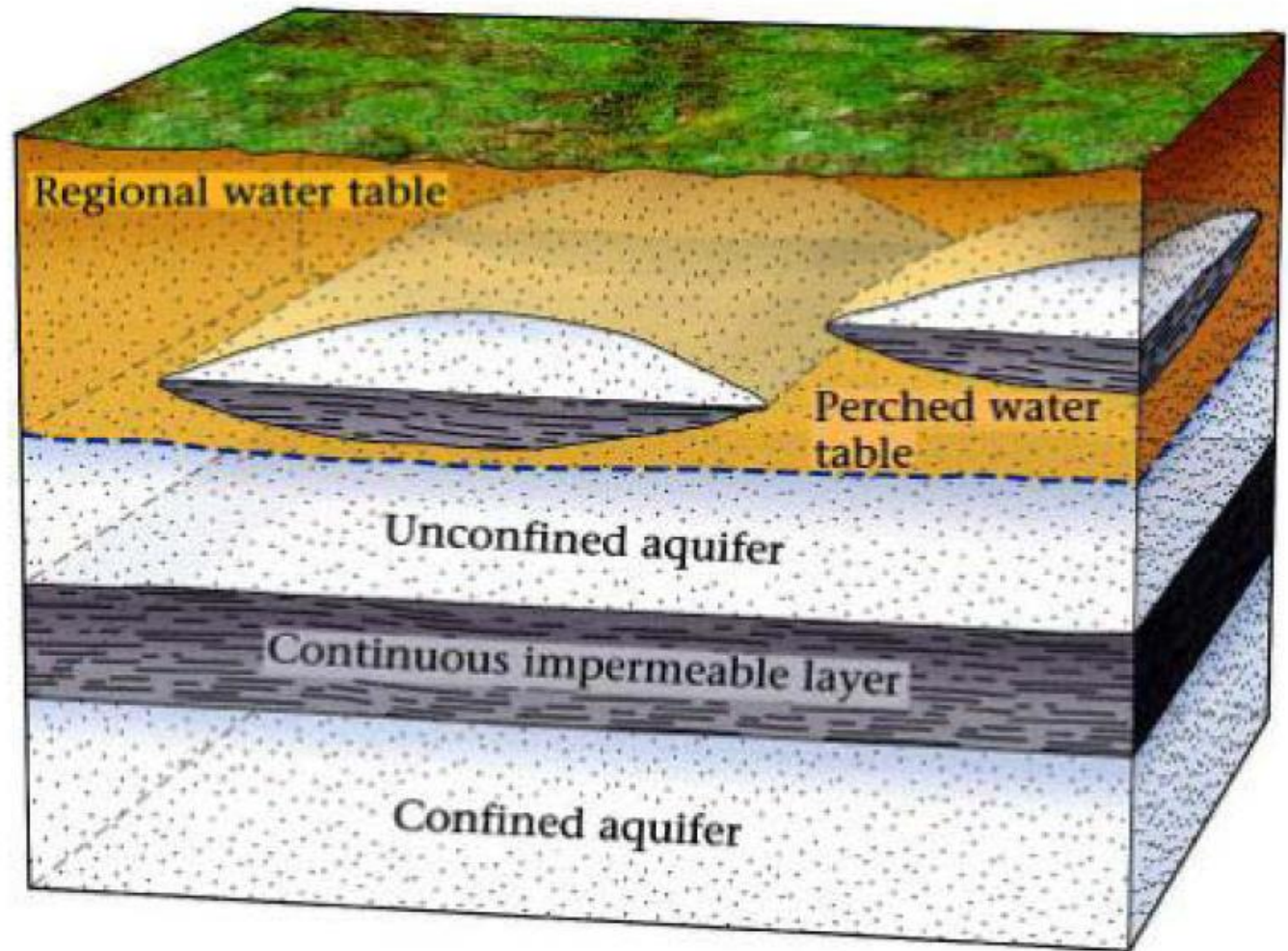


Water Table Topography

❖ The water table often follows the land's topography



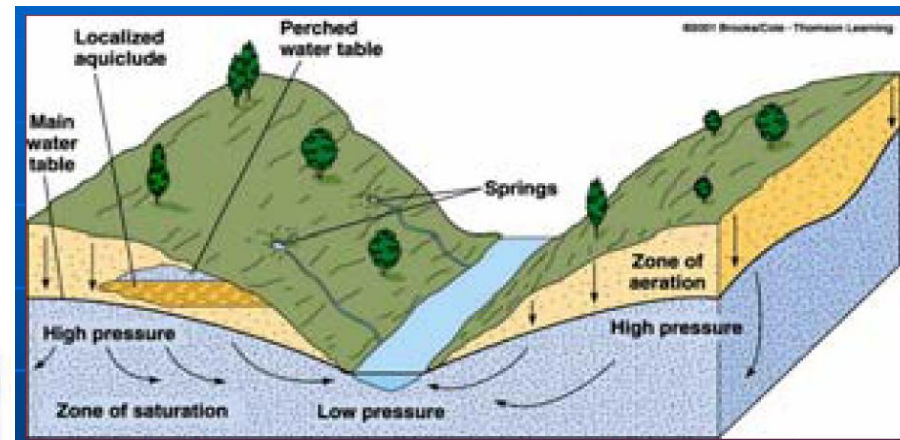
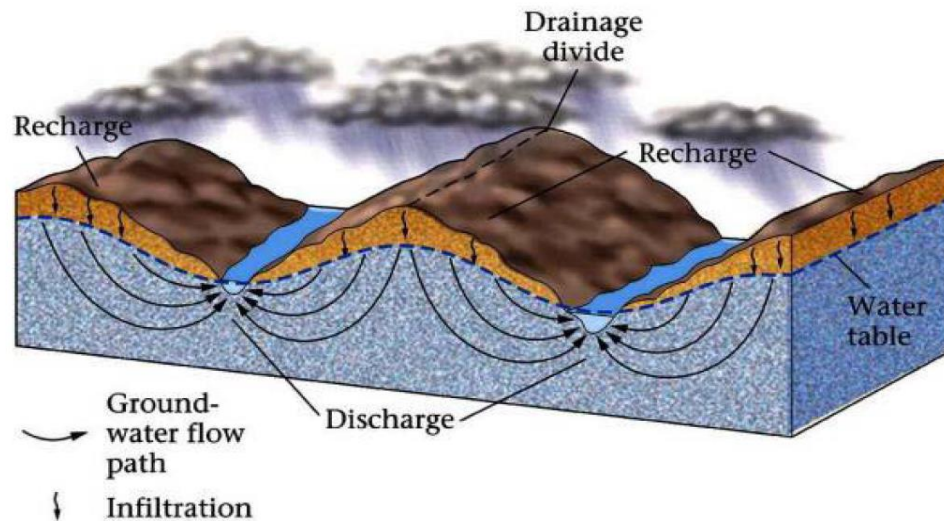
- ❖ Discontinuous aquitards
- ❖ Aquitards can form perched water tables



Groundwater Movement

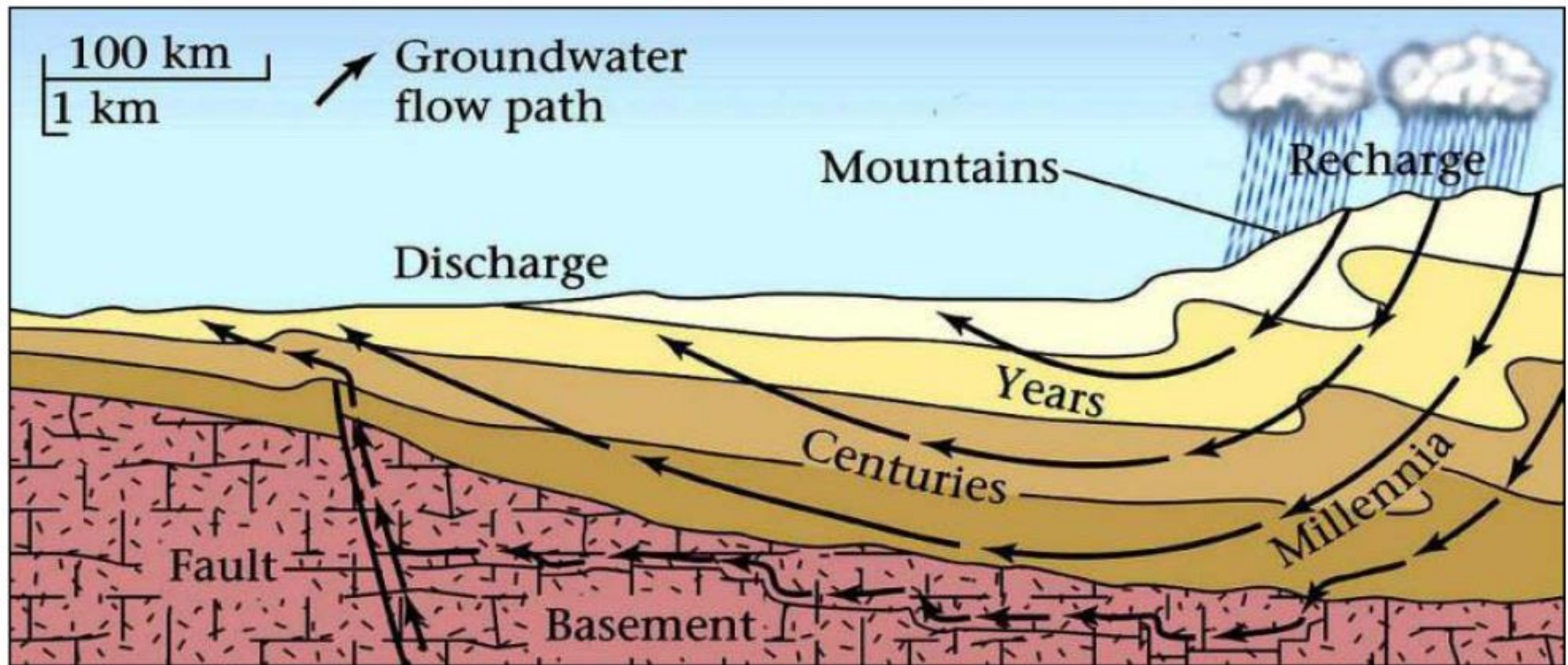
Gravity moves groundwater, just as it does water in channels

- ❖ moves from areas of high pressure to areas of low pressure
- ❖ may move up to 250 m per day, or less than a few cm/day



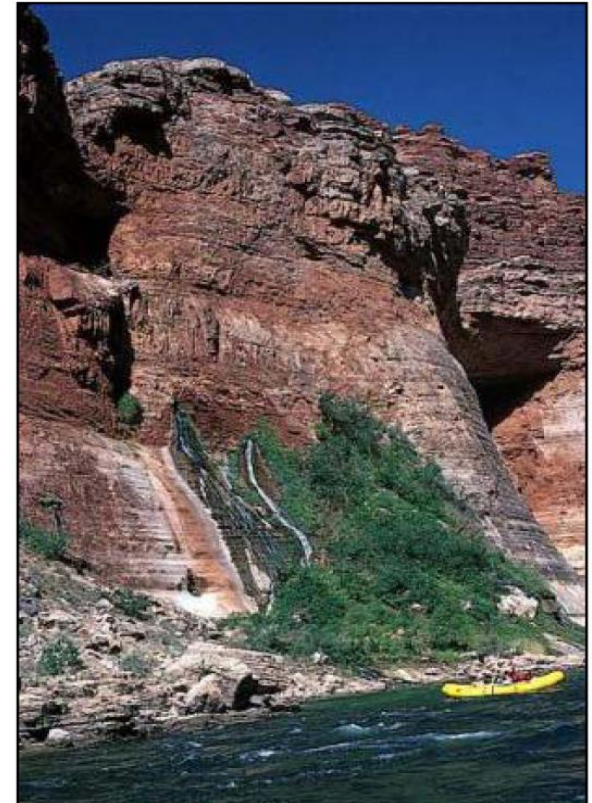
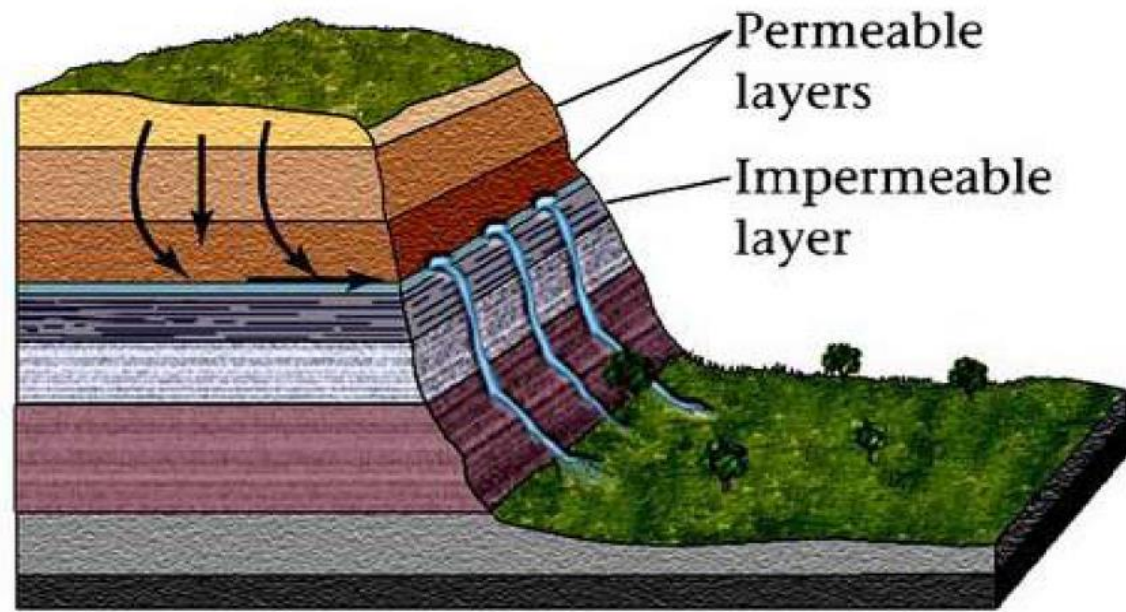
■ Groundwater flow occurs on a variety of scales.

