# BHARATHIDASAN UNIVERSITY

## Tiruchirappalli- 620024
## Tamil Nadu, India

**Programme : M.Tech., Geological Technology and Geoinformatics**

**Course Title : Geomorphology and Geodynamics**
**Course Code : MTIGT0506**

# Unit-5: Volcanic, Glacial, Groundwater and Biogenic Geomorphology


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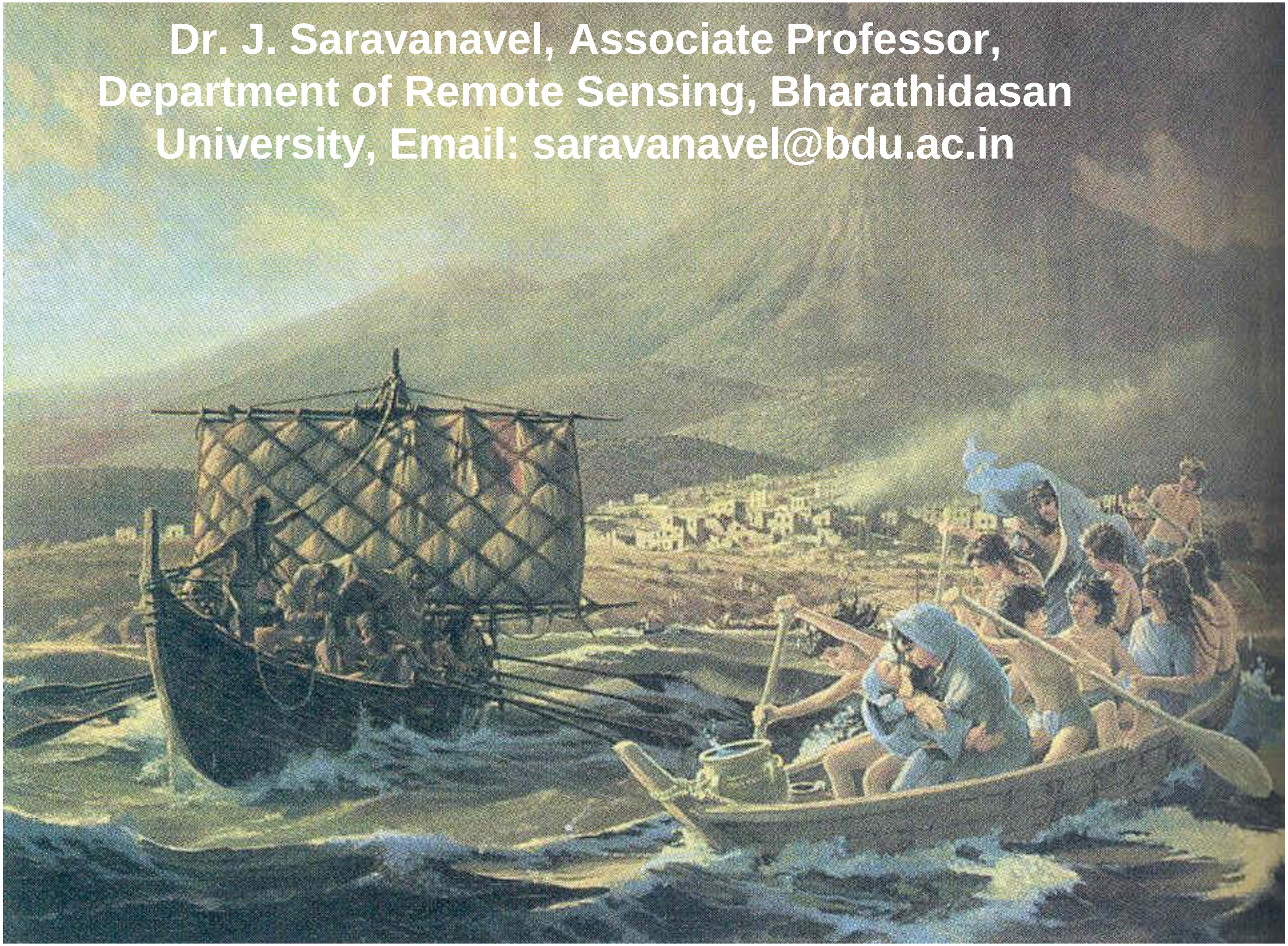
An artist’s rendition of the volcanic eruption on Thera that destroyed most of the island in about 1390 BC. Most of the island’s inhabitants escaped the devastation



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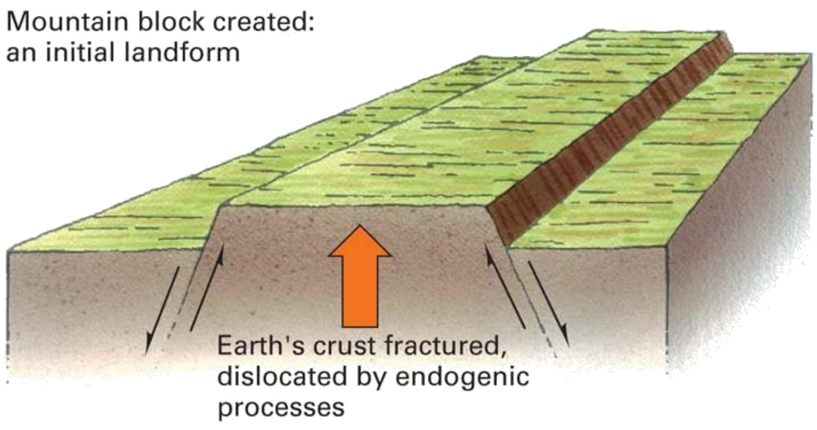
# Continental landforms are the result of endogenic and exogenic processes.

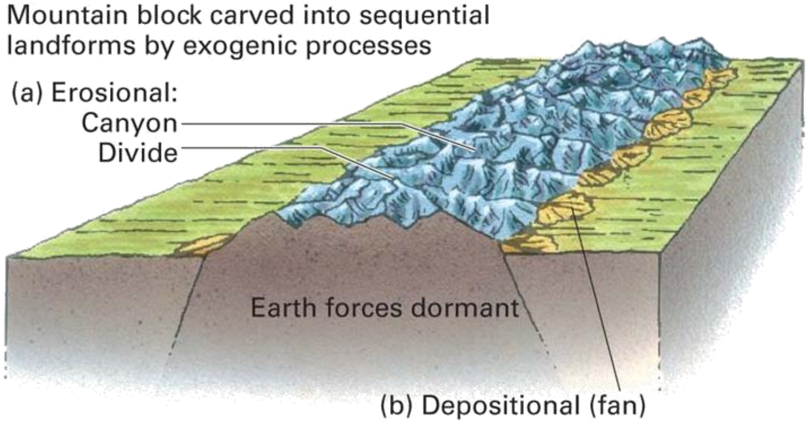
## *Endogenic* process: works from within the Earth

- Produces *initial landforms*
- Uplifts; brings fresh rock to the surface
- Powered by Earth's internal energy

## *Exogenic* process: works at Earth's surface

- Wears down initial landforms
- Creates *sequential landforms*



**A VOLCANO is a vent in earth's crust through which molten rock, steam, gas, and ash are expelled**

**volcano:** **opening in Earth's crust through which molten rock, gases, & ash erupt to the land around the opening**

**Volcanoes is the Windows of Earth's interior**

- **Help us understand plate tectonic process and mantle convection**
  - ***At present, but also millions to billions of years in past using radioisotopic dating***
- **Impact Earth's atmosphere and hydrosphere**
- **Pose hazards to millions of people**
- **Geothermal energy sources**

  **Regions near hot springs and geysers have hot water that can be tapped and used to drive turbines to generate electricity.**

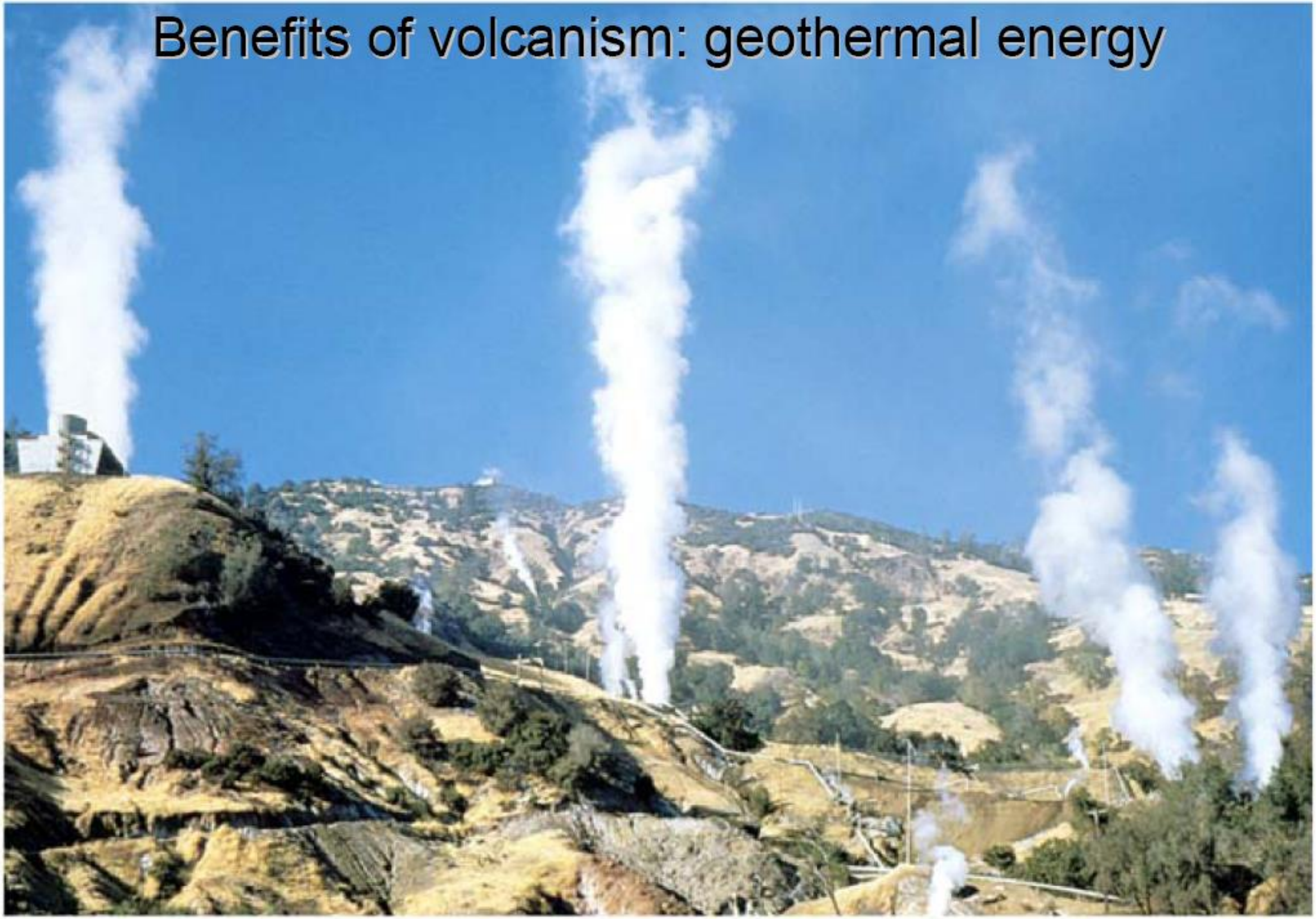
# Volcanic Hazards

- **Lava flows**
- **Pyroclastic flow and falls**
- **Ash flows**
- **Lahars and Debris Avalanches**
- **Volcanic gases**
- **Volcanic dome collapse**
- **Caldera collapse**
- **Eruption clouds**
- **Landslides**
- **Seismicities**
- **Tsunami**