- Local
- Intermediate
- Regional

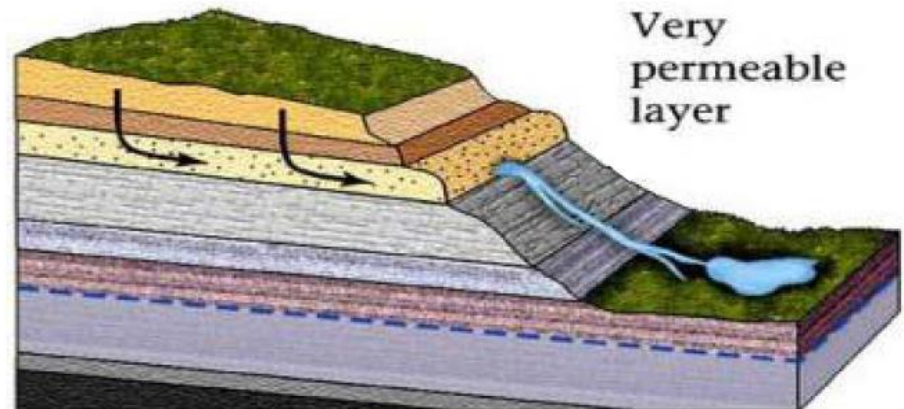
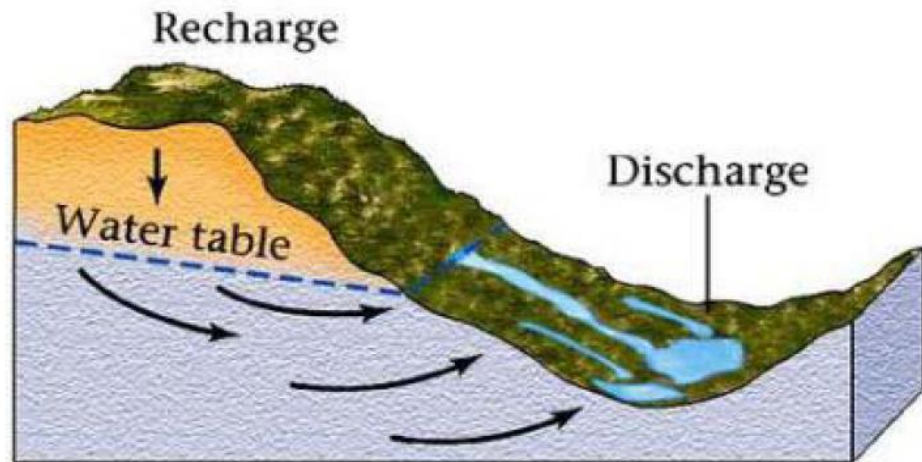
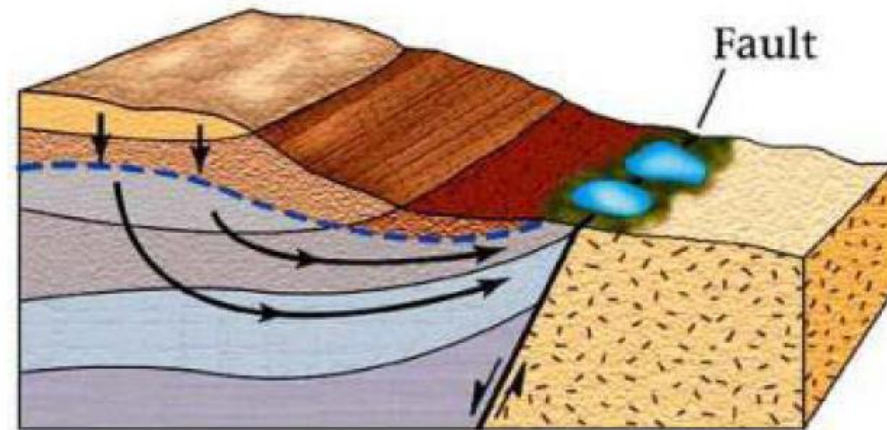
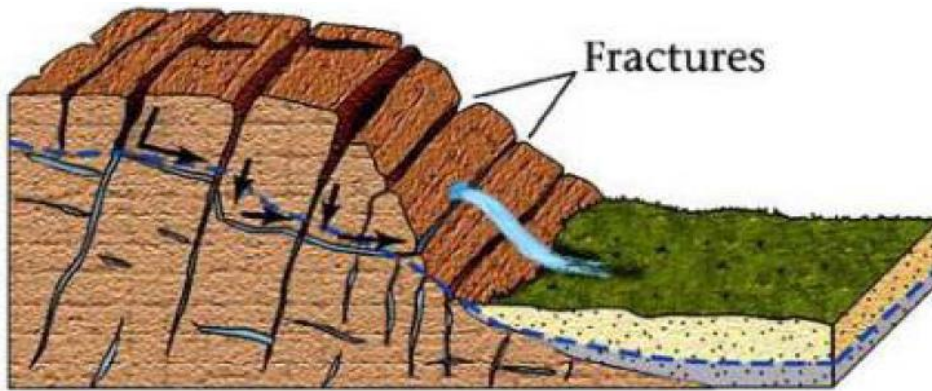


Springs?

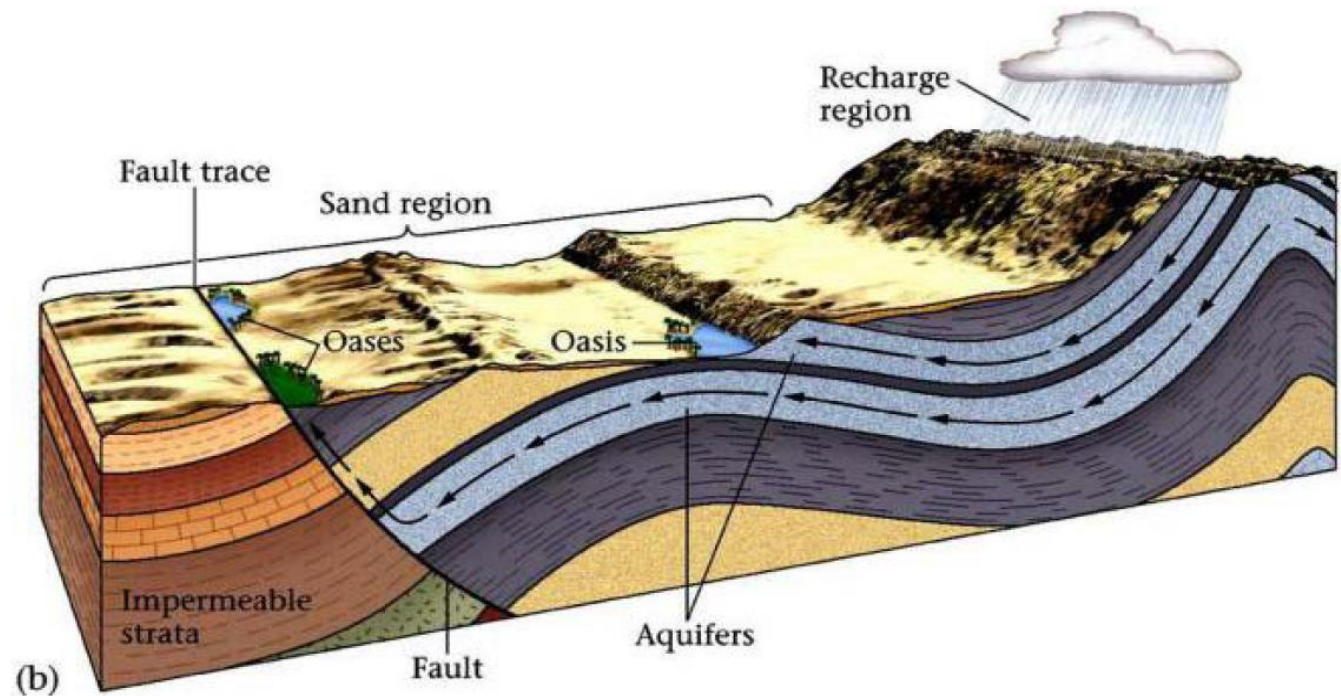
- ❖ Springs are locations of natural groundwater discharge.
- ❖ Places where groundwater flows or seeps out of the ground
- ❖ when percolating water reaches the water table or impermeable layer, it flows laterally and may intersect the surface



Springs result from varied geologic features.

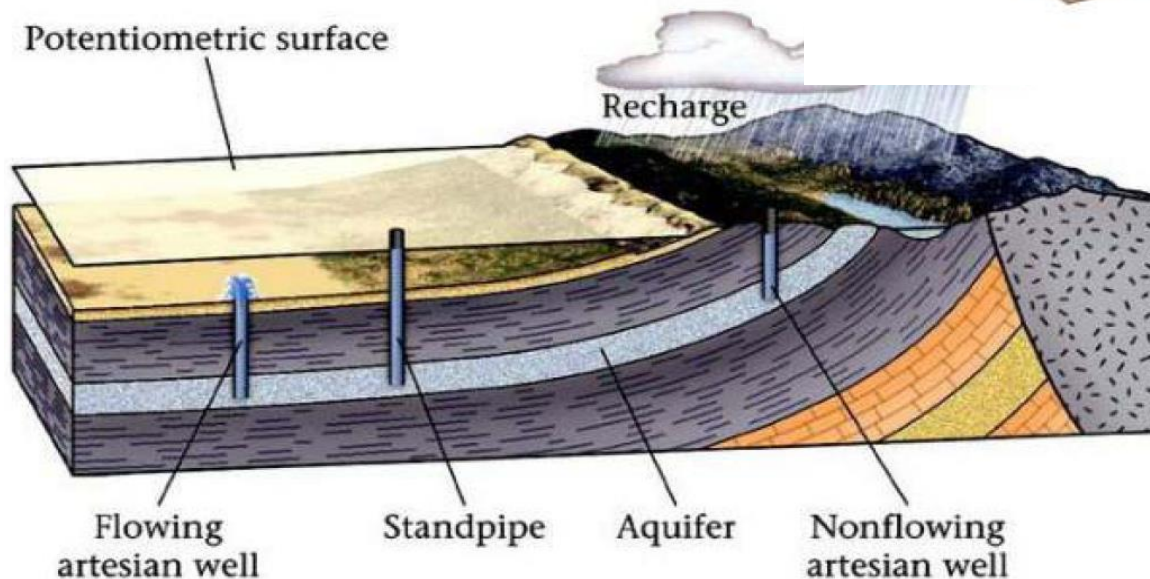
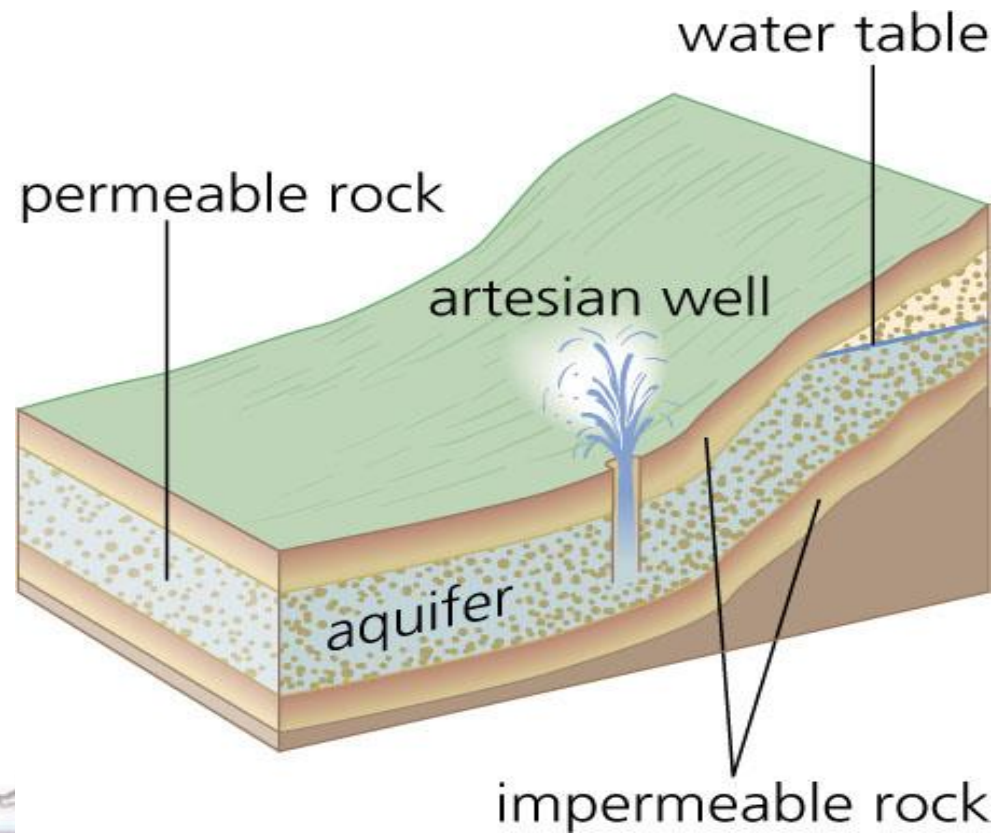


- Oases in the Sahara desert develop from spring flow.
- Water from recharge areas flows to oasis discharge points.