## Resources

- volcanic soils
- industrial materials
- ore formation
- geothermal energy

# Benefits of volcanism: geothermal energy



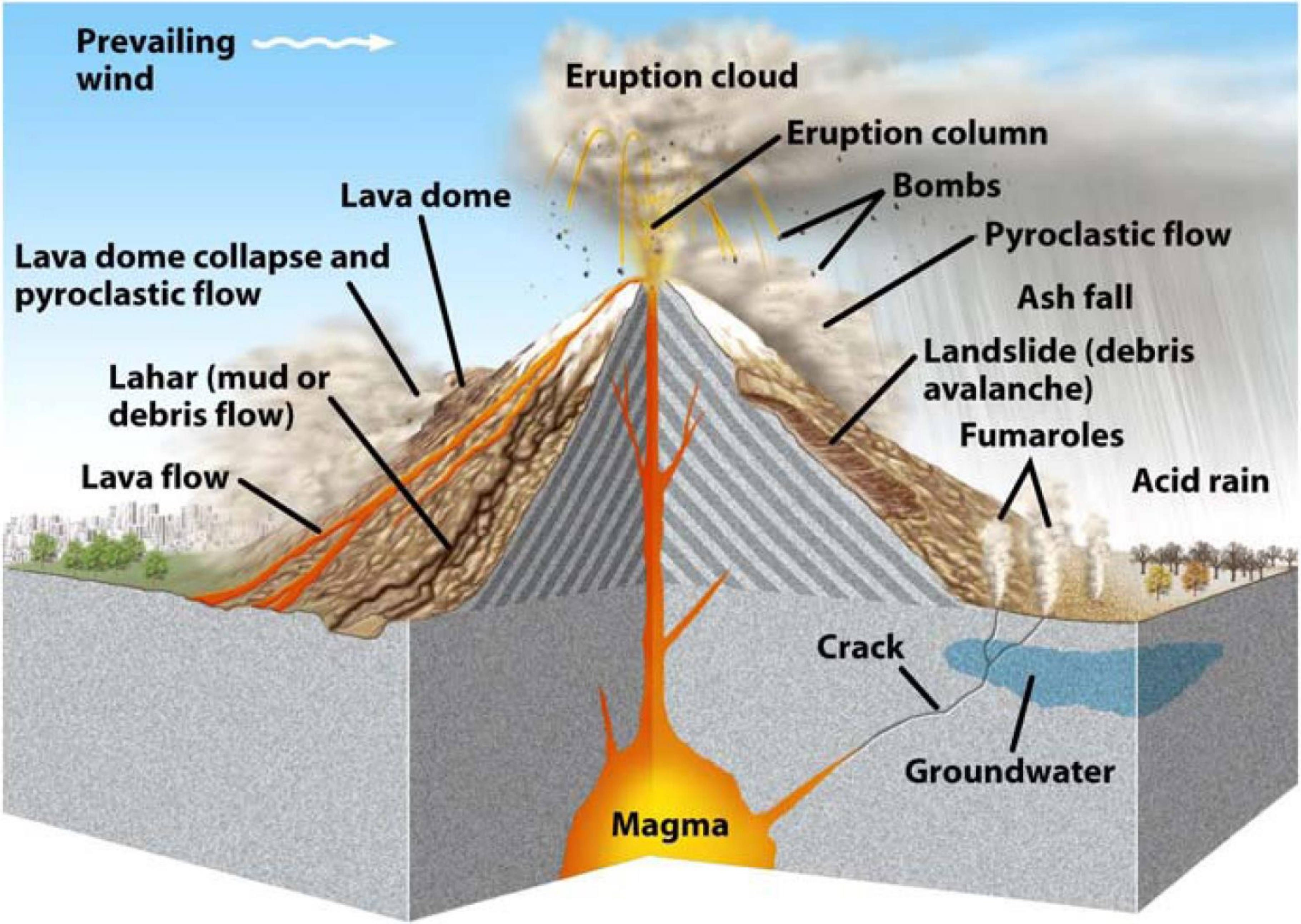
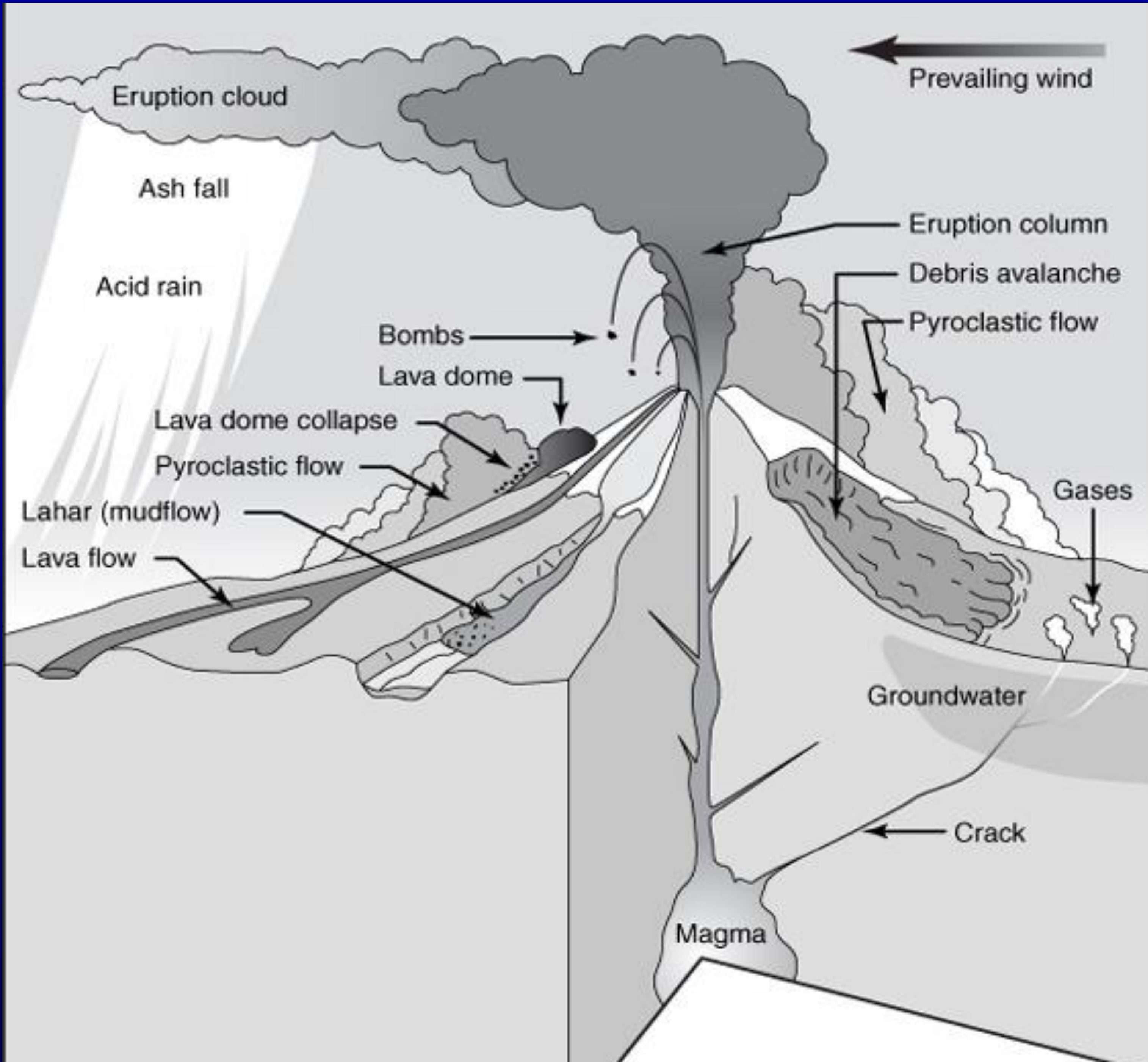



**Figure 12-25**
***Understanding Earth, Fifth Edition***


Eruption cloud
Prevailing wind
Ash fall
Acid rain
Eruption column
Debris avalanche
Pyroclastic flow
Bombs
Lava dome
Lava dome collapse
Pyroclastic flow
Lahar (mudflow)
Lava flow
Gases
Groundwater
Crack
Magma

## Magma Formation

A volcanic eruption occurs where magma (molten rock) rises to the surface.

Most of the asthenosphere is solid because of the pressure exerted on it by the lithosphere above it, but some materials do melt.

# Conditions for Magma Formation in the Asthenosphere

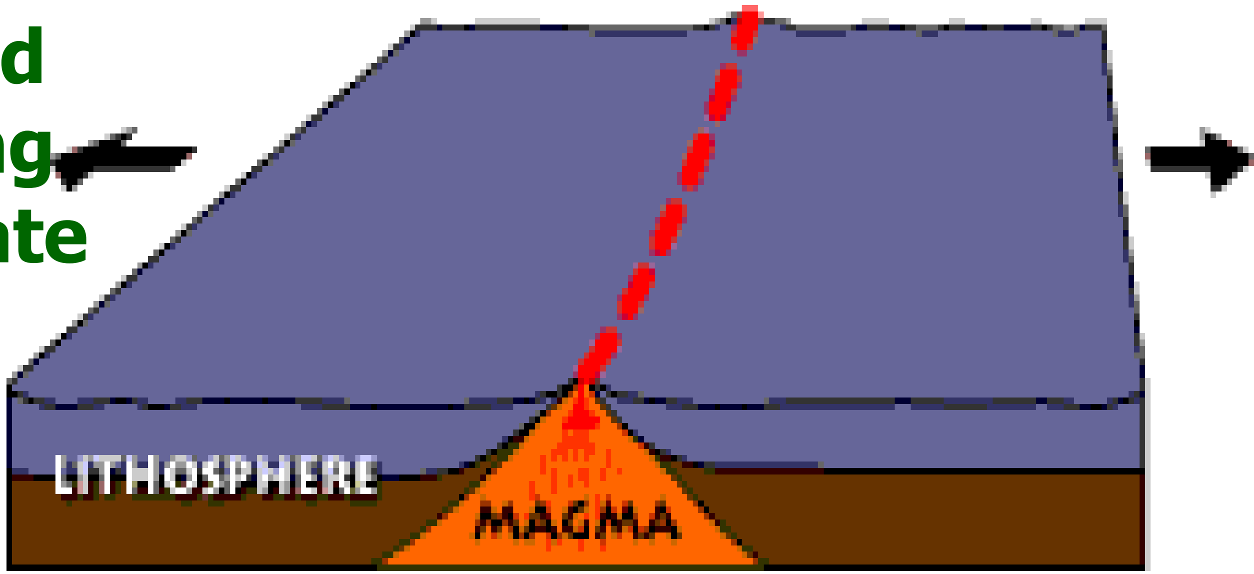
1. A decrease in pressure can lower the melting temperature of the materials.
   ➔ along rift valley at mid-ocean ridge where the lithosphere is thinner & exerts less pressure

2. An increase in temperature can cause materials to melt.
   ➔ at a hotspot

3. An increase in the amount of water in the asthenosphere can lower the melting temperature of the materials.
   ➔ At subduction boundaries

# Magma generation at mid-ocean ridges

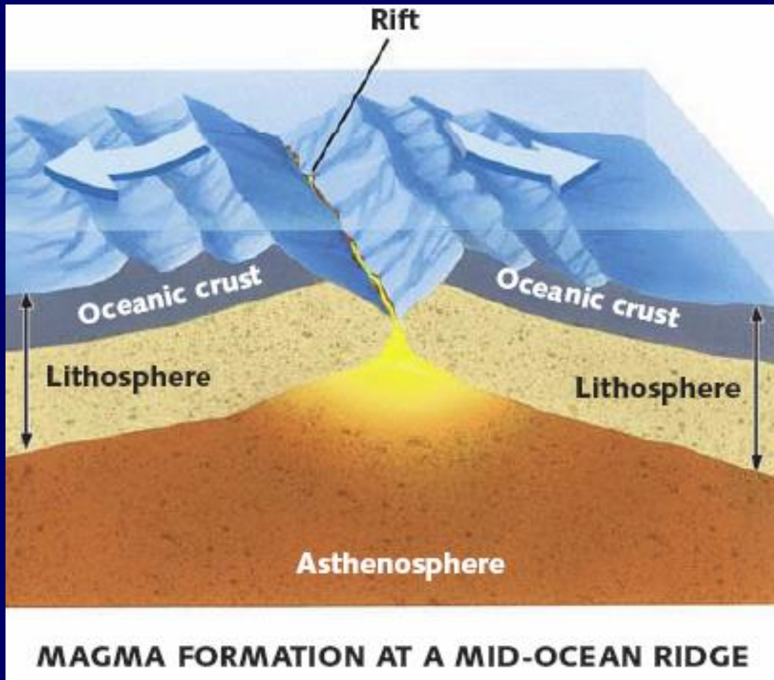
- **In these zones, the mantle rises and melts, producing magma of silicate composition**




- **the magma continues to rise, and erupts mainly as basaltic lava flows**

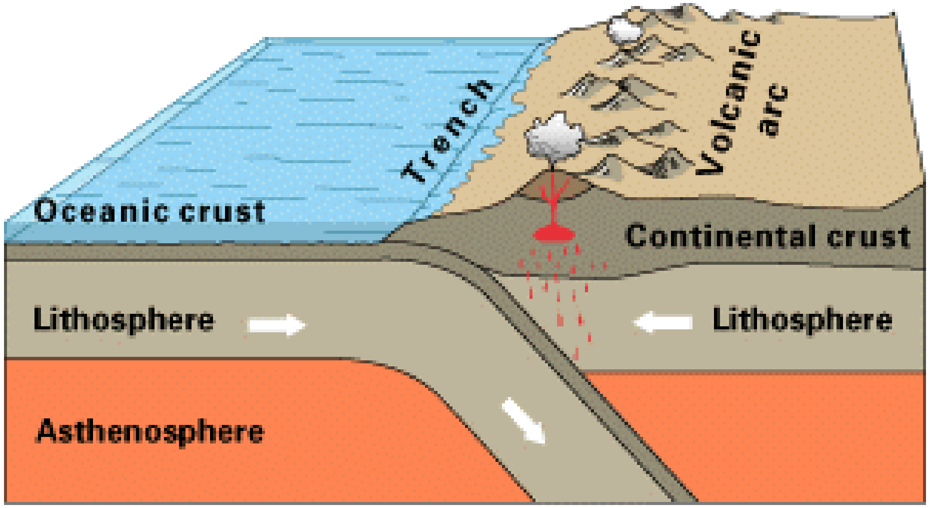
# At Divergent Boundaries


- Most magma that reaches the Earth's surface is at divergent boundaries along mid-ocean ridges
  - Most volcanic activity takes place beneath oceans
  - Iceland → Mid-Atlantic Ridge is ABOVE sea-level



# Magma generation at subduction zones

- During subduction, the subducted oceanic plate is heated as it plunges into the mantle
- At a depth of 80-120 km, melting begins, and volcanoes are produced which parallel the subduction zone