Artesian well – Confined groundwater that flows at the surface under Hydrostatic pressure

Artesian well – Water from a confined aquifer rises above the land surface producing a flowing well that spouts water continuously into the air



Artesian wells generally in confined, tilted aquifers

Hot springs

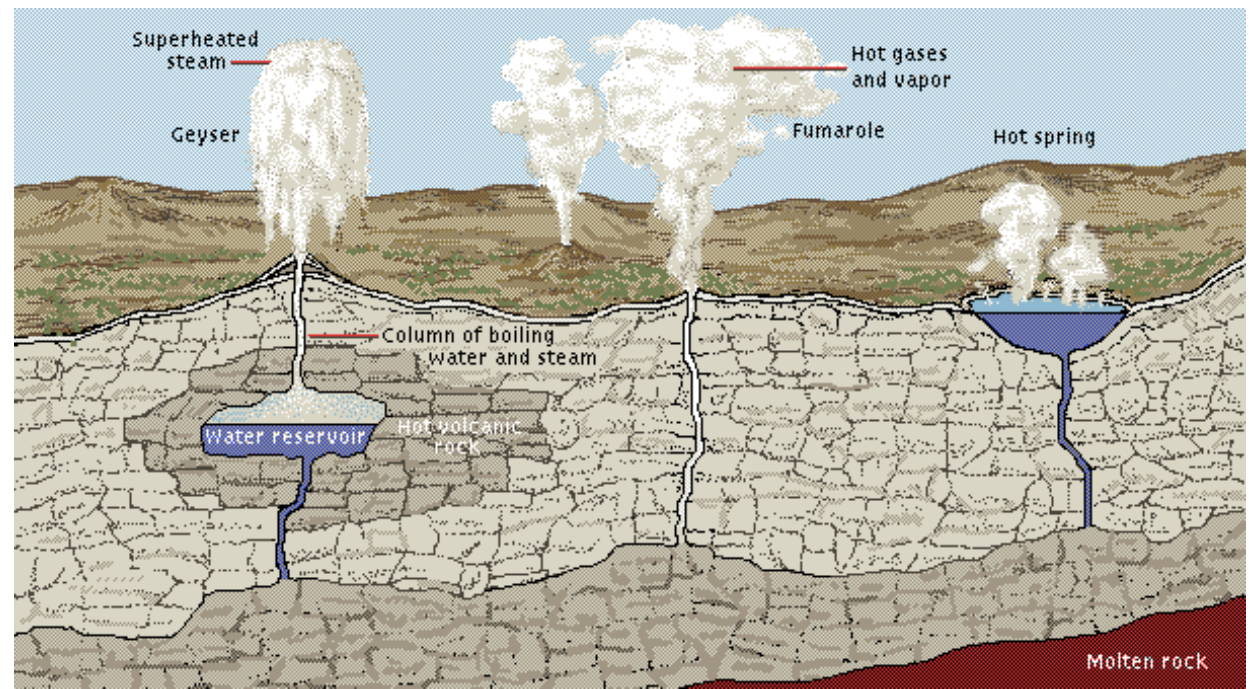
- ❖ Water is 6-9°C warmer than the mean air temperature of the locality
- ❖ Heated by Magma

Geysers

- a type of hot spring that periodically erupts hot water and steam



geyser in Yellowstone National Park





Old Faithful Geyser

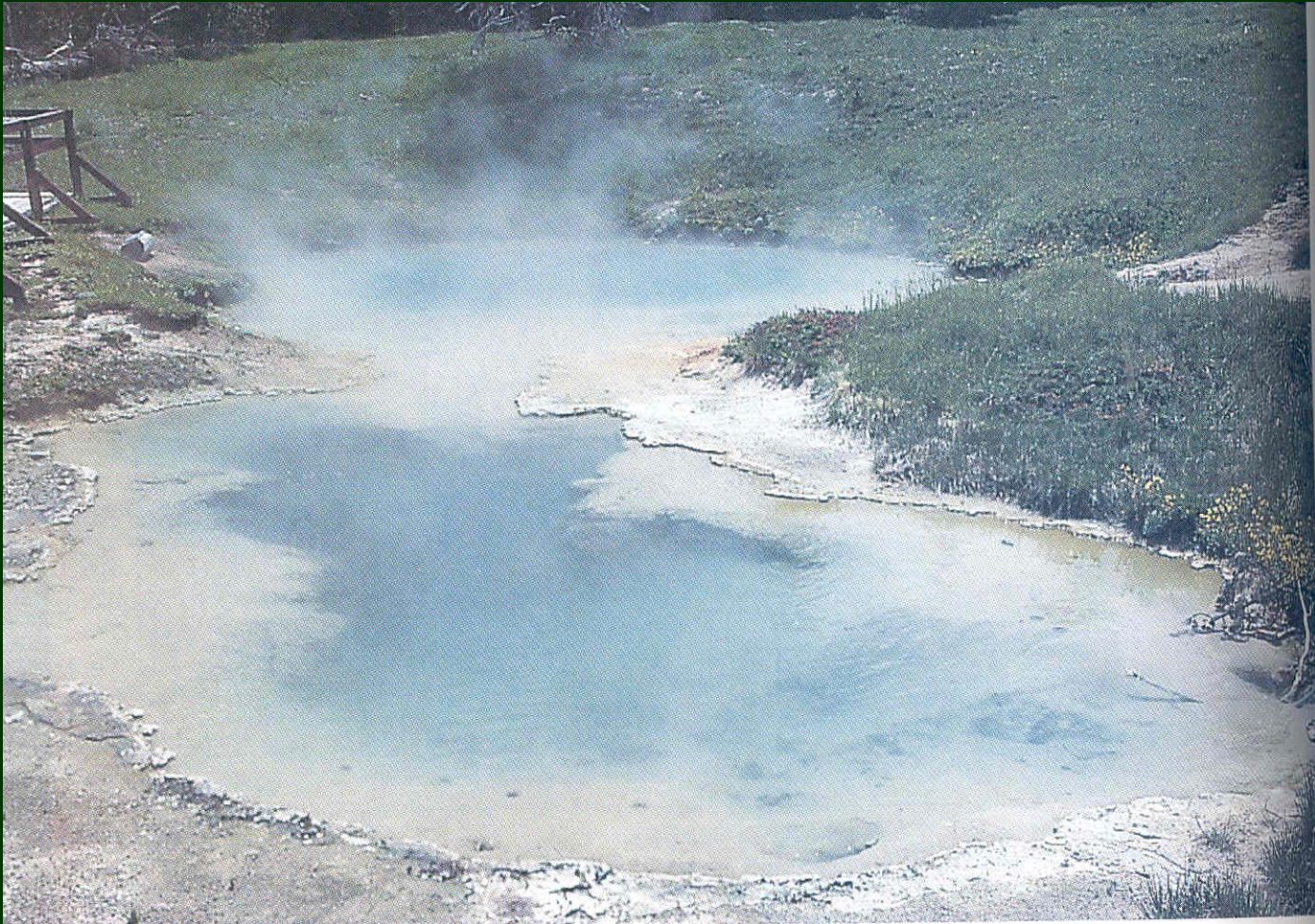
(Yellowstone National Park, Wyoming)

One of the world's most famous geysers, erupting approximately every 30 to 90 minutes

Geysers are hot springs that intermittently eject hot water and steam with tremendous force. The word come from Icelandic geysir means to gush or to rush forth. Geysers are the surface expression of an extensive underground system of interconnected fractures within hot igneous rocks

Hot Springs

(West Thumb Geyser Basin, Yellowstone National Park, Wyoming)



Hot spring (thermal spring or warm spring) is a spring in which the water temperature is warmer than the human body (37°C). The heat for most hot springs comes from magma or cooling igneous rocks.

Mudpot – a type of hot spring that contains thick boiling mud and strong sulfurous acids

- Intense chemical weathering



Mud Pot

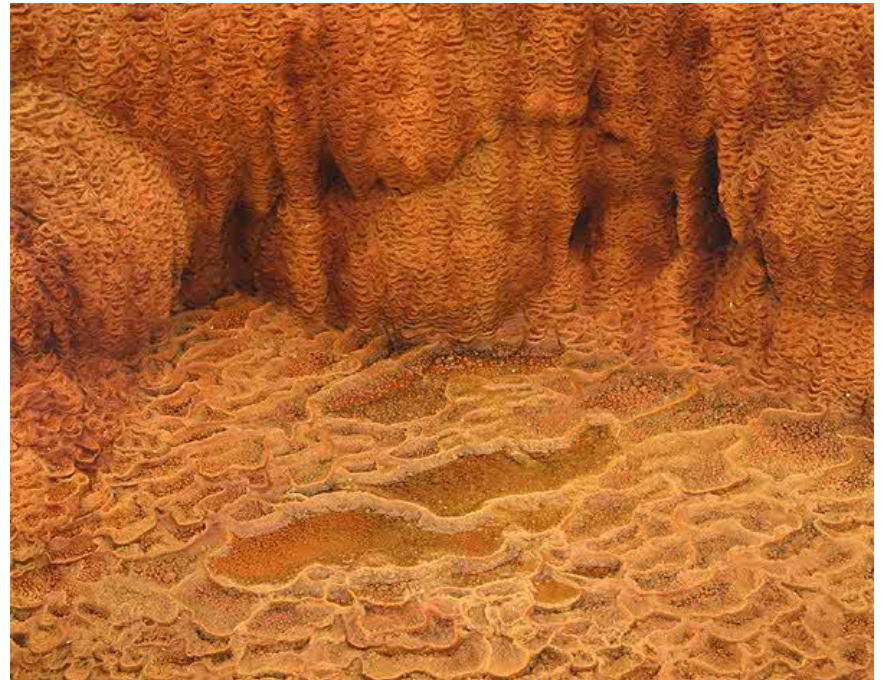
Geothermal deposits

- **Travertine** – a deposit of calcite that forms around hot springs
- **Sinter (or geyserite)** – a deposit of precipitated silica

Sinter



Travertine



TRAVERTINE DEPOSITS, MINERVA TERRACE, MAMMOTH HOT SPRINGS, YELLOWSTONE NATIONAL PARK, WYOMING



Travertine (CaCO_3) formed by the warm spring water cooled and evaporated

Fumeroles

Mammoth Hot Spring, Yellowstone National Park, Wyoming



Sometimes hot water incorporates sulfur on its way to the surface, the spring emits the distinctive rotten-egg odor of sulfur dioxide and the deposits have a yellowish tinge

Subsidence

- Loose grains of the aquifer are packed tighter after groundwater withdrawal
 - subsidence of the land has lowered Mexico City more than 3m in some places



Like other Geological agents, Groundwater also modify the surface and subsurface of the earth by erosional and processes through solution activities

When soluble rock is exposed at the surface, water can attack minerals chemically and become a significant erosional agent and create the various erosional and depositional landforms

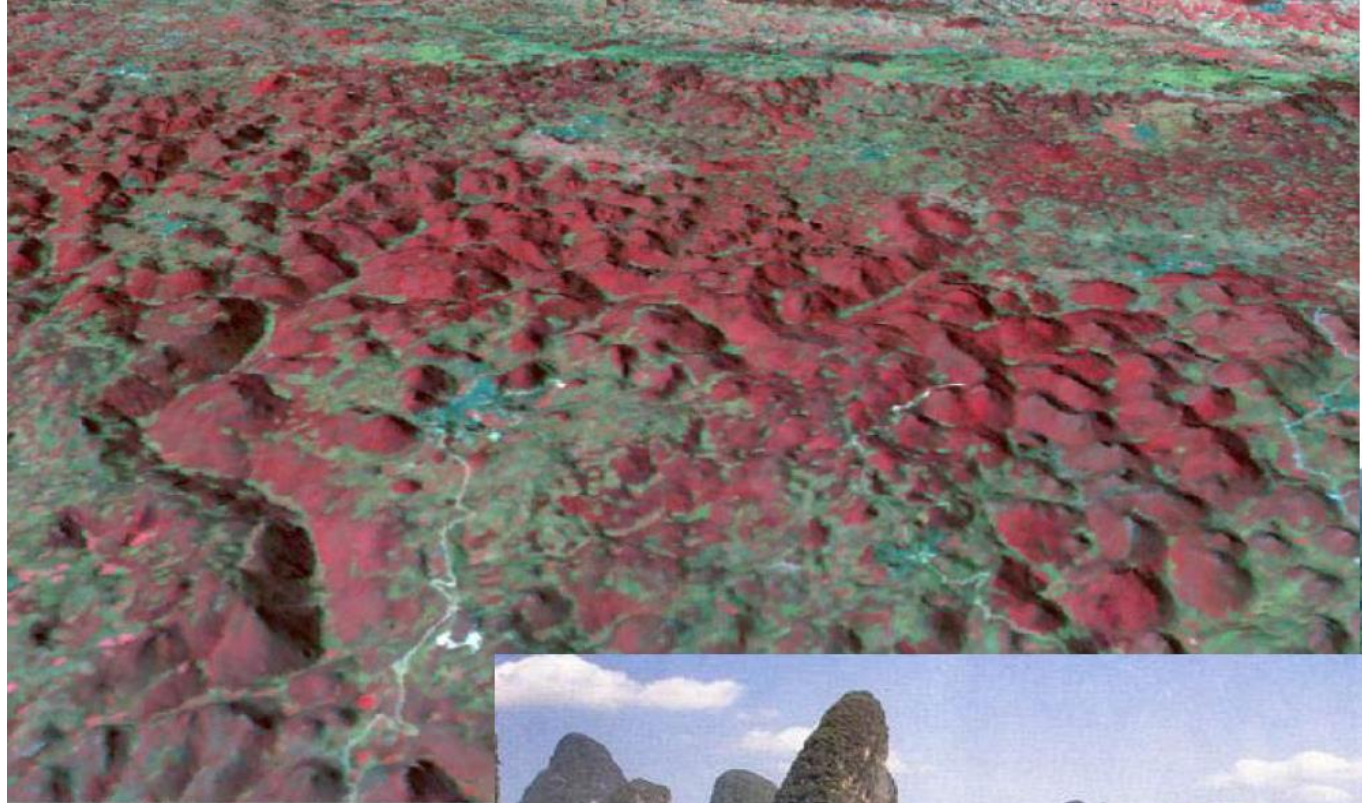
The resulting topography with shallow depression and small mounts is termed Karst Topography (After the area Karst in Italy)

The Karst topography are generally associated with limestone region (because limestone easily soluble and taken as solution by water)

Karst Topography

Definition by Jennings (1985)

“A terrain with distinctive landforms and drainage arising from greater rock solubility in natural water that is found elsewhere.”