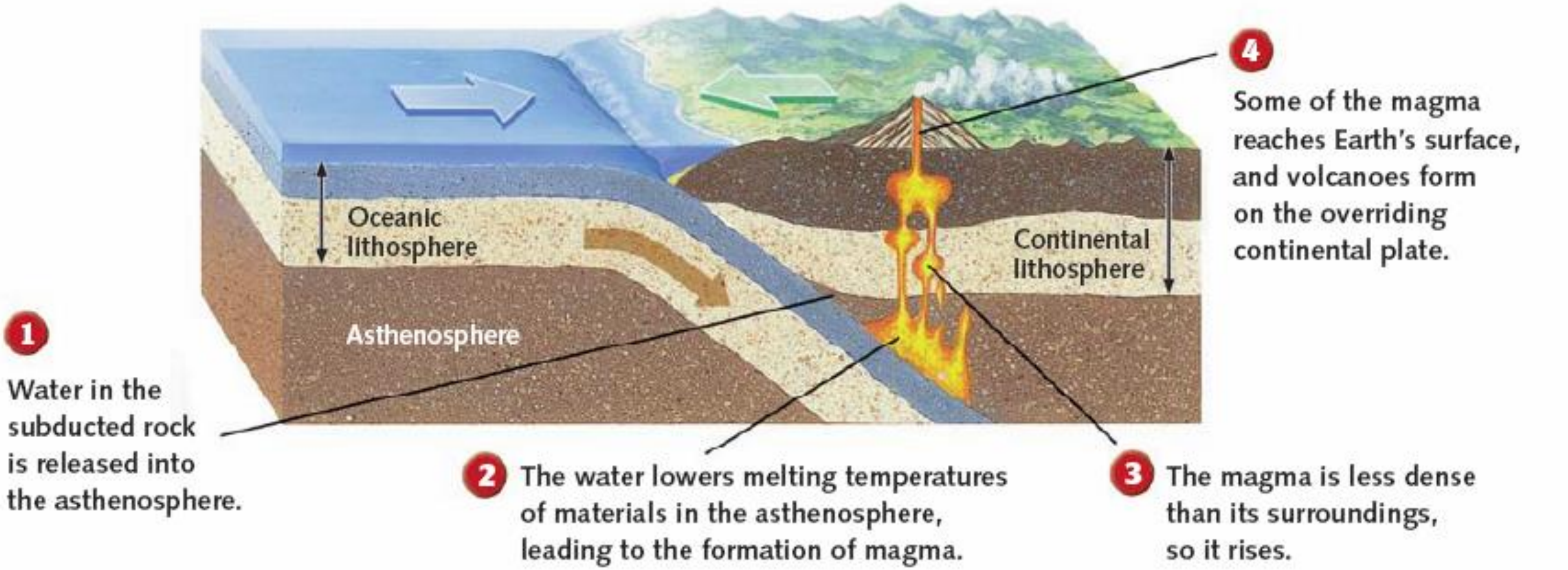



Oceanic-continental convergence

Andesitic magmas are typical of these volcanoes

# Volcanic Activity at a Subduction Boundary

## BETWEEN AN OCEANIC PLATE AND A CONTINENTAL PLATE

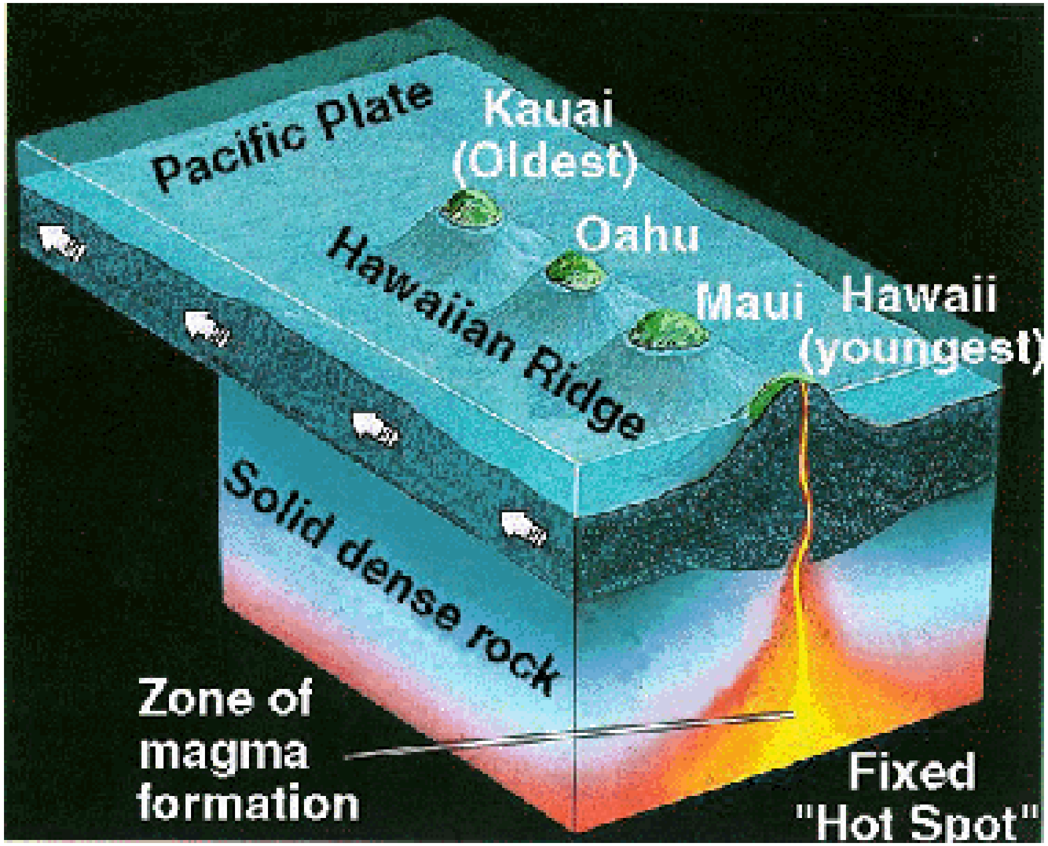



## BETWEEN OCEANIC PLATES

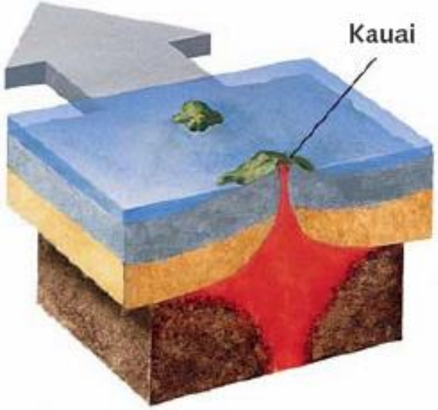
The process by which magma forms at an oceanic-oceanic subduction boundary is similar to the process at an oceanic-continental boundary. Notice that the difference between the two processes occurs at step 4.

# Magma generation at hot spots

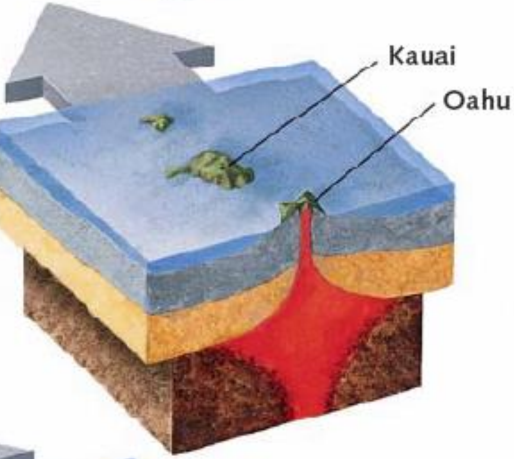
- Magmas at hot spots are derived from deep within the mantle
- the magmas are fed by deep mantle plumes which are stationary relative to the drifting tectonic plates



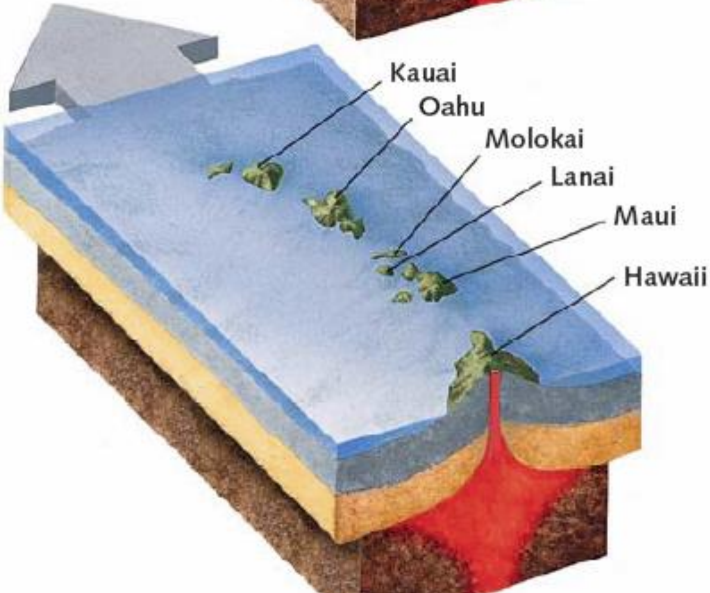
# Formation of Hawaiian Islands



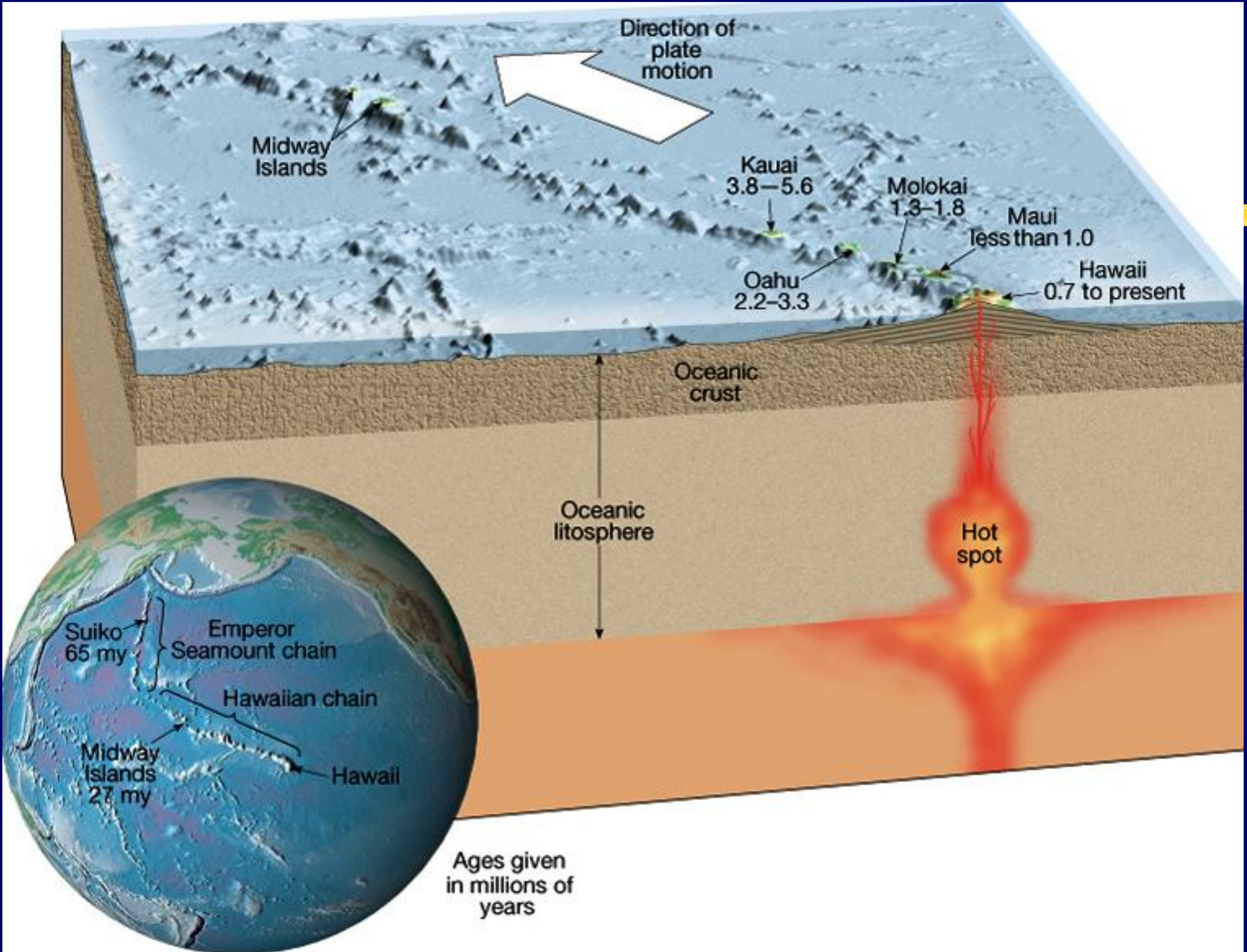

**5.3 TO 4.9 MILLION YEARS AGO** The island of Kauai formed as molten rock hardened and built up on the seafloor over the hot spot. As the plate moved northwest, it carried the island away from the hot spot.




**3.8 TO 2.5 MILLION YEARS AGO** The island of Oahu formed after the volcano on Kauai had moved away from the hot spot. Again, molten rock hardened and built up until Oahu rose above sea level.

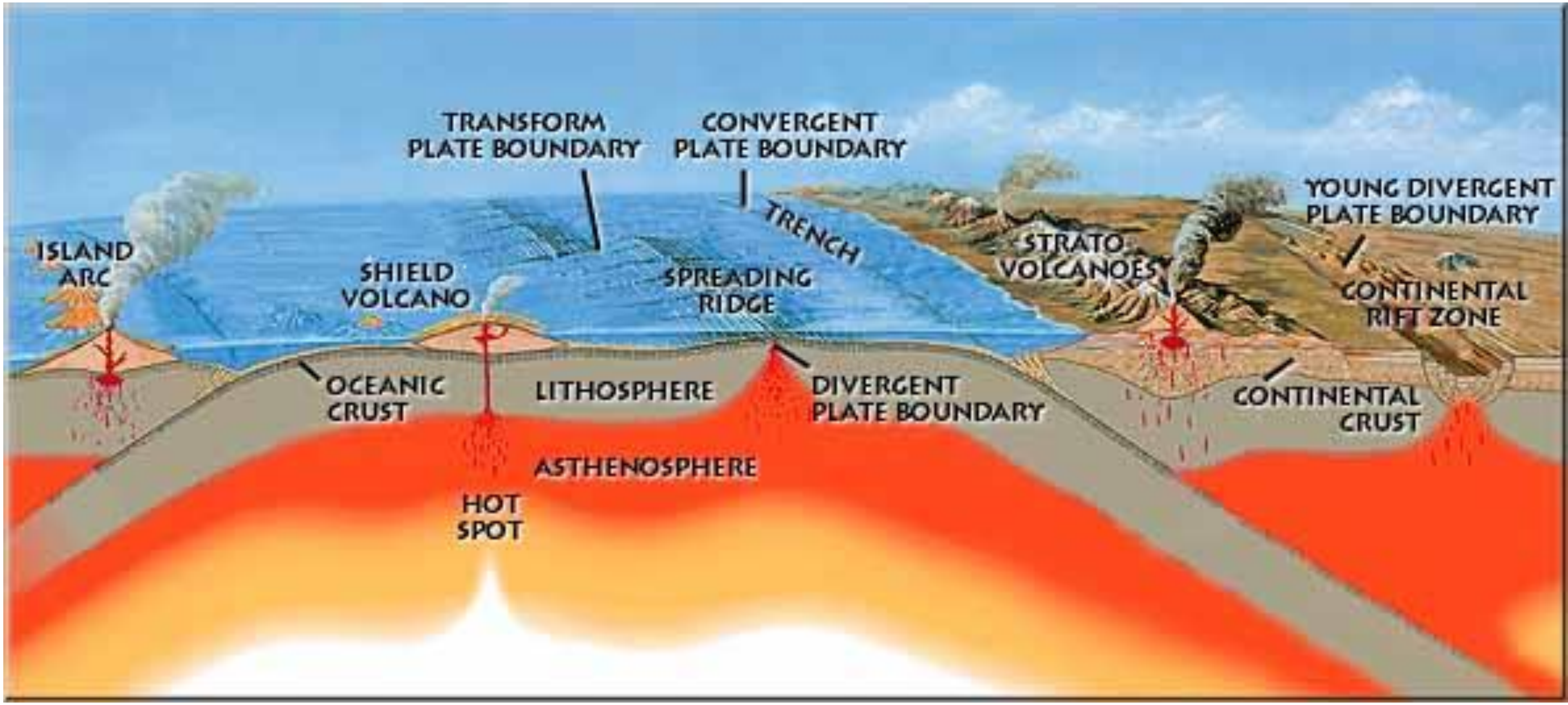



**TODAY** The island of Hawaii now sits over the hot spot. The hot spot fuels three active volcanoes, including one underwater (not shown here). This seamount is located to the east of the island.



Direction of plate motion
Midway Islands
Kauai 3.8–5.6
Molokai 1.3–1.8
Maui less than 1.0
Hawaii 0.7 to present
Oahu 2.2–3.3
Oceanic crust
Oceanic litosphere
Hot spot
Suiko 65 my
Emperor Seamount chain
Hawaiian chain
Midway Islands 27 my
Hawaii
Ages given in millions of years

# Plate tectonics and volcanism



## Factors that determine the violence of an eruption and viscosity

- Composition of the magma
- Temperature of the magma
- Dissolved gases in the magma

## Viscosity of magma

- Viscosity is a measure of a material's resistance to flow

- Factors affecting viscosity
  - Temperature (hotter magmas are less viscous)
  - Composition (silica content)
    - High silica – high viscosity (e.g., rhyolitic lava)
    - Low silica – more fluid (e.g., basaltic lava)
- Dissolved gases (volatiles) (Provide the force to extrude lava, Violence of an eruption is related to how easily gases escape from magma)
  - Mainly water vapor, Sulper, and carbon dioxide
  - Gases expand near the surface

# DISTRIBUTION OF VOLCANOES

## CIRCUM-PACIFIC BELT

More than 60 % of active volcanoes
Ring of Fire ( follows the convergent boundary of the pacific plate)
Alaskan volcanoes

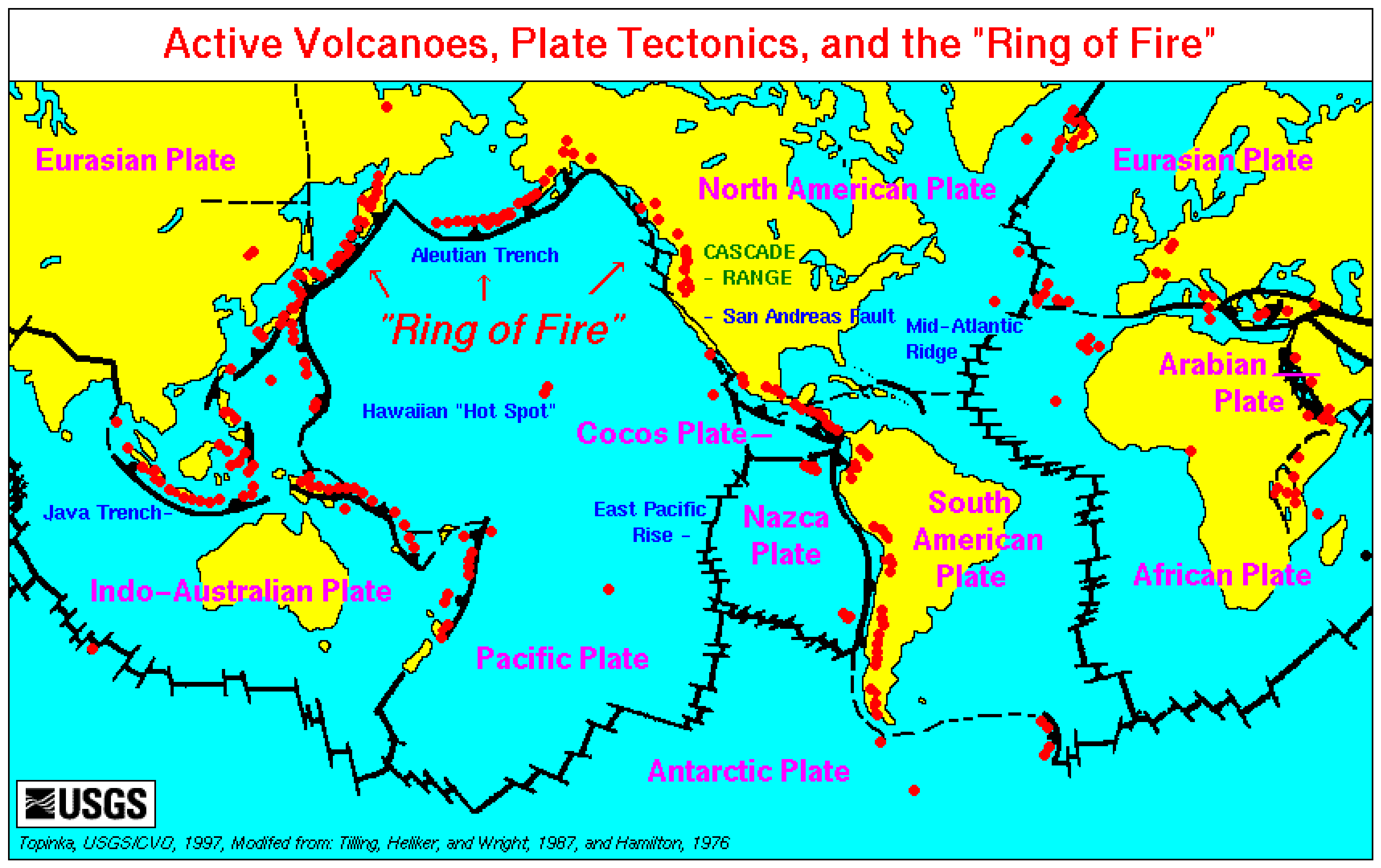
## MEDITERRANEAN BELT

About 20 % of active volcanoes
Mount Etna, Italy.

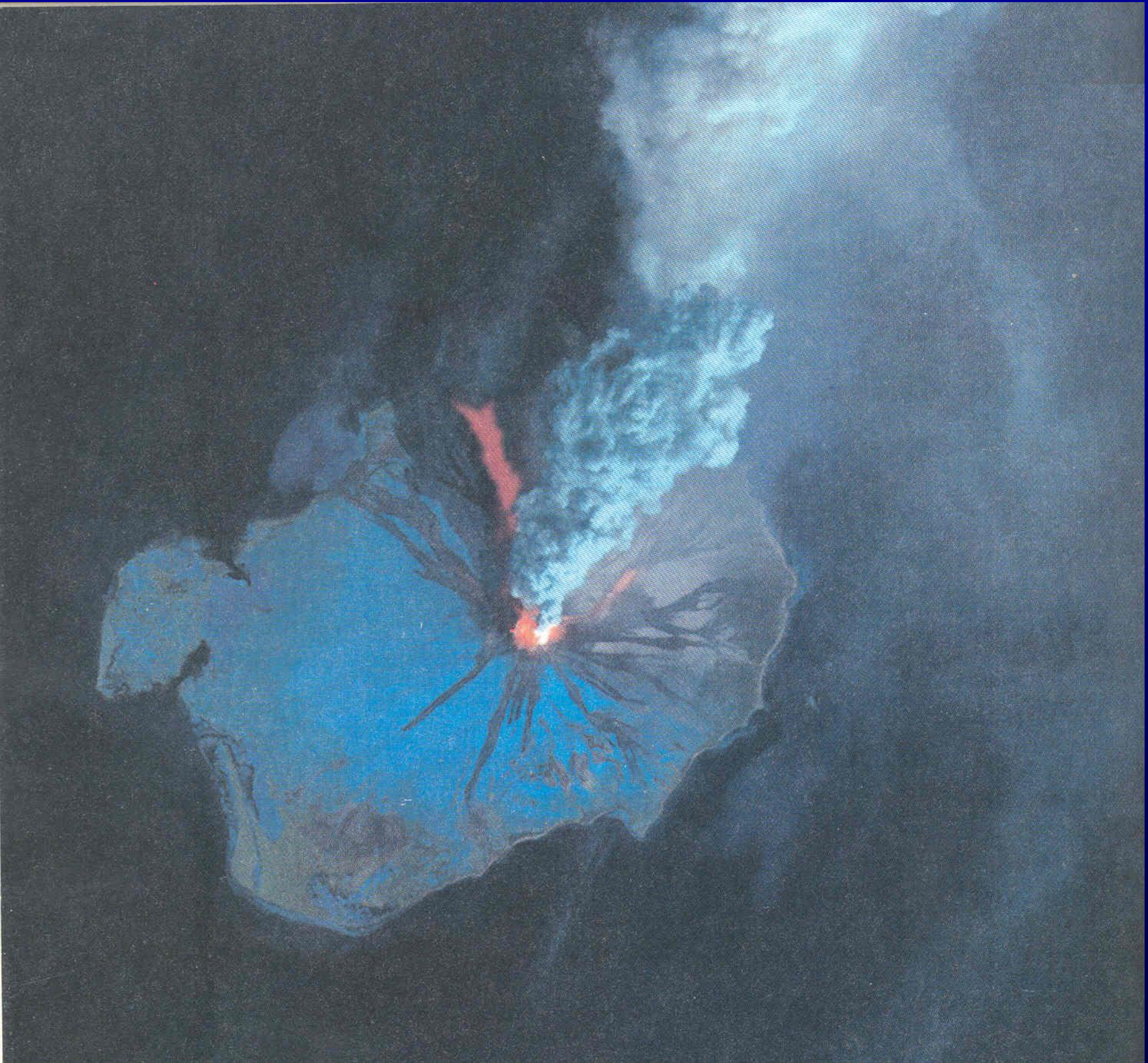
Rest of the active volcanoes are at or near mid-oceanic ridges.

The longest of these ridges is the MID-ATLANTIC RIDGE.