ASTER/VNIR (9-Feb-2002)

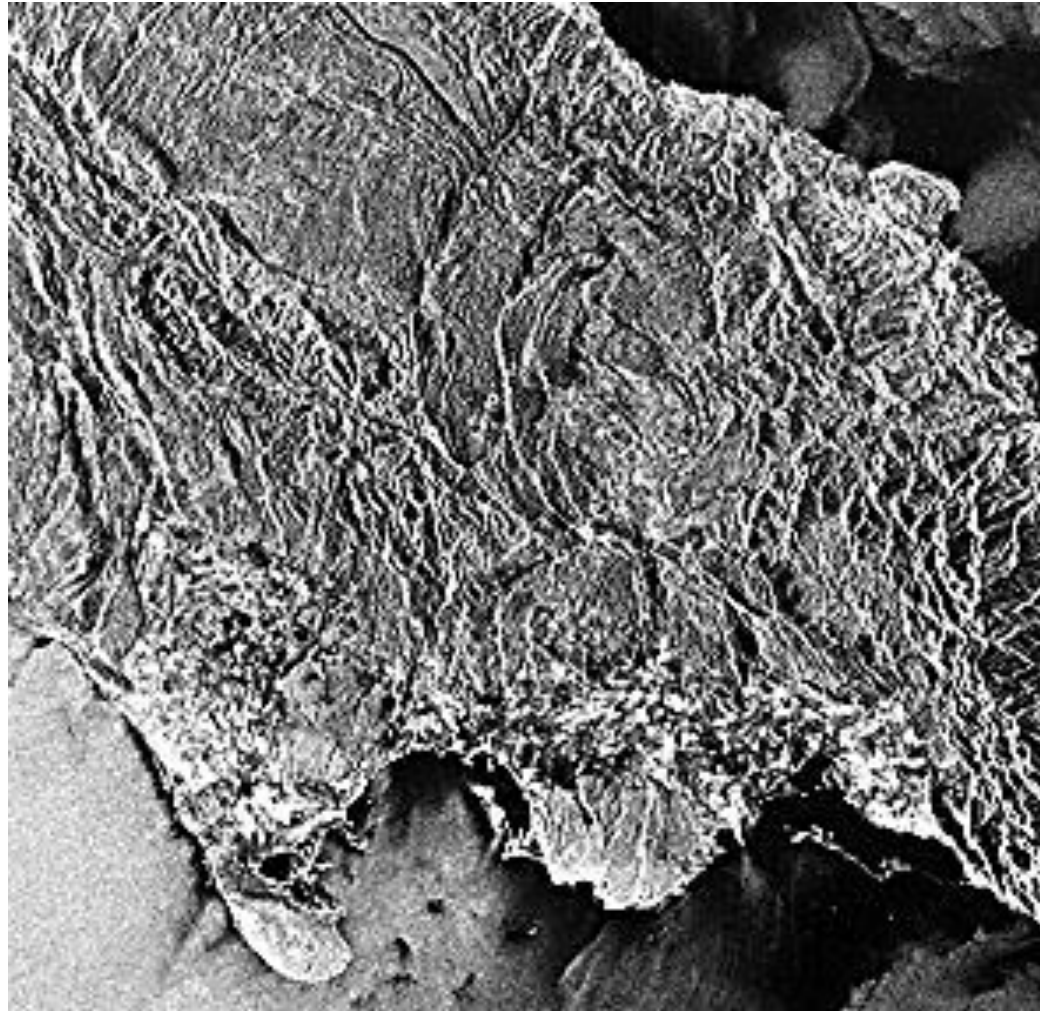


The "type locality" for karst terrain is in the Dinaric Alps of Croatia, where Mesozoic limestones are notably pitted by solution, as seen in this astronaut photo:





The karst topography in this scene appears in the darker-toned surfaces. These karsts are a thick series of carbonate rocks that elsewhere in the image have their outer rock removed to expose older non-carbonates underneath



The island of Jamaica in the Caribbean is composed mostly of limestones. As such, it is subject to intensive karst development in response to high annual rainfall. This Seasat radar image shows the typical karst topography developed under subtropical conditions.

perspective view of Jamaican cockpit karst using IKONOS and DEM inputs



FOUR TYPES OF KARST TOPOGRAPHY

1. True Karst, 2. Tropical Karst, FLuviokarst, 4. Glaciokarst

1.True Karst:

Jugoslavian Karst topography is called True Karst. It is developed in Limestone mountainous regions.

Deep cavities and solution dolines (sinkhole) are common. Surface streams are absent and underground drainage is not a reflection of surface features

2. Tropical Karst

Cone karst and tower karst are common.

Cone Karst is the assemblage of peaks and intermittent depressions resembling egg box

Tower karst are steep sided hills of hums studded in alluvial plains

Tropical karst extensively developed in southern China

Cone Karst



Tower karst



3. Fluviokarst

In the areas of western and central Europe and the USA, both solutional and fluvial activity are seen.

Limestones are less developed. River gorges and dryvalleys are common.

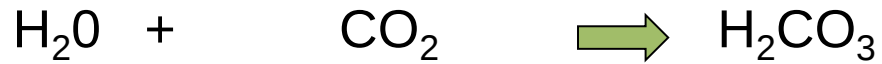
Disappearance and resurgence of streams, springs, blindvalleys and sinkholes are common features. Caves are characteristic features of fluviokarsts and soil cover is thicker

4. Glaciokarst

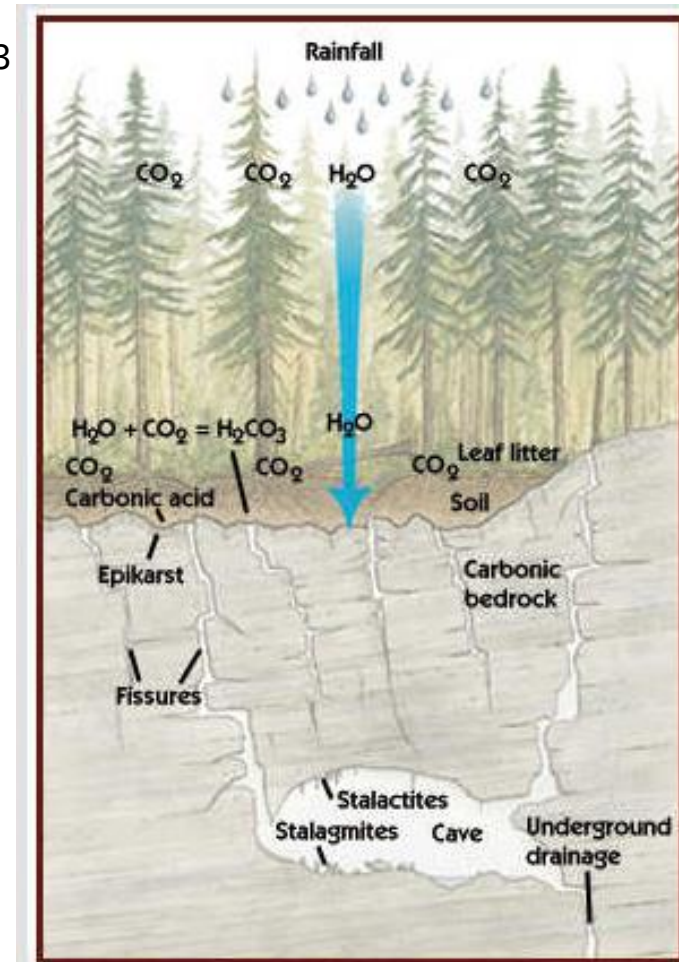
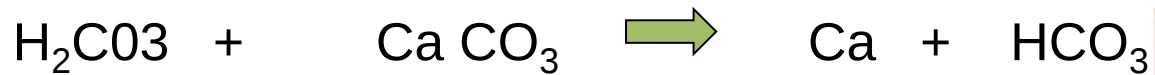
Glaciokarst seen in periglacial, glacial and permofrost regions are with limestone pavements, dolines and potholes

Dissolution Reactions

- water + carbon dioxide $\longrightarrow$ carbonic acid



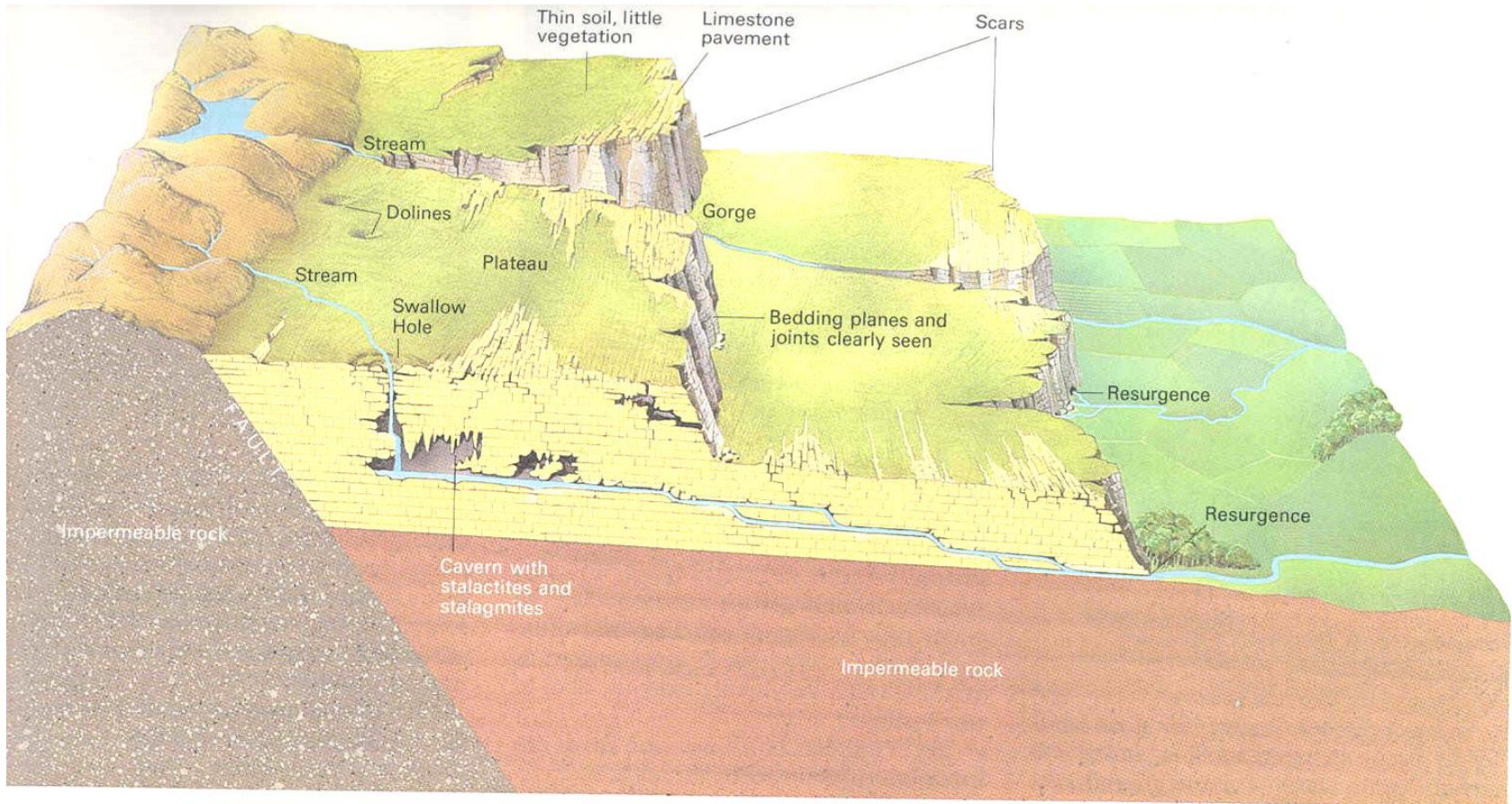
- carbonic acid + limestone $\longrightarrow$ calcium + bicarbonate