# Global distribution of volcanoes

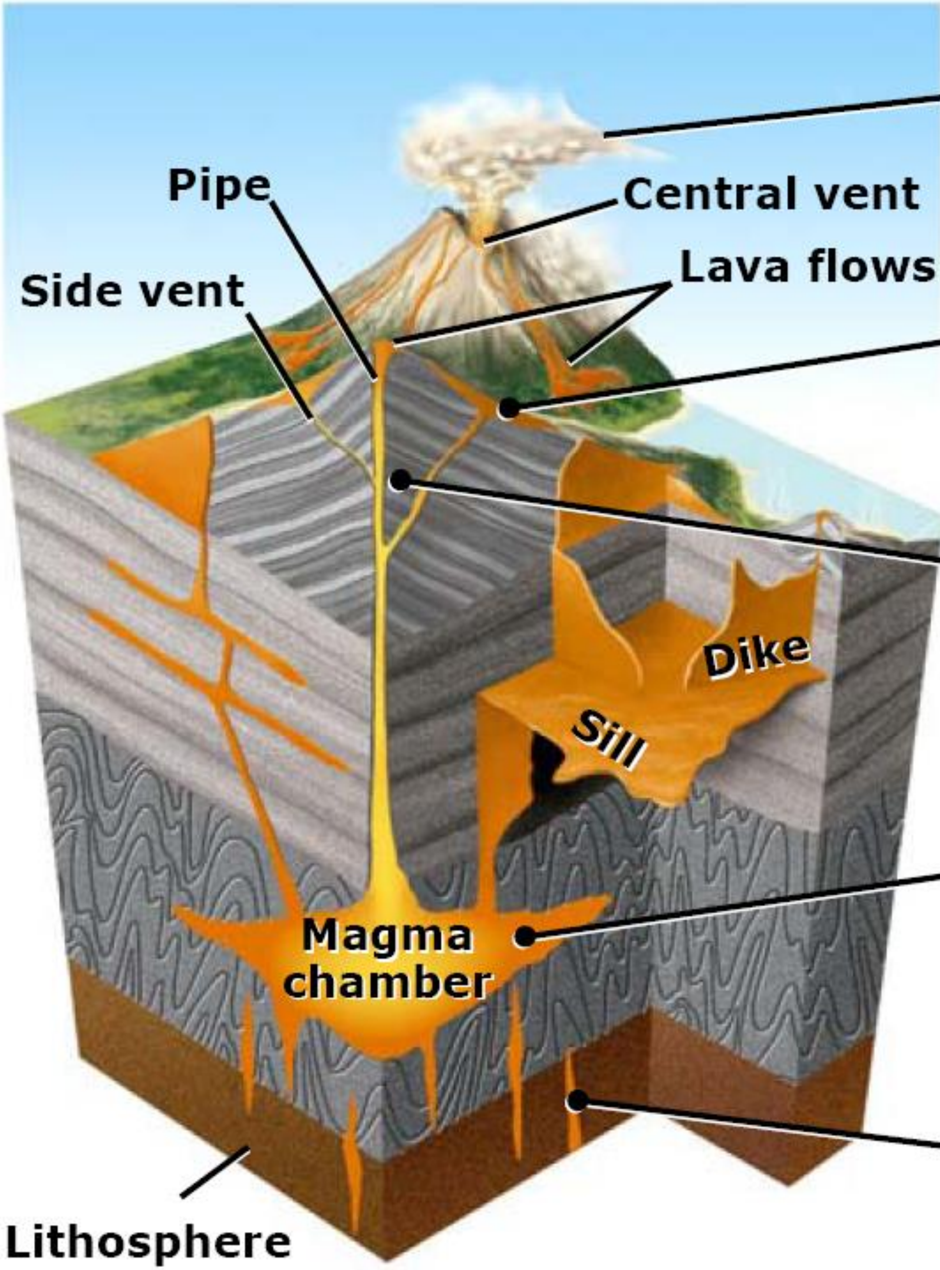


# VOLCANO, AUGUSTINE ISLAND, ALEUTIAN ISLAND ARC



This image was recorded by Landsat 5.  Red represents flowing hot ash, blue indicates snow and gray-brown shows flows of cool ash. This type of explosive eruption represents a fundamental type of volcanism resulting from converging tectonic plates.

# Volcanic geosystem




Gases injected into atmosphere ($H_2O$, $CO_2$, $SO_4$).

...accumulating on the surface to form a volcano.

Lavas erupt through a central vent and side vents,...

...rises through the lithosphere to form a crustal magma chamber.

Magma, which originates in the asthenosphere...

# Classification of Volcanoes

**Based on . . . . .**

***State***

1. Active
2. Dormant
3. Extinct

***Mode of Eruption***

1. Central Vent type or cone
2. Fissure type

***Type of Eruption***

1. *Hawaiian*
2. *Strombolian*
3. *Vulcanian*
4. *Vesuvian*
5. *Pelean &*
6. *Plinian*

# Based on the State of the Volcanoes

*Active volcano*

- are those which are active at present or have been in eruption at least during the historic past.

*Dormant or Slumbering volcano*

- are those which have not been in eruption in the historic period but at the same time may have time to erupt in future.

*Extinct volcanoes*

- these are geologically ancient and have totally stopped all their activities.

# ACTIVE VOLCANO


10 m high fountain of lava

# Based on the mode of Eruption

**1. CENTRAL VENT TYPE :**

Based on eruptive force, composition and Viscosity of the magma …

- VOLCANIC CONES ( due to low viscosity magma )
- CINDER CONES ( glassy material around the cone )
- COMPOSITE CONES ( alternating layers of pyroclastic material and lava )

**2. FISSURE TYPE :**

Lava eruption takes place through fractures and fissures.

# Based on eruption

- **Hawaiian:** Volcanoes with mild eruption belong to this phase is free from explosion (e.g. Hawaiian volcanoes). Lava is ejected mildly. Such quite eruption build shield volcanoes and lava plateaus and plains. Low silica basaltic composition make the lava mobile.

- **Strombolian:** Eruption of lava punctuated by periodic, mild explosions is known as Strombolian phase. (e.g. Stromboli, Italy). In this type of eruption lava is ejected out in fountains with bombs and scoria and light-colored clouds (mostly steam) reach upward only to moderate heights.

- **Vulcanian:** More Viscous and less mobile lavas; allowing gas buildup below surface; over longer periods of quiet until lava crust is broken up, ejecting bombs, pumice, ash and thick clouds and built the Composite cone. (e.g. Vulcano, Sicily)

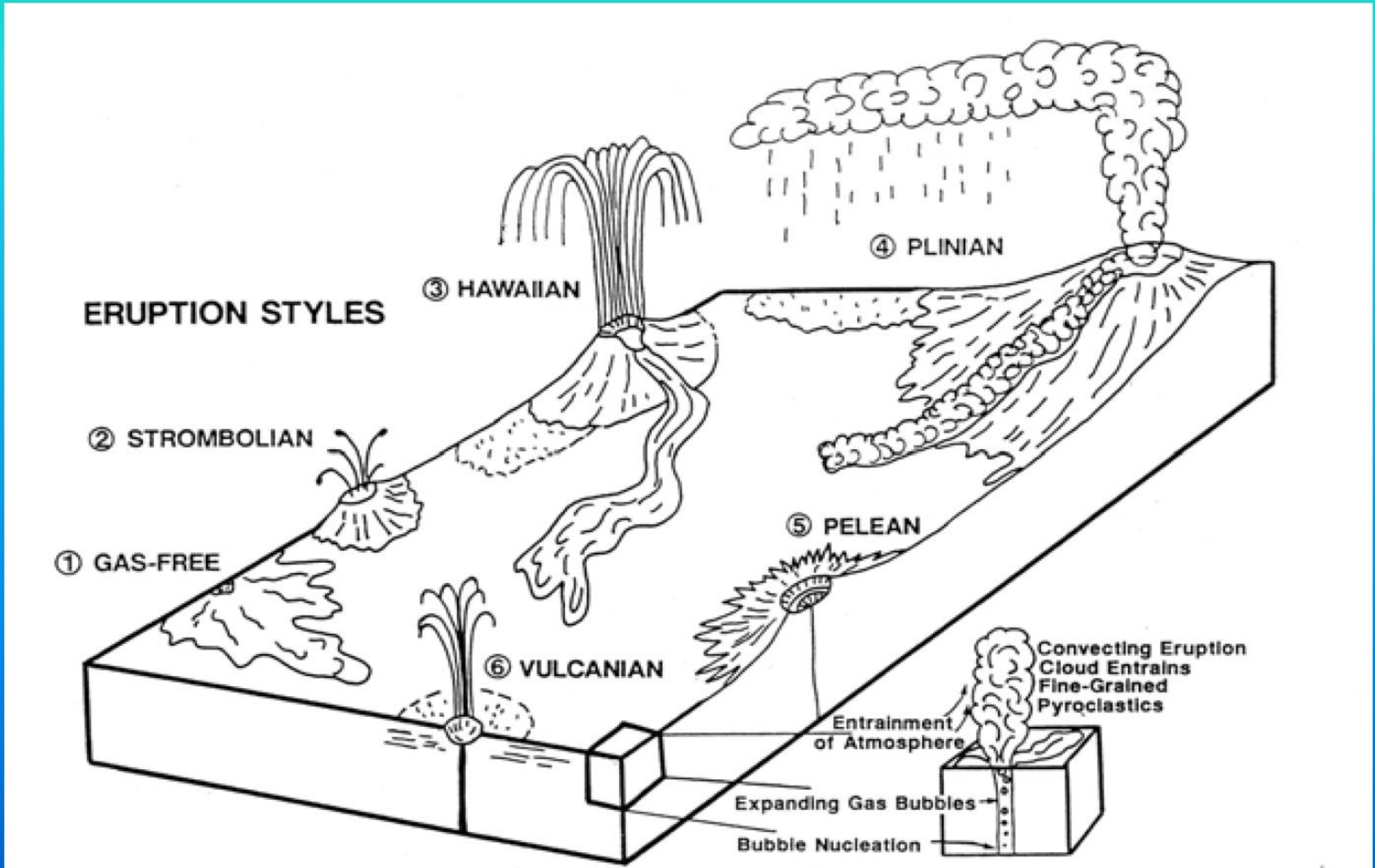
• **Vesuvian:** More stronger then Strombolian or Vulcanian types; extremely violent expulsion of gas; eruption occurs after long interval of quiescence of mild activity; vent tends to be emptied to considerable depth; lava ejects in explosive spray, repeated clouds (cauliflower) that reach great heights and deposit tephra.

• **Plinian**: More violent form of Vesuvian eruption; Calderas are formed. Volume of erupted materials is enormous. It is named after the observer Pliny who lost his life during the observations.

• **Pelean:** Results from high-viscosity lavas, erupts pyroclastics in violent explosion, forming the Volcanic domes, Glowing cloud is typical are typical feature of Pelean phase (e.g. Mount Pelee, West Indies)

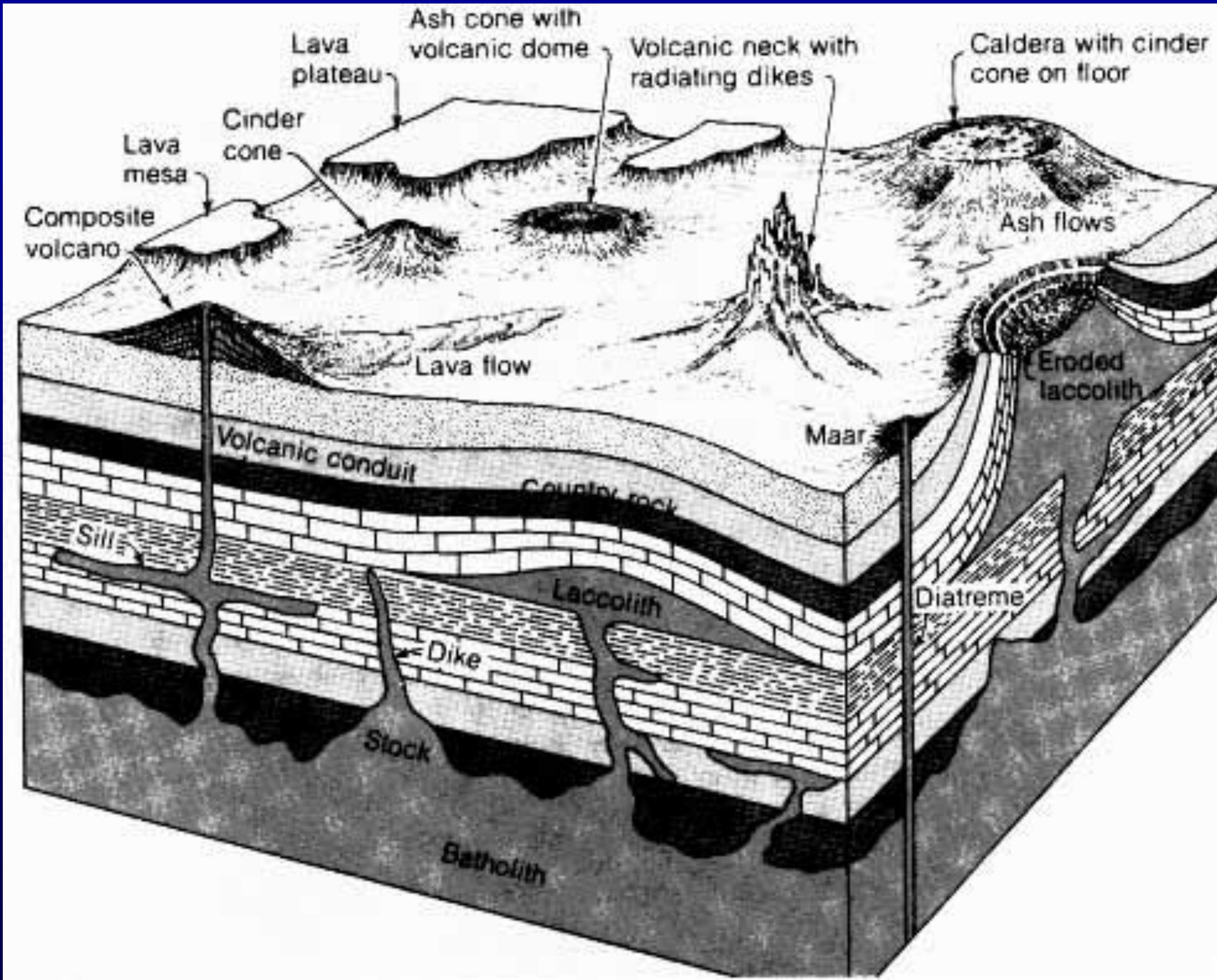
No volcano erupts in the same manner through out its life. A single Volcano may erupt in different types at different times

# Eruption styles
## based on example volcanoes




Wilson and Head, 1994

# Volcanic Landforms



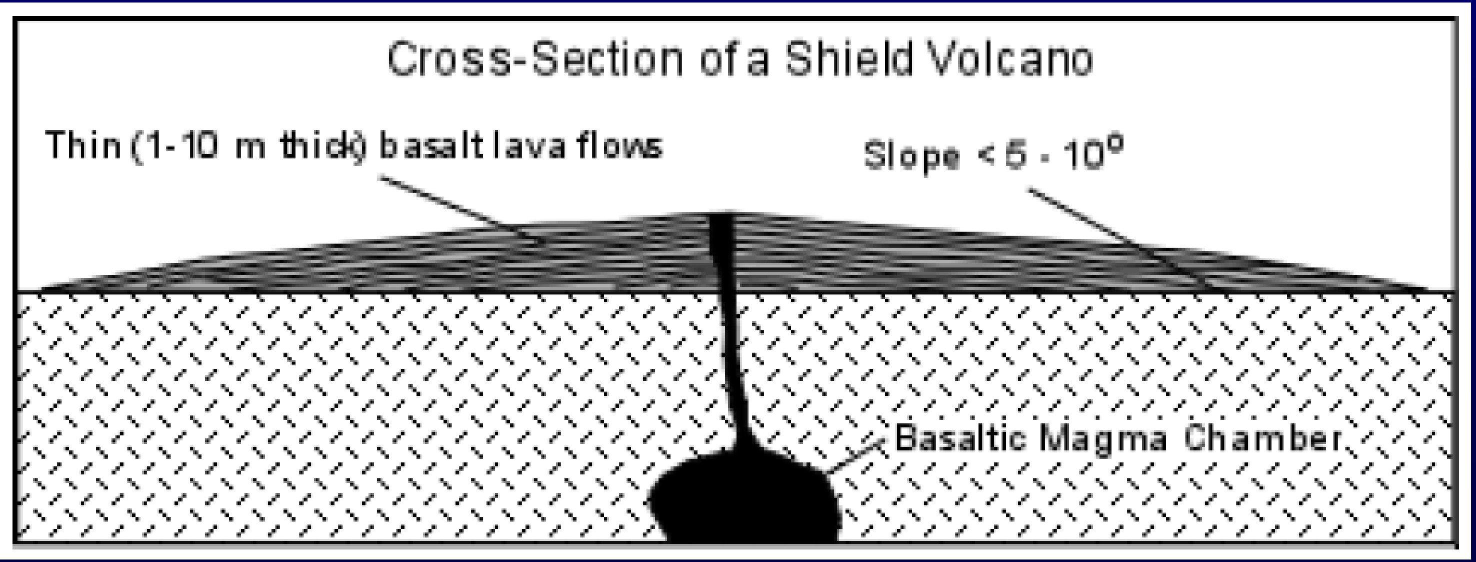
Ash cone with volcanic dome
Lava plateau
Volcanic neck with radiating dikes
Caldera with cinder cone on floor
Cinder cone
Lava mesa
Composite volcano
Ash flows
Lava flow
Eroded laccolith
Maar
Volcanic conduit
Country rock
Sill
Laccolith
Diatreme
Dike
Stock
Batholith

# Shield Volcanoes

A shield volcano is characterized by gentle upper slopes (about 5º) and somewhat steeper lower slopes (about 10º).

Shield volcanoes are composed almost entirely of relatively thin lava flows built up over a central vent.

Most shields were formed by low viscosity basaltic magma that flows easily down slope away form the summit vent.

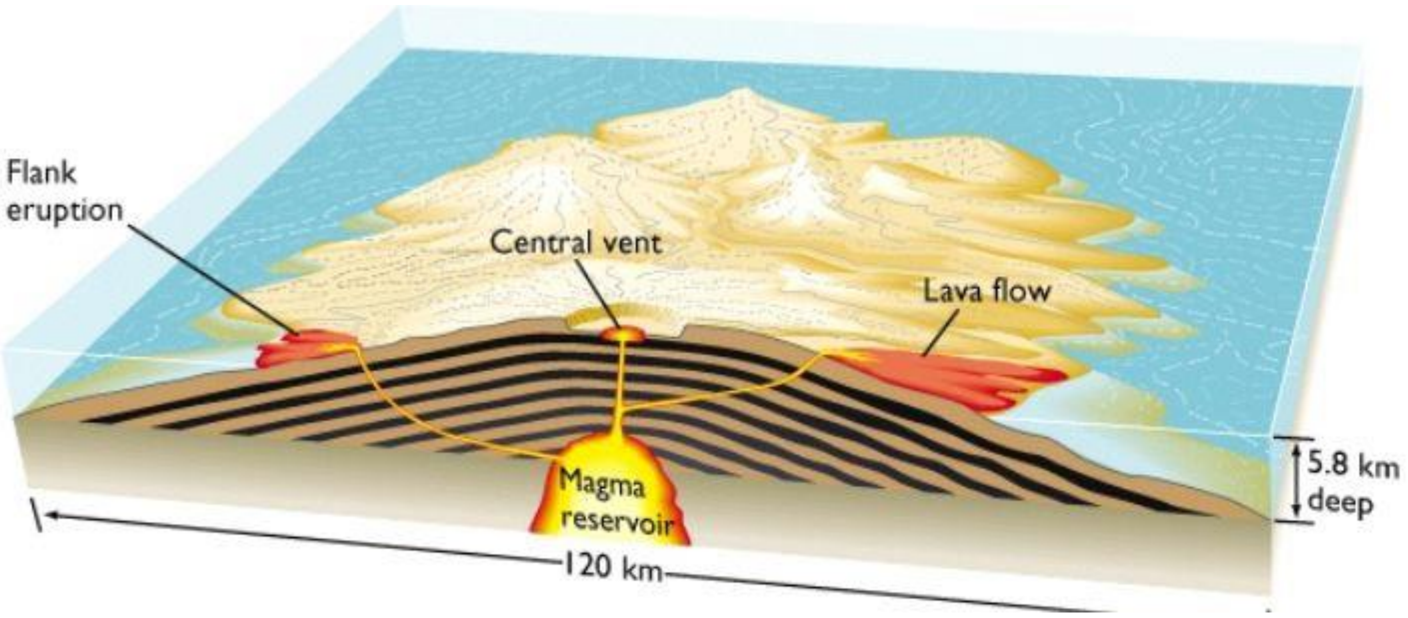


# Shield Volcanoes

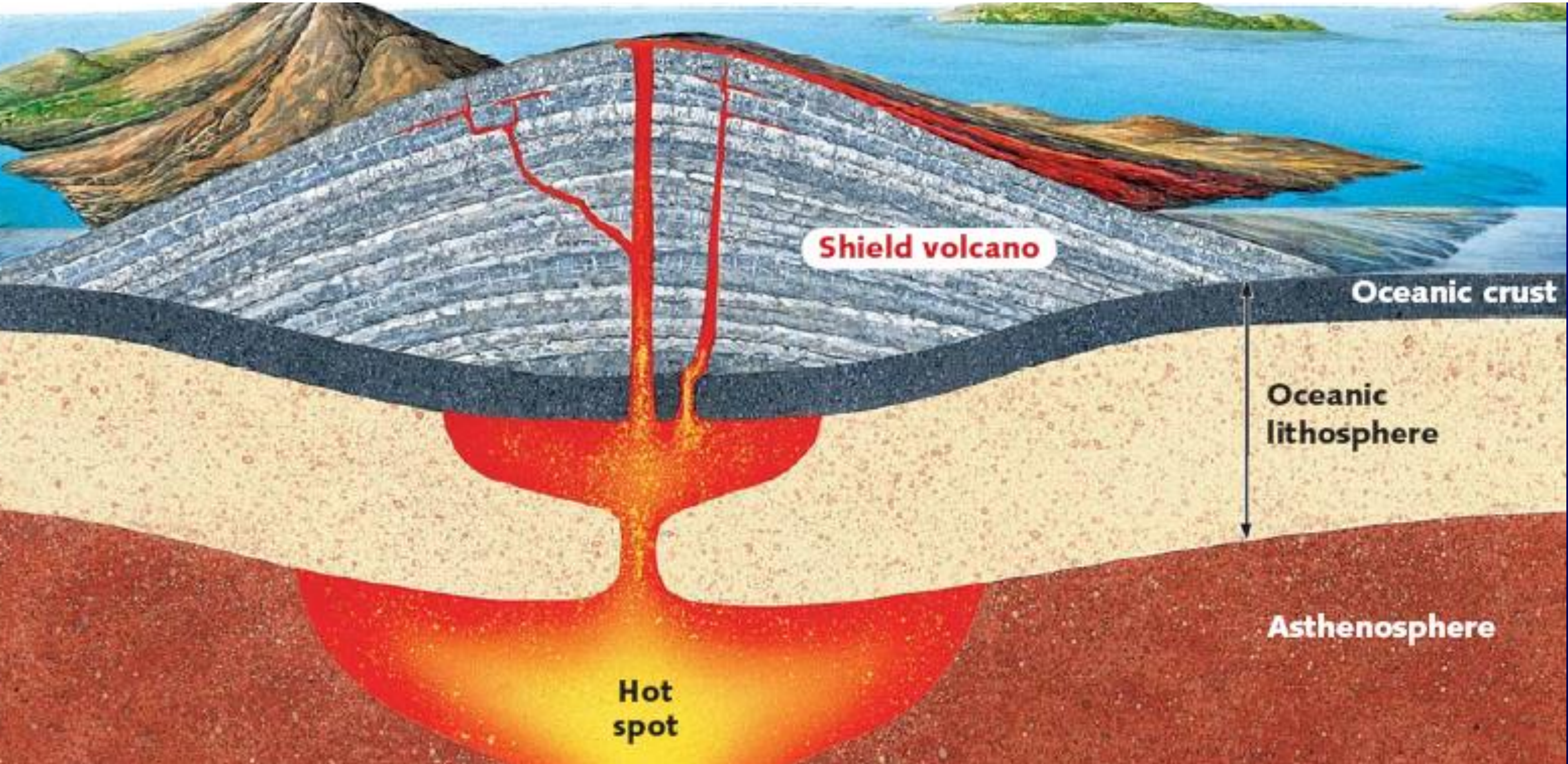
Most shield volcanoes have a roughly circular or oval shape in map view.

Very little pyroclastic material is found within a shield volcano, except near the eruptive vents, where small amounts of pyroclastic material accumulate as a result of fire fountaining events.

Shield volcanoes thus form by relatively non-explosive eruptions of low viscosity basaltic magma.



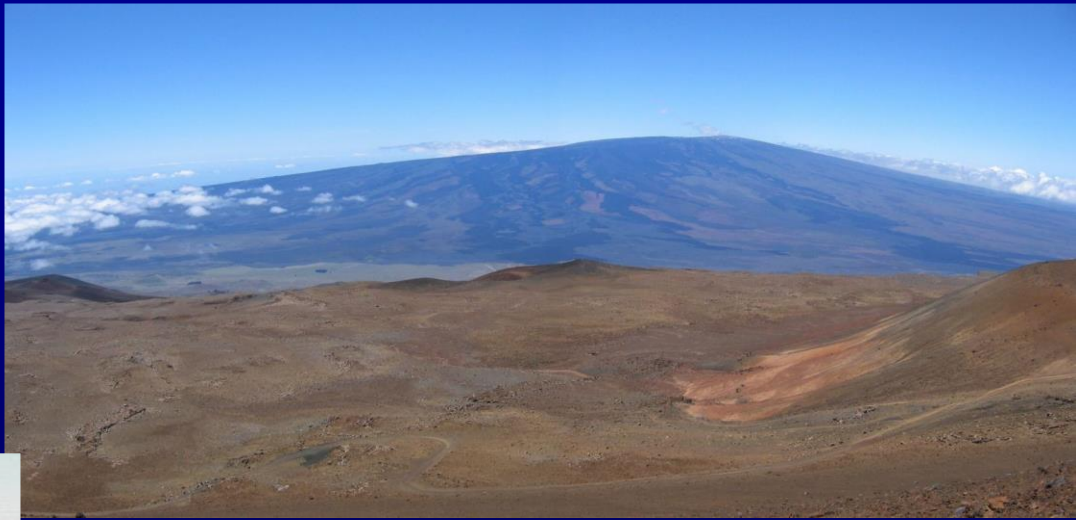
»**Ex. Mauna Loa in Hawaii is 9170 m tall (4170 m above sea level & 5000 m below sea level)**



Tend to be less explosive than other types of volcanoes

However, flows may be frequent & large in volume and results in damage to homes, highways, & other property