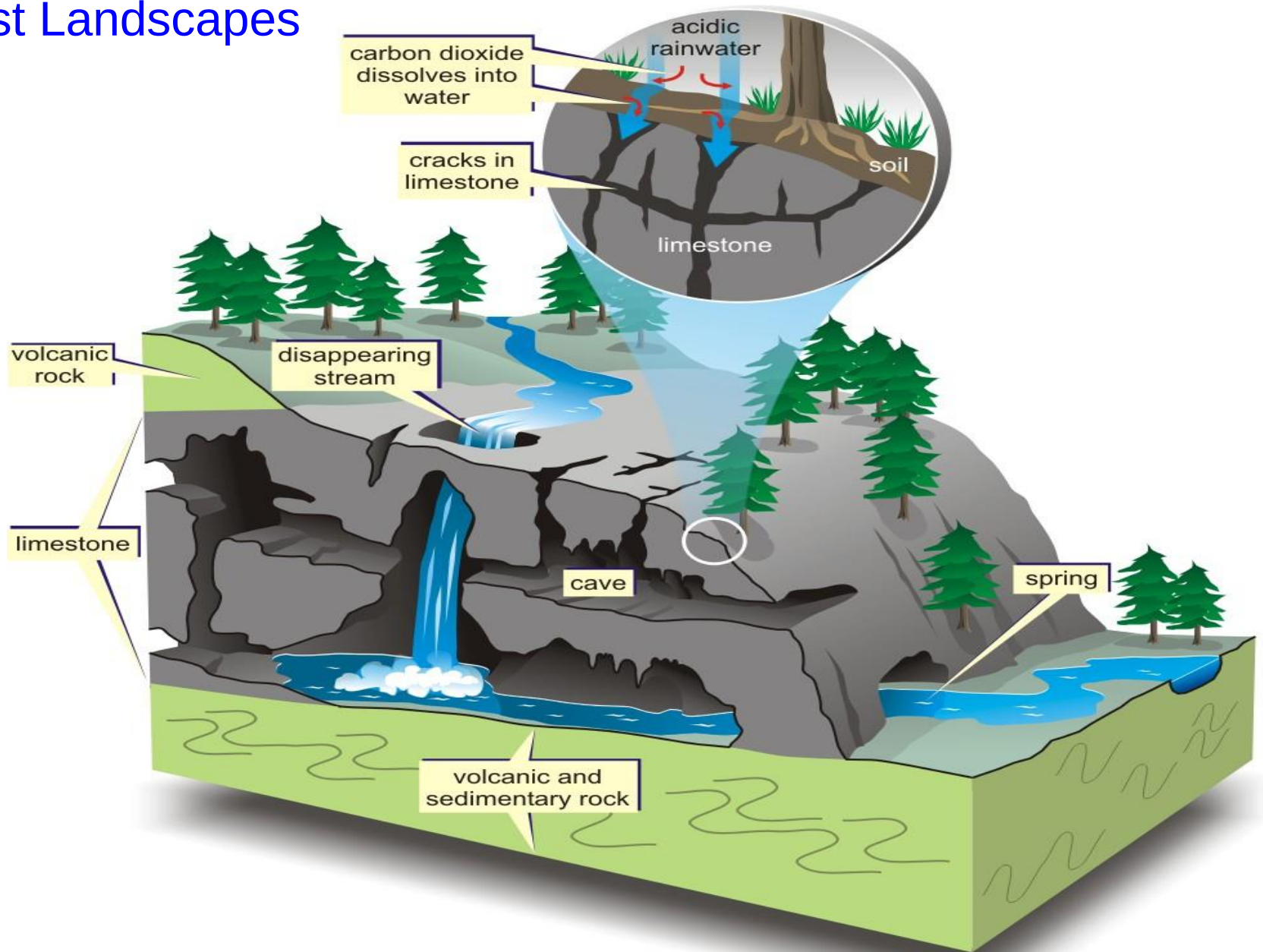
Karst topography

Generally associated with

- ❖ Numerous caves, springs, solution valleys, sinkholes, and disappearing streams



Karst Landscapes

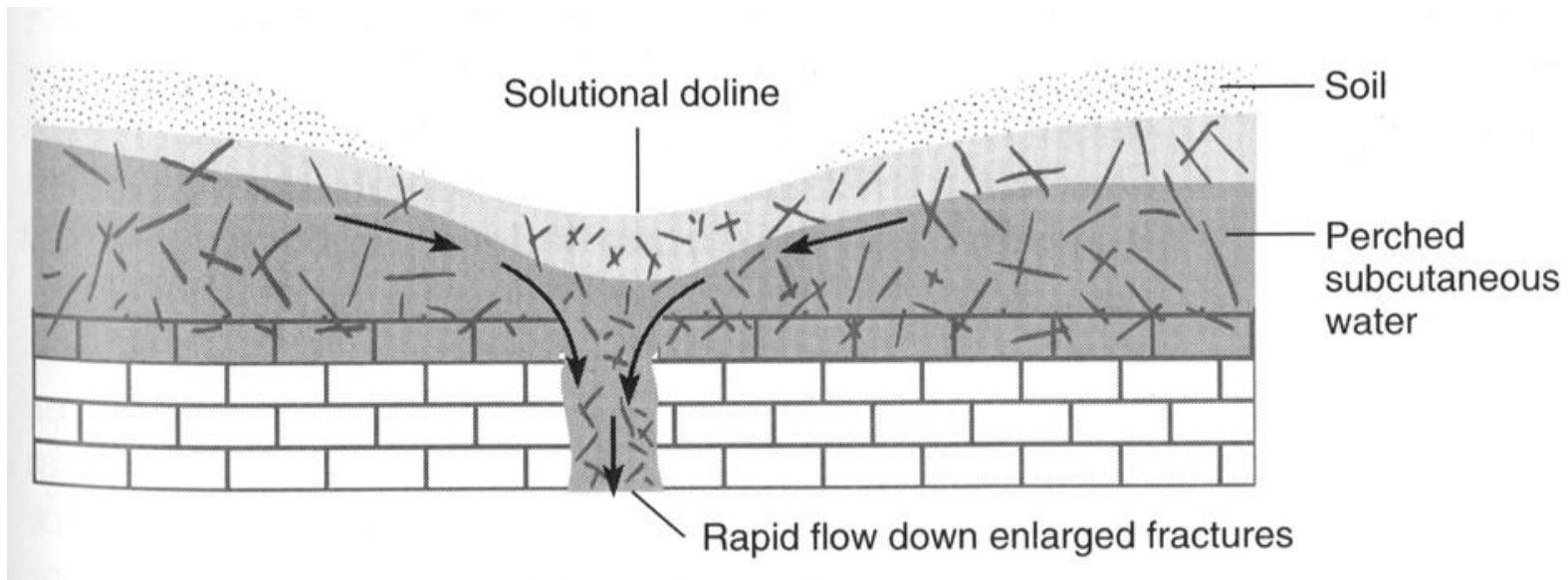


Karst Landforms

Sink holes: are large solution cavities. In karst regions, sinkholes are numerous and in some sinkholes streams may disappear

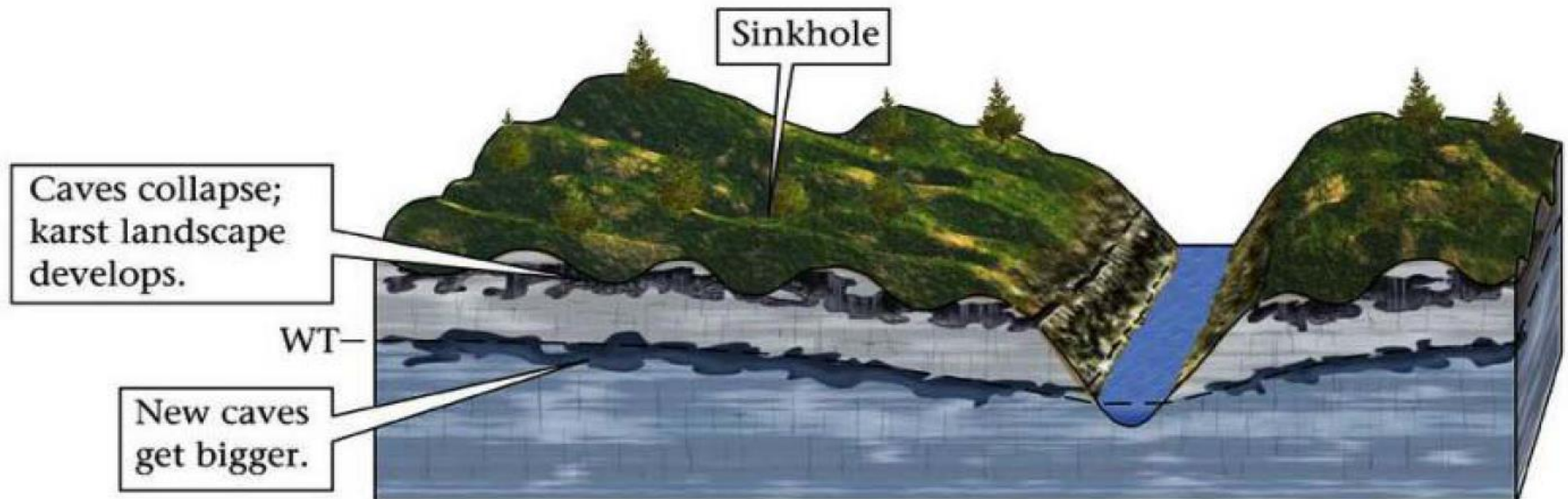
Dolines or Solution sinkholes: Sink holes developed mainly by solution activity are known as Dolines. These are generally shallow basins to depth of 2-100 m and are 100 – 1000 m across. The sides are rocky or covered with vegetation

Concentration of joints are suitable place for Doline development



Solution sinkholes

- Formed by dissolution along joints
- Near vertical
- Funnel-shaped
- Most common on
 - flat terrain and elevated plateaus lacking surface drainage



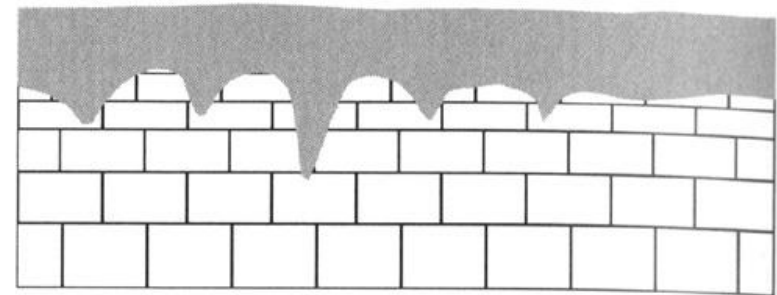
Collapse Sinkhole

Collapse Sinkhole: material fails into subsurface cavity previously created by dissolution

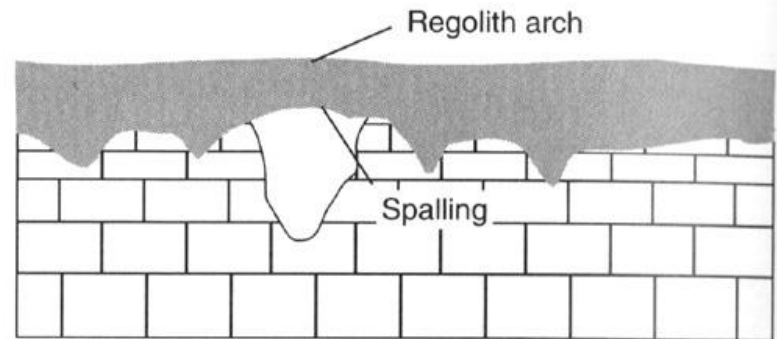
Removal basement causes subsidence of roof and as a result of a depression on the surface, it is known as **Collapse Sinkhole**

Collapse Sinkholes

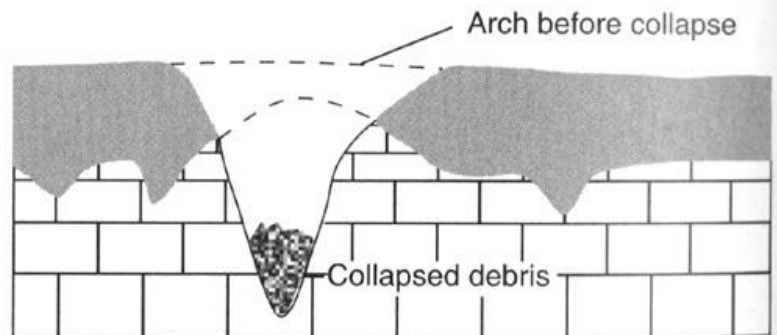
- Near-vertical walls
- Roof collapse over solution cavities
- Rapid collapse
 - Often associated with groundwater lowering
 - Filled with blocks of overlying bedrock
 - Common in Florida



(A)



(B)



(C)

Karst Hazards – Sinkhole Collapse



Winter Park, FL



Crooked Lake, FL



Tucson, AZ ----Karst??



Guatemala City

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

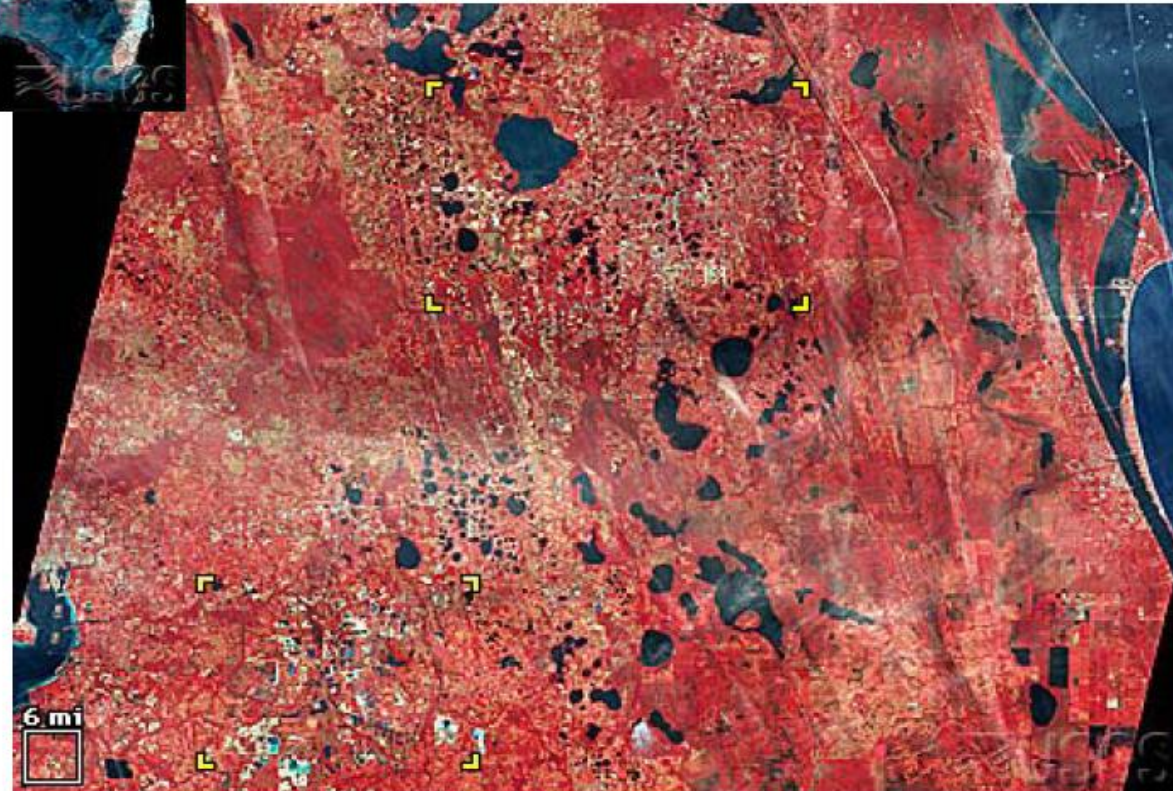
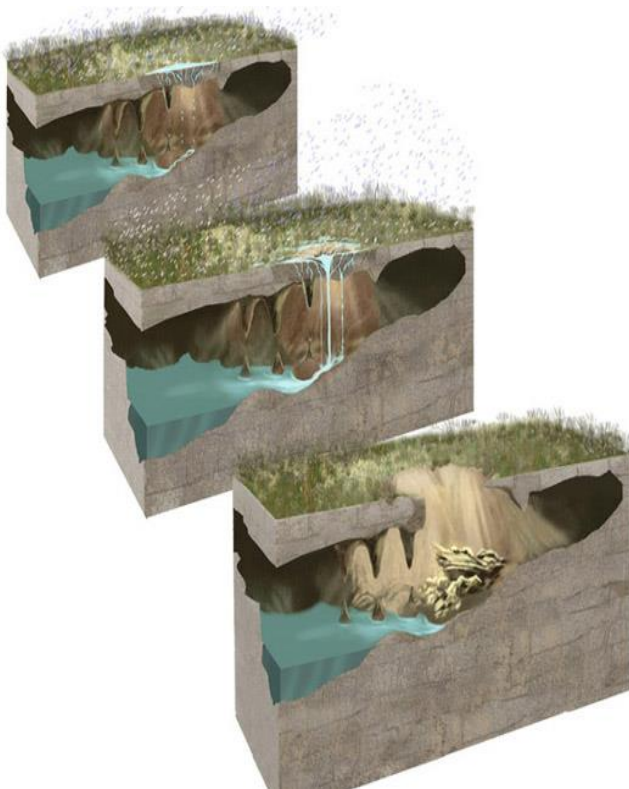




Winter Park, FL sinkhole

- Collapse sinkhole
- Florida is predominantly limestone
- High rainfall and warm temperatures
- Active karst formation

■ Collapse Sinkhole, South Australia



- Uvala is simply a compound sinkhole
 - Enlargement and coalescence of smaller sinkholes
 - Irregular in shape
 - Several square km
 - Up to a few hundred meters deep



Polje

- is a large closed depression formed by solutional processes
- Broad flat alluvial floor that may flood during wet periods
- Contain blind valleys
- Often related to geologic structure (folding)
- Up to 60 km in length and up to 5 km wide

Sinkhole Flooding



Sinkhole plain before a rain.

Sinkhole plain after a rain.

- **Blind Valley:** A valley that end abruptly where stream vanishes underground.
- **Sinking Stream:** stream that vanishes underground, usually at terminus of blind valley.
- **Resurgence:** point where waters from sinking stream reemerges from underground.
- **Dry Valley:** Valley that no longer exhibits channelized flow.
- **Cave:** A natural underground room or series of rooms large enough to be entered by a person.
- **Swallet (swallow hole):** A place where water disappears underground in karst region. Swallet commonly used to describe loss of water in stream bed.

Swallow Hole

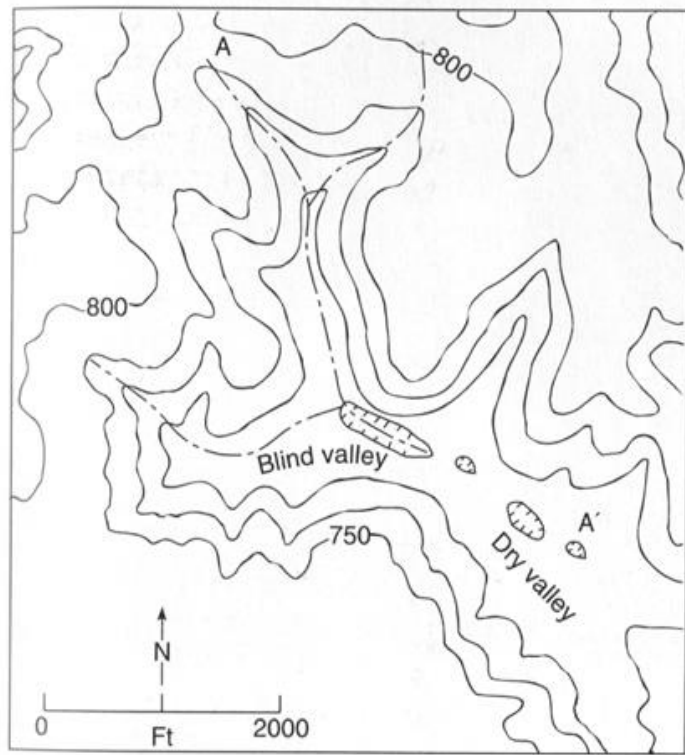


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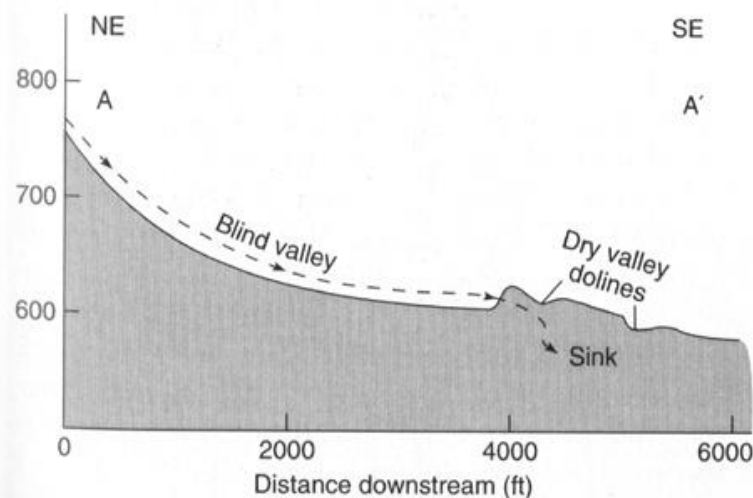


Blind Valley

- A sinking stream flows into groundwater system
- Upstream is called a blind valley
- Downstream is called a dry valley



(A)



(B)

DIAGRAM SHOWING LIMESTONE CAVERN ENVIRONMENT

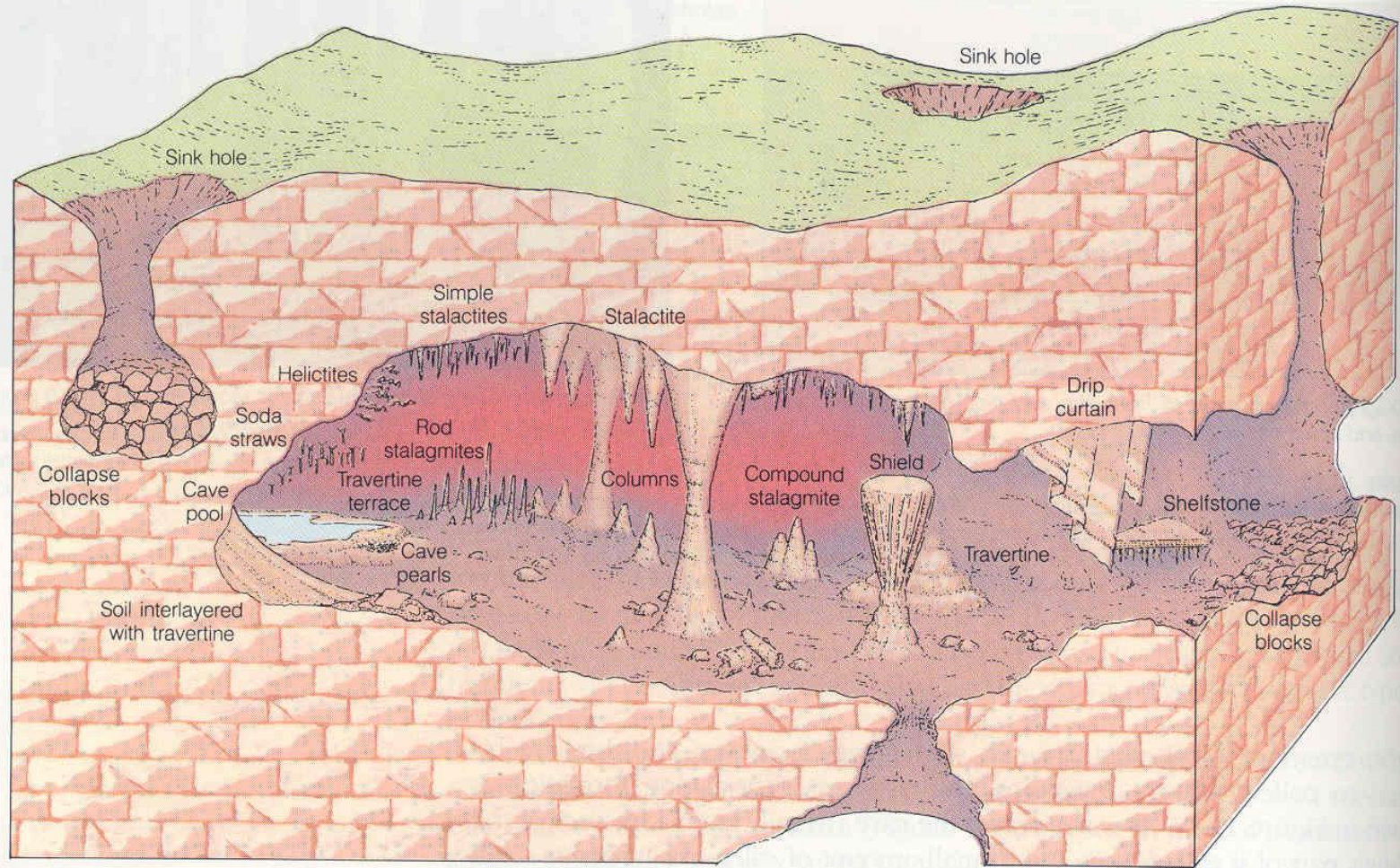
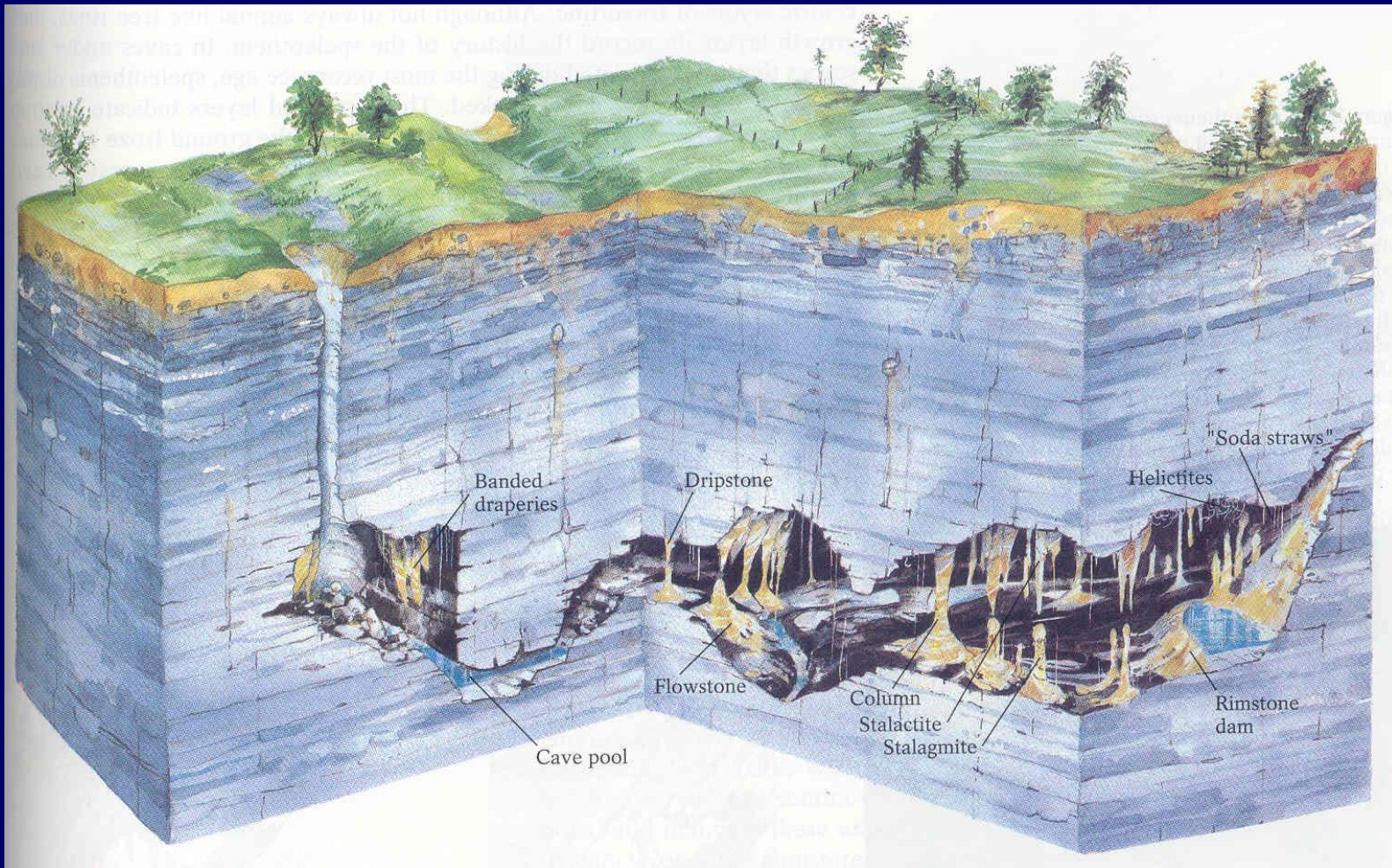