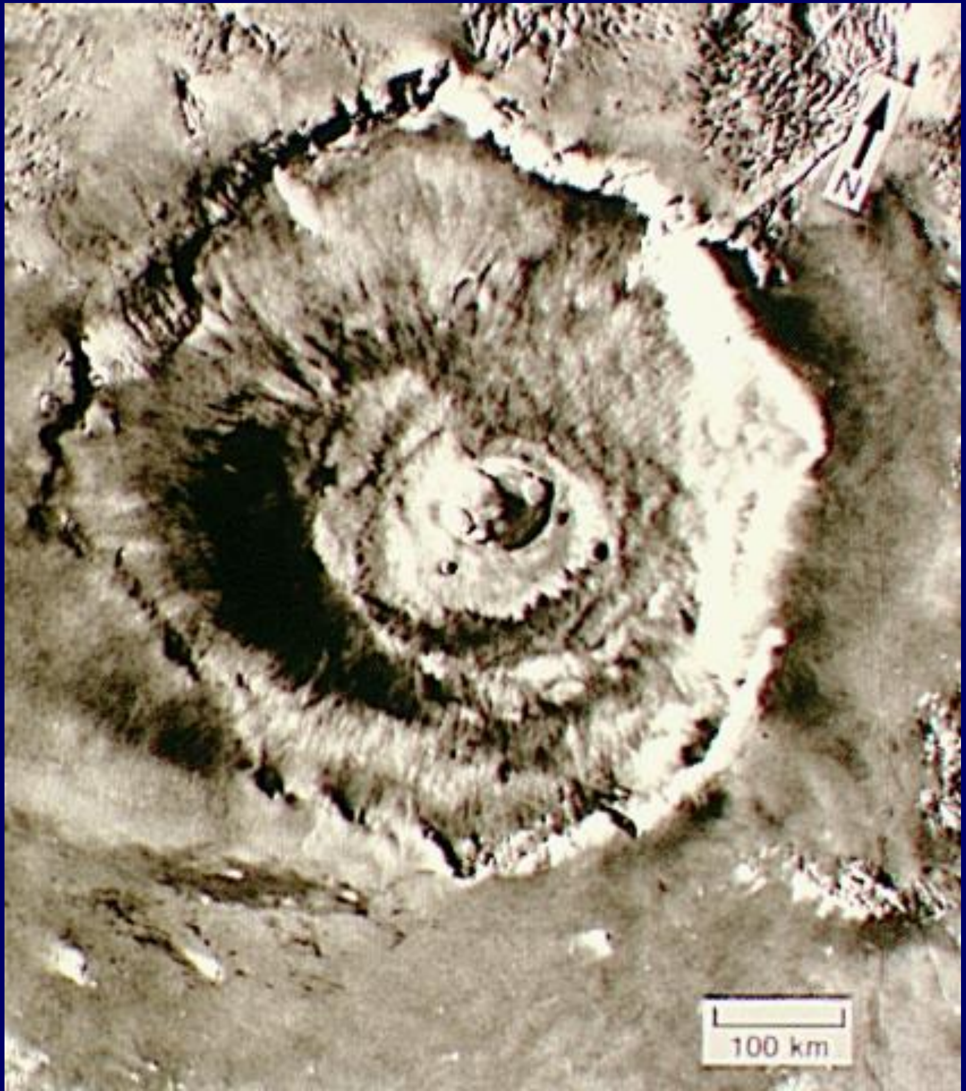
Tend to form over hotspots & in oceans (b/c oceanic crust is made of basalt)



Mauna Loa is the tallest volcano on Earth, as measured from the sea floor

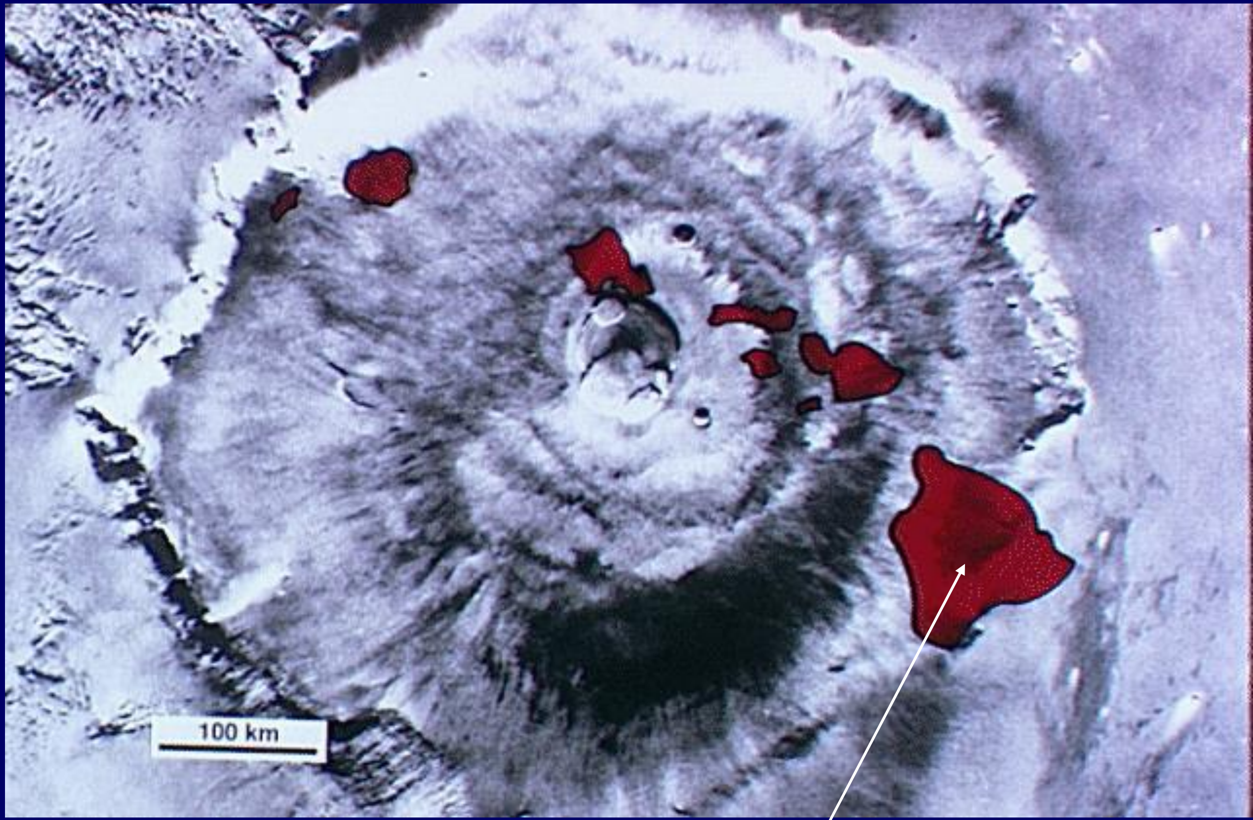
# Shield volcanoes on Mars

- Other planets also have shield volcanoes
- This is the largest shield volcano in the solar system, Olympus Mons on Mars



# Shield volcanoes: Earth vs. Mars

- Red = Hawaiian chain, which is superimposed on Olympus Mons



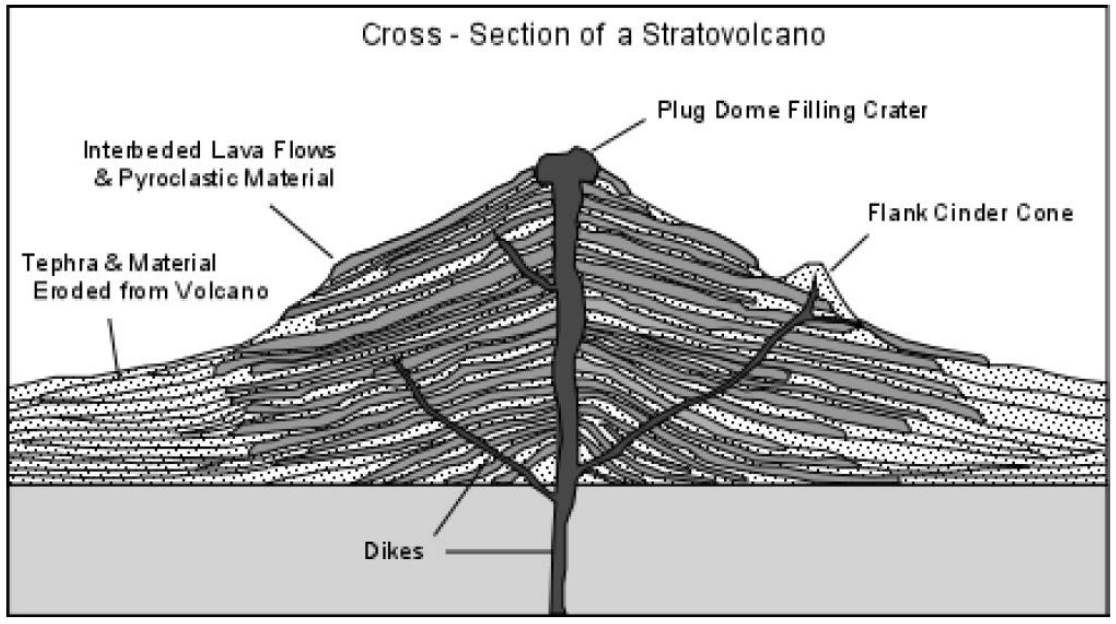

Mauna Loa is about here

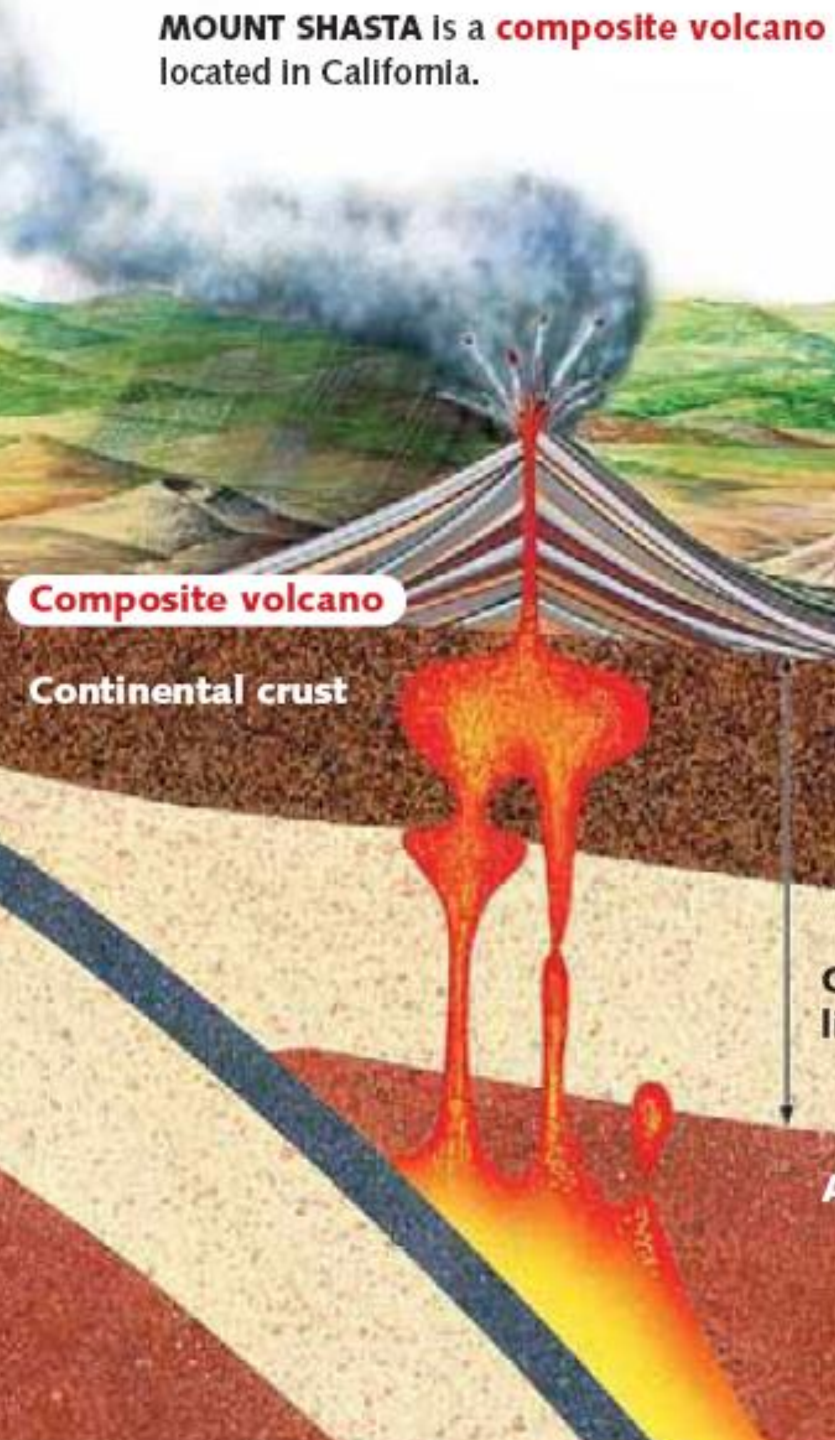
# **Stratovolcanoes** (also called **Composite Volcanoes**)

**Have steeper slopes than shield volcanoes, with slopes of 6 to 10º low on the flanks to 30º near the top.**

**The steep slope near the summit is due partly to thick, short viscous lava flows that do not travel far down slope from the vent.**

**They show an internal layered structure due to varying intensities of the explosions that deposit different sizes of pyroclastics.**






Mt. Shasta


Mount St. Helens

- The gentler slopes near the base are due to accumulations of material eroded from the volcano
- Stratovolcanoes show inter-layering of lava flows and pyroclastic material, So it is also called composite volcanoes. Pyroclastic material can make up over 50% of the volume of a stratovolcano.
- Lavas and pyroclastics are usually andesitic to rhyolitic in composition.
- Due to the higher viscosity of magmas erupted from these volcanoes, they are usually more explosive than shield volcanoes.
- Stratovolcanoes sometimes have a crater at the summit that is formed by explosive ejection of material from a central vent. Sometimes the craters have been filled in by lava flows or lava domes, sometimes they are filled with glacial ice, and less commonly they are filled with water.
- Long periods of repose (times of inactivity) lasting for hundreds to thousands of years, make this type of volcano particularly dangerous, since many times they have shown no historic activity, and people are reluctant to heed warnings about possible eruptions.