DIAGRAM SHOWING LIMESTONE CAVERN ENVIRONMENT



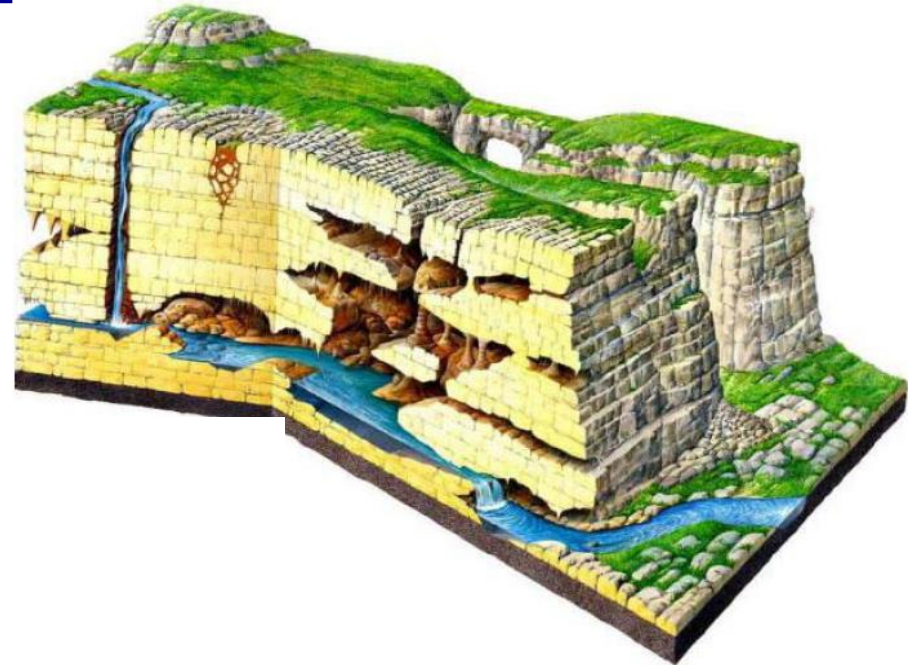
Epigenic and Hypogenic Caves

■ Epigenic:

- Movement of water from overlying or adjacent recharge surfaces
- 90% of caves
- Atmospheric and biologic CO_2 source for aggressive waters

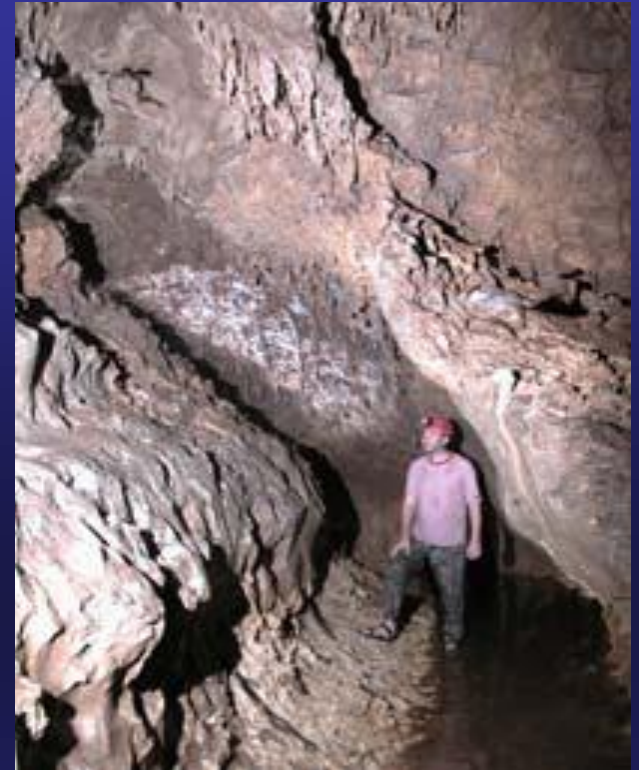
■ Hypogenic:

- Deep-seated water sources
- 10% of caves
- Hydrosulfuric acid (H_2S) and igneous carbonic (H_2CO_3) acid
- Carlsbad Caves, New Mexico

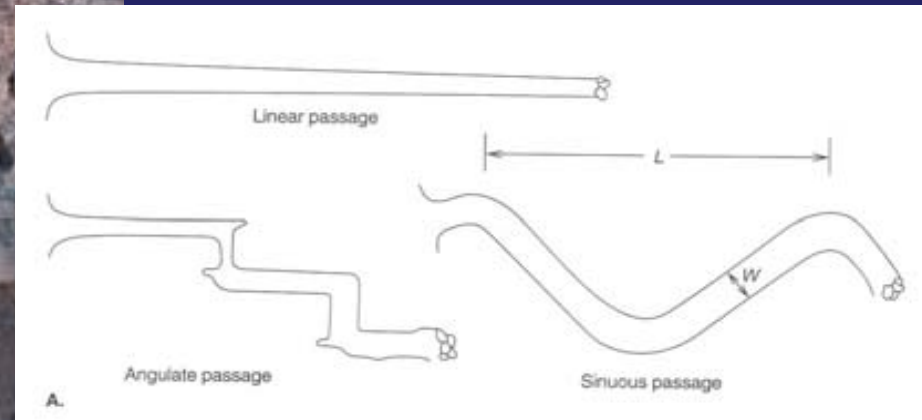


Cave Formation

- Form in 10^4 to 10^5 years (typo p. 205)
- A cave is a solutional opening large enough for a person to enter
- Consist of
 - Passages – longer than they are high
 - Rooms – higher than wide

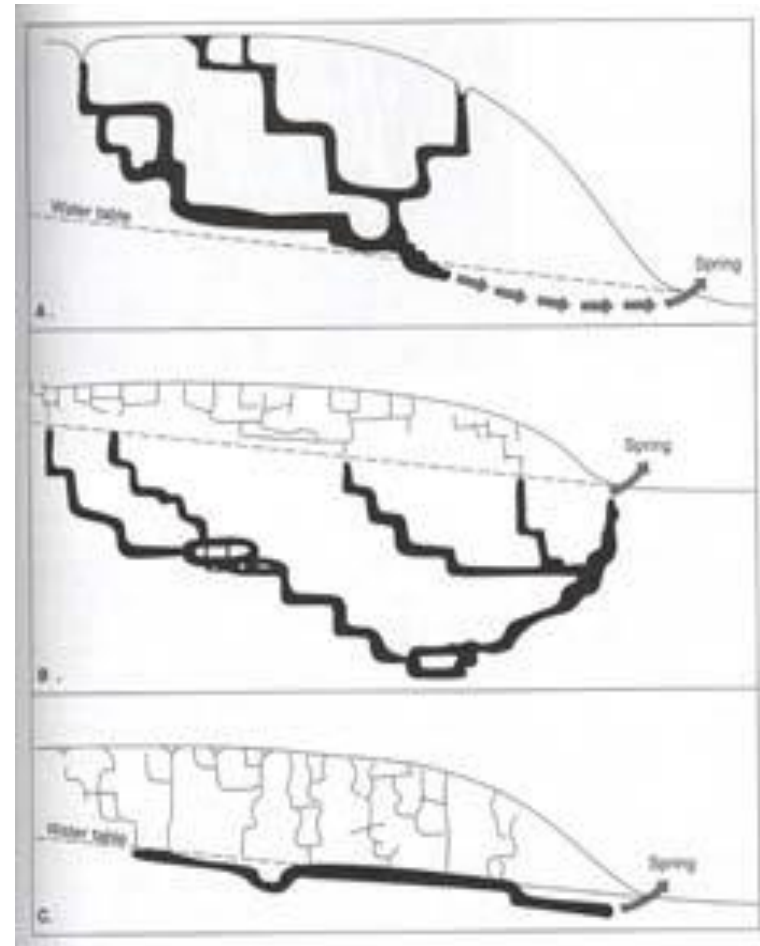


Sinuous Cave



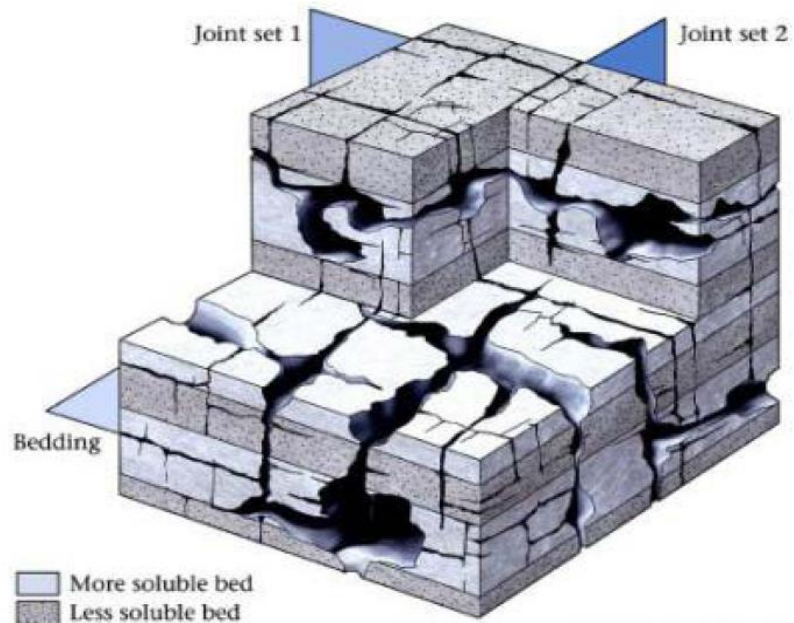
Three principle theories of Cave origins

- 1) Form above water table by *vadose water* (unsaturated zone water)
- 2) Form beneath water table by circulation of *phreatic water* (=saturated zone water)
- 3) Form at water table = *water table caves*

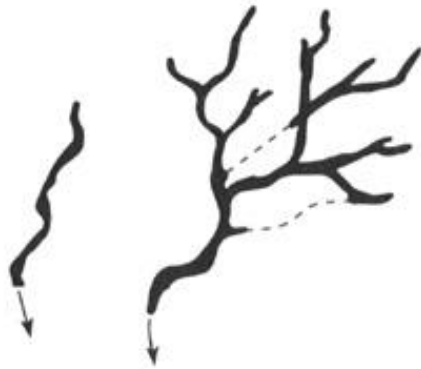




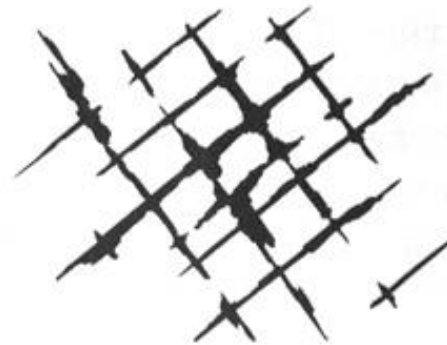
WATER TABLE CAVE



Cave Patterns



Branchwork



Network maze



Anastomotic maze



Spongework maze

Reprecipitation in Caves

When groundwater with dissolved Ca and 2HCO_3 seeps into an open cavity, it releases CO_2 and deposits CaCO_3 and create various type of landforms (Speleothems).

Speleothems

- Stalactites
- Stalagmites
- Columns
- Flowstone
- Cave popcorn
- Helictites



Speleothems

Calcite deposits formed by dripping water are called speleothems



Speleothems

deposits in caves

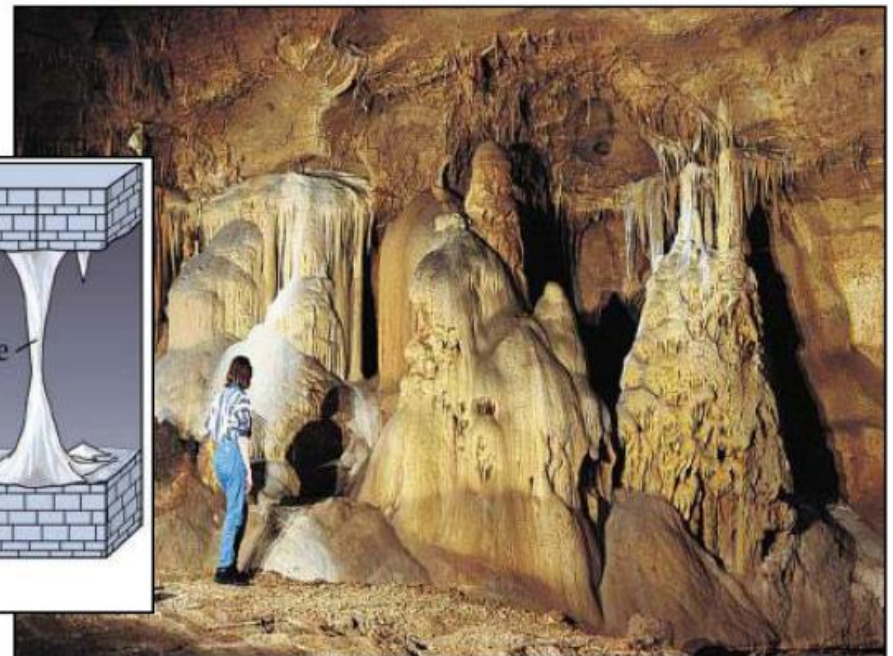
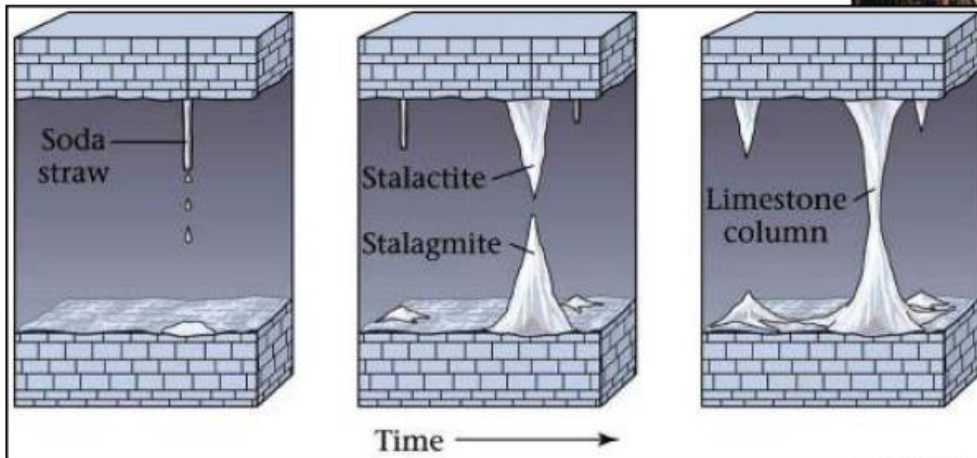
- Stalactite- icicle like deposit from dripping water from cave ceiling
- Stalagmite- same as above but builds from cave floor up
- Flowstone- produced by flowing water over a wall

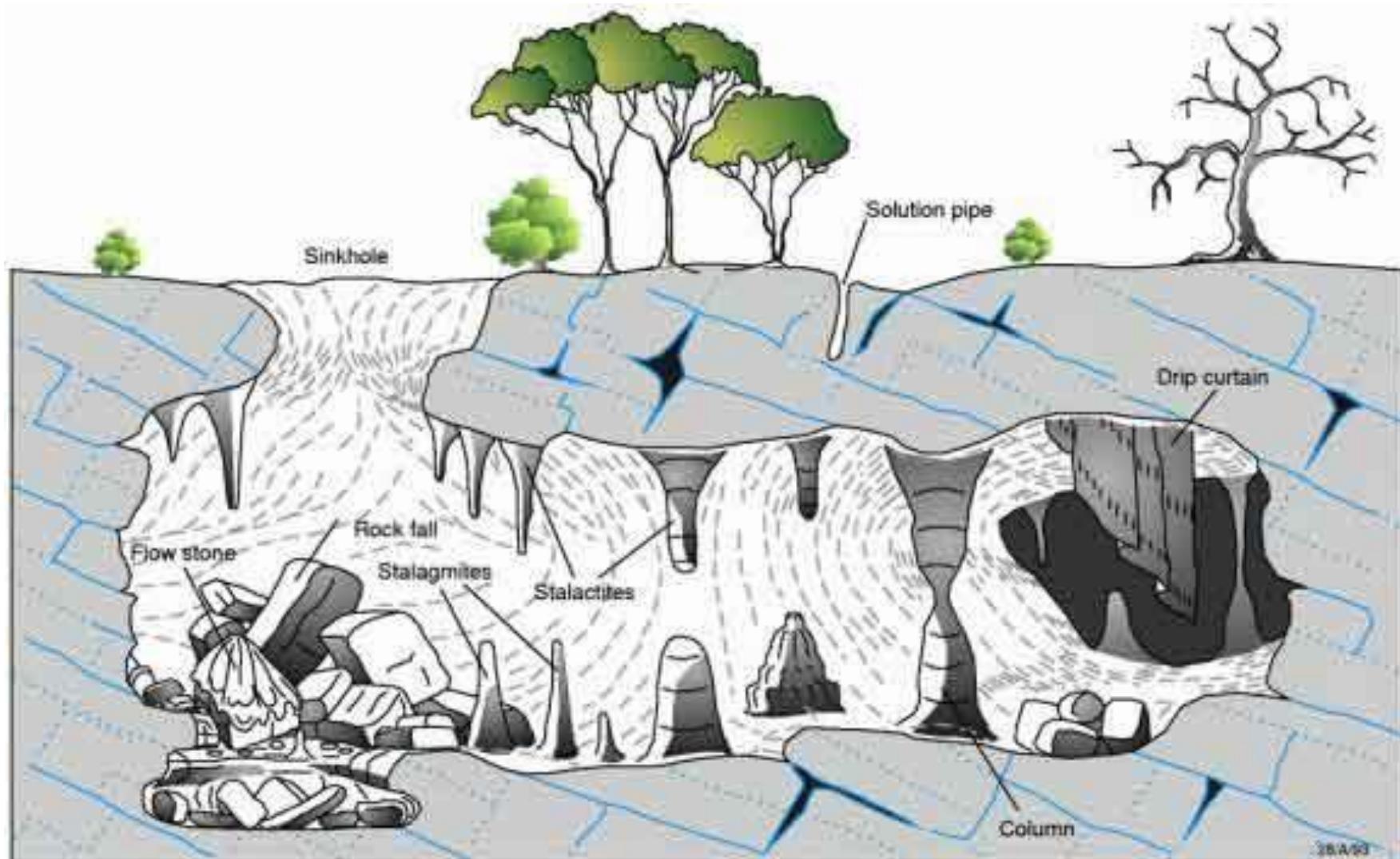
Caves and Karst

■ Speleothems are formed from precipitation of dripstone.

- ▶ Stalactites – Hang down.
- ▶ Stalagmites – Point up.
- ▶ Columns.

Kartchner Caverns State Park, Arizona





Stalagmite- same as above but builds from cave floor up

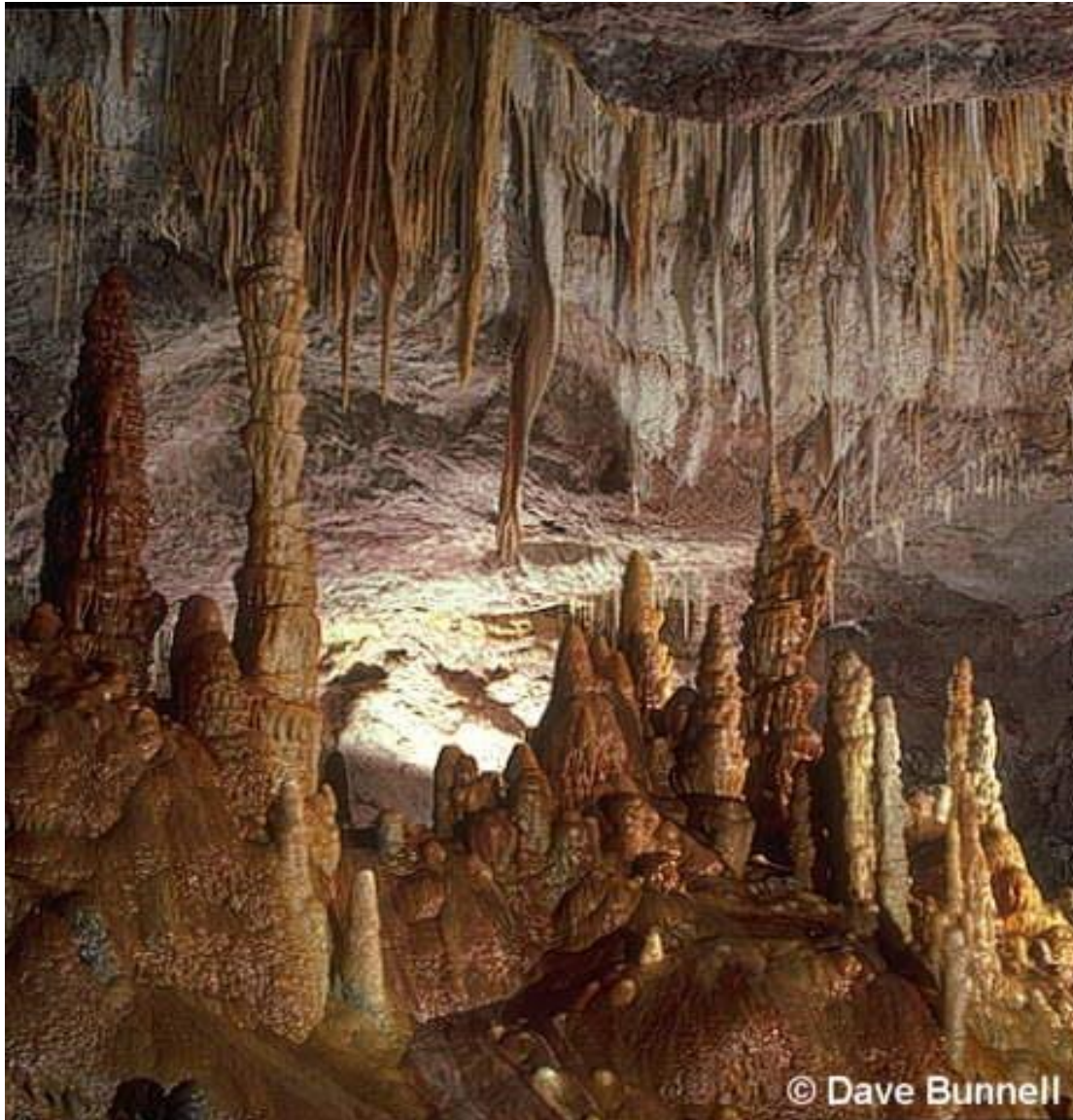


- **Stalagmite**- same as above but builds from cave floor up



Stalacmite





Stalactites
and
Stalagmites

© Dave Bunnell



‘Column’

Stalactites hanging from the cave ceiling and stalagmites growing upward from the floor merge to form a column



**Column – a joined
stalactite and
stalagmite**

Drip of a drop

Drop of water collects at the end of a growing stalactite. As the water loses carbon dioxide, a tiny amount of calcium carbonate precipitates from the solution and is added to the end of the dripstone formation



CARLDSBAR CAVERNS, NEW MEXICO



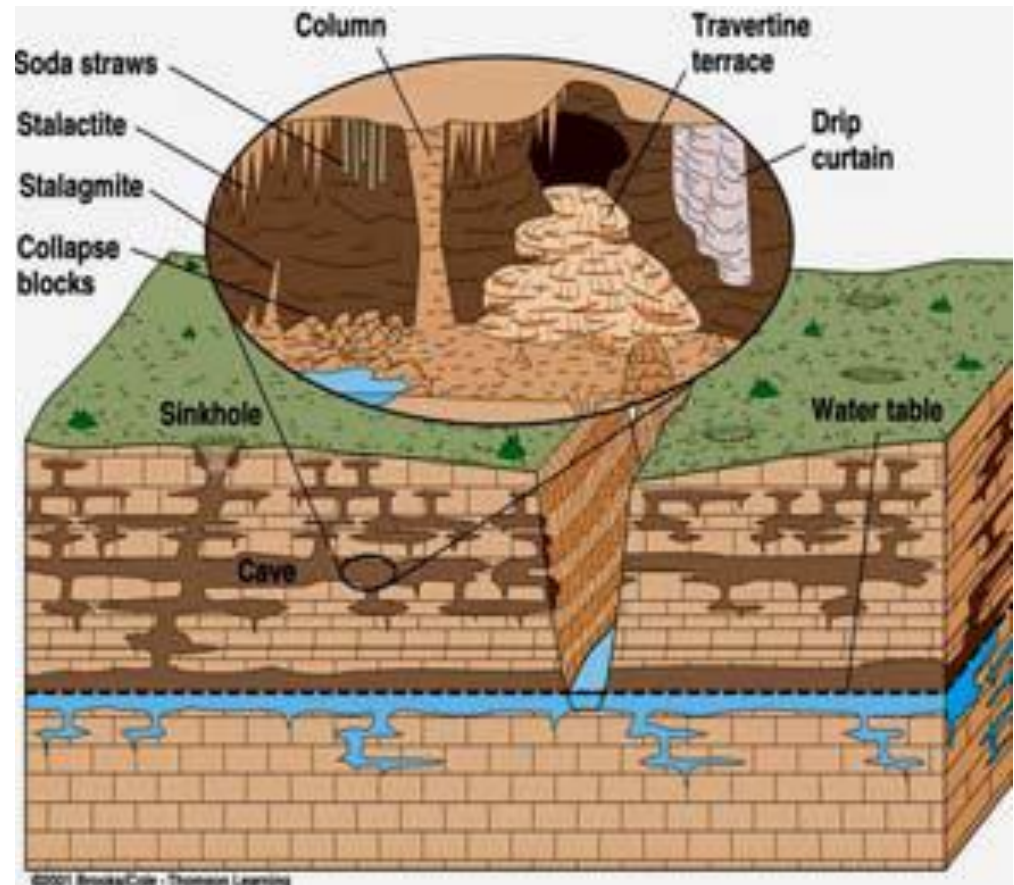
show many of the forms of dripstone. Dripstone originates on the ceilings of caves. Water seeps through a crack and partially evaporates. This causes a small ring of calcite to be deposited around the crack. The ring grows into a tube, which commonly acquires a tapering shape as water seeps from adjacent areas and flows down its outer surface



Flow stone

**Flowstone- produced by
flowing water over a
wall**

DRIP CURTAINS: are the curtain like deposits hanging from the ceiling formed by the percolation of water through fractures



‘Helictites’



Helictites form by capillary action and can grow in any direction

Cave 'Pearls'



Cave pearls form when layers of travertine precipitate around a sand grain or similar particle

Cave 'Popcorn'



Giant cave popcorn forms by the precipitation of travertine at the surface openings of large speleothems

Karst Window (skylight)



THANK YOU

Form when roof collapses over a cave stream