# Cinder cones (Tephra Cones)

- Cinder cones are volcanoes which erupt only during one episode
- They are explosive, but small in size
- The cone is a pile of pyroclastic debris which piles up at the angle of repose

# Cinder cones

- The cinders are generally of basaltic composition
- The eruptive activity typically lasts a few months or years

# Cinder cones: Parícutin

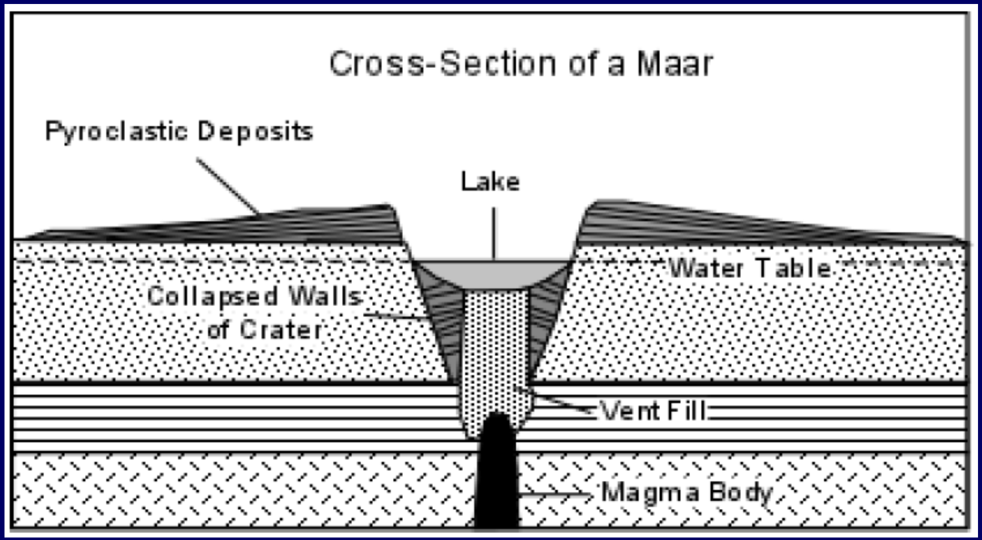
- Parícutin volcano in Mexico is a classic cinder cone
- The region contains many cinder cones
- It consists of both pyroclastics and lava

# Parícutin

- Here is a photo of the volcano showing the classic form of cinder cones
- In the foreground is the obviously distressed farmer, Dionisio Pulido

# Maars

Maars result from phreatic or phreatomagmatic activity, wherein magma heats up water in the groundwater system, pressure builds as the water to turns to steam, and then the water and preexisting rock (and some new magma if the eruption is phreatomagmatic) are blasted out of the ground to form a tephra cone with gentle slopes.



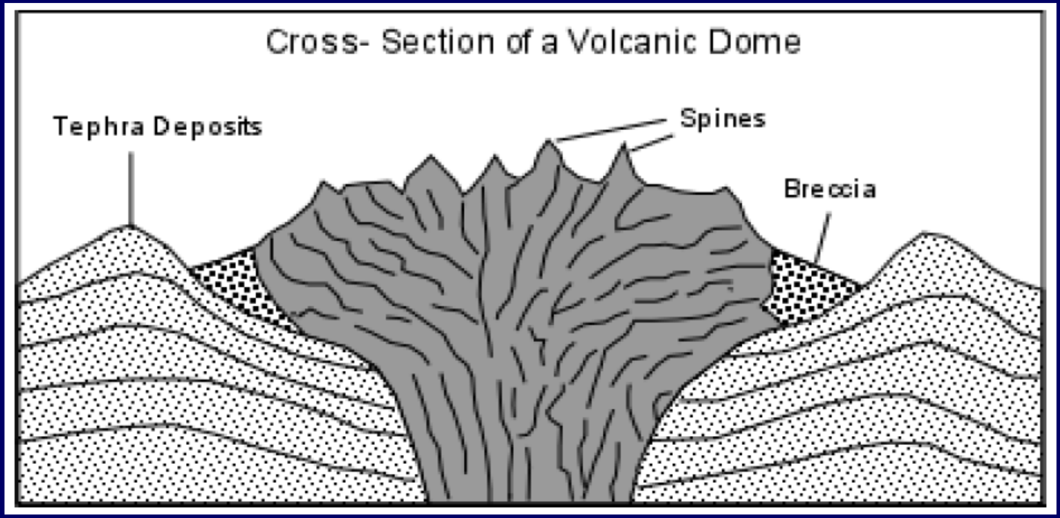

Parts of the crater walls eventually collapse back into the crater, the vent is filled with loose material, and, if the crater still is deeper than the water table, the crater fills with water to form a lake, the lake level coinciding with the water table.

# **Lava Domes** (also called **Volcanic Domes**)

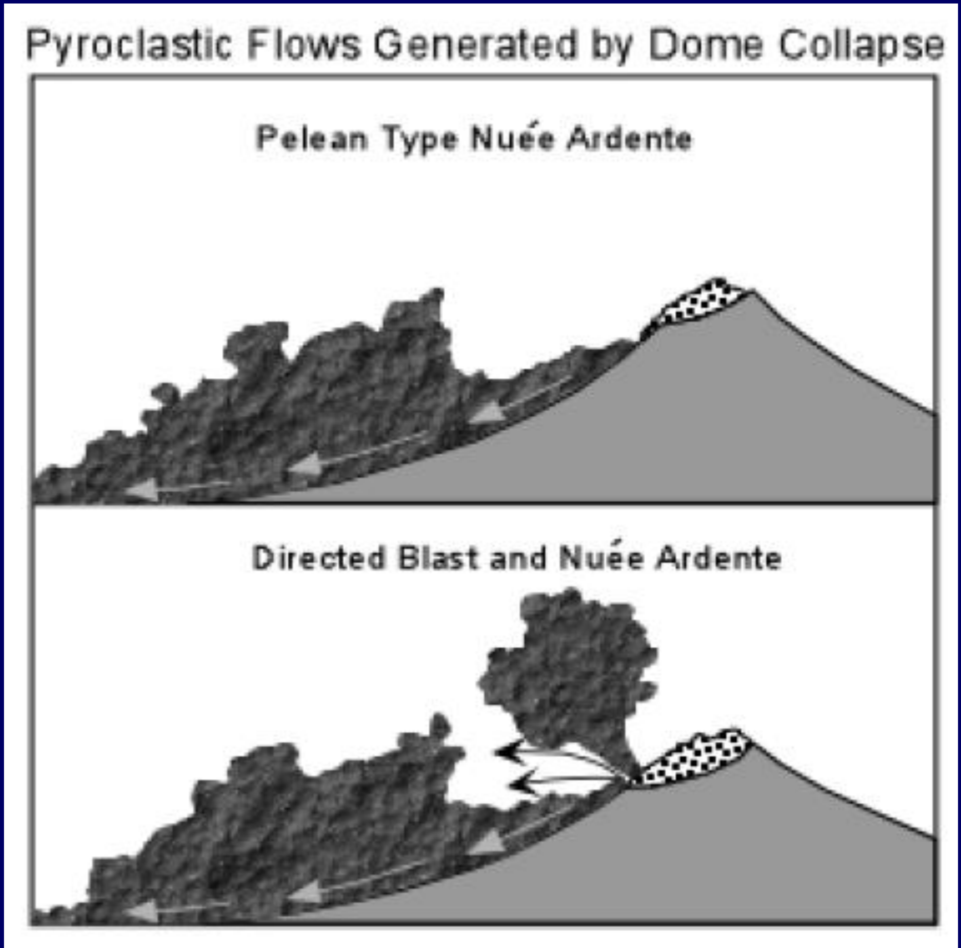
**Volcanic Domes result from the extrusion of highly viscous, gas poor andesitic and rhyolitic lava. Since the viscosity is so high, the lava does not flow away from the vent, but instead piles up over the vent.**

**Blocks of nearly solid lava break off the outer surface of the dome and roll down its flanks to form a breccia around the margins of domes.**

**The surface of volcanic domes are generally very rough, with numerous spines that have been pushed up by the magma from below.**



Most dome eruptions are preceded by explosive eruptions of more gas rich magma, producing a tephra cone into which the dome is extruded.




Volcanic domes can be extremely dangerous. because they form unstable slopes that may collapse to expose gas-rich viscous magma to atmospheric pressure. This can result in lateral blasts or Pelean type pyroclastic flow (nuéeardentes) eruptions.

# CRATERS AND CALDERAS

- Craters are circular depressions, usually less than 1 km in diameter, that form as a result of explosions that emit gases and tephra.

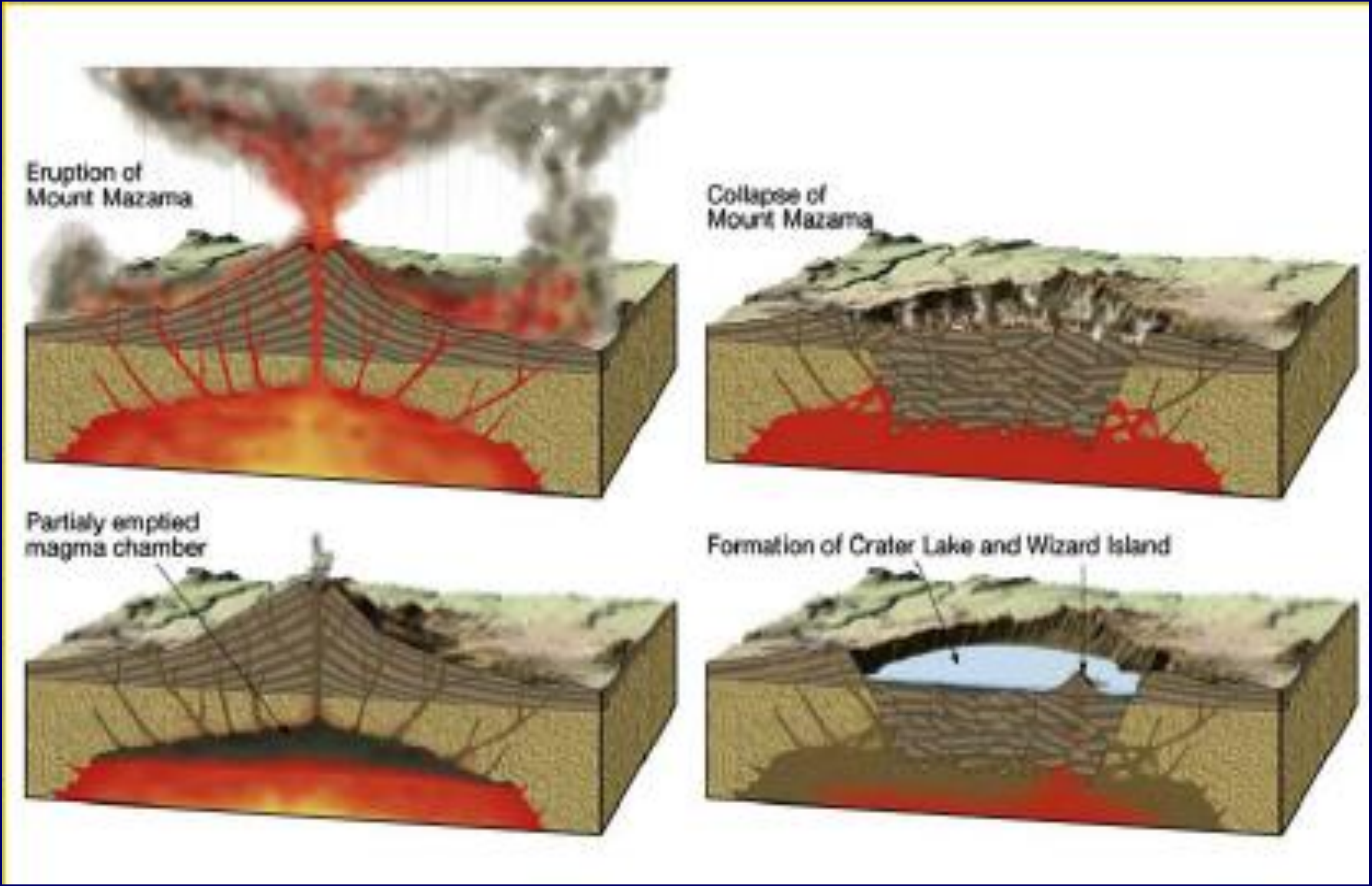
- Calderas are much larger depressions, circular to elliptical in shape, with diameters ranging from 1 km to 50 km. Calderas form as a result of collapse of a volcanic structure. The collapse results from evacuation of the underlying magma chamber.

- In shield volcanoes, like in Hawaii, the evacuation of the magma chamber is a slow drawn out processes.

- In stratovolcanoes the collapse and formation of a caldera results from rapid evacuation of the underlying magma chamber by voluminous explosive eruptions that form extensive fall deposits and pyroclastic flows.

- Calderas are often enclosed depressions that collect rain water and snow melt, and thus lakes often form within a caldera.

# CALDERAS


Eruption of
Mount Mazama
Collapse of
Mount Mazama
Partialy emptied
magma chamber
Formation of Crater Lake and Wizard Island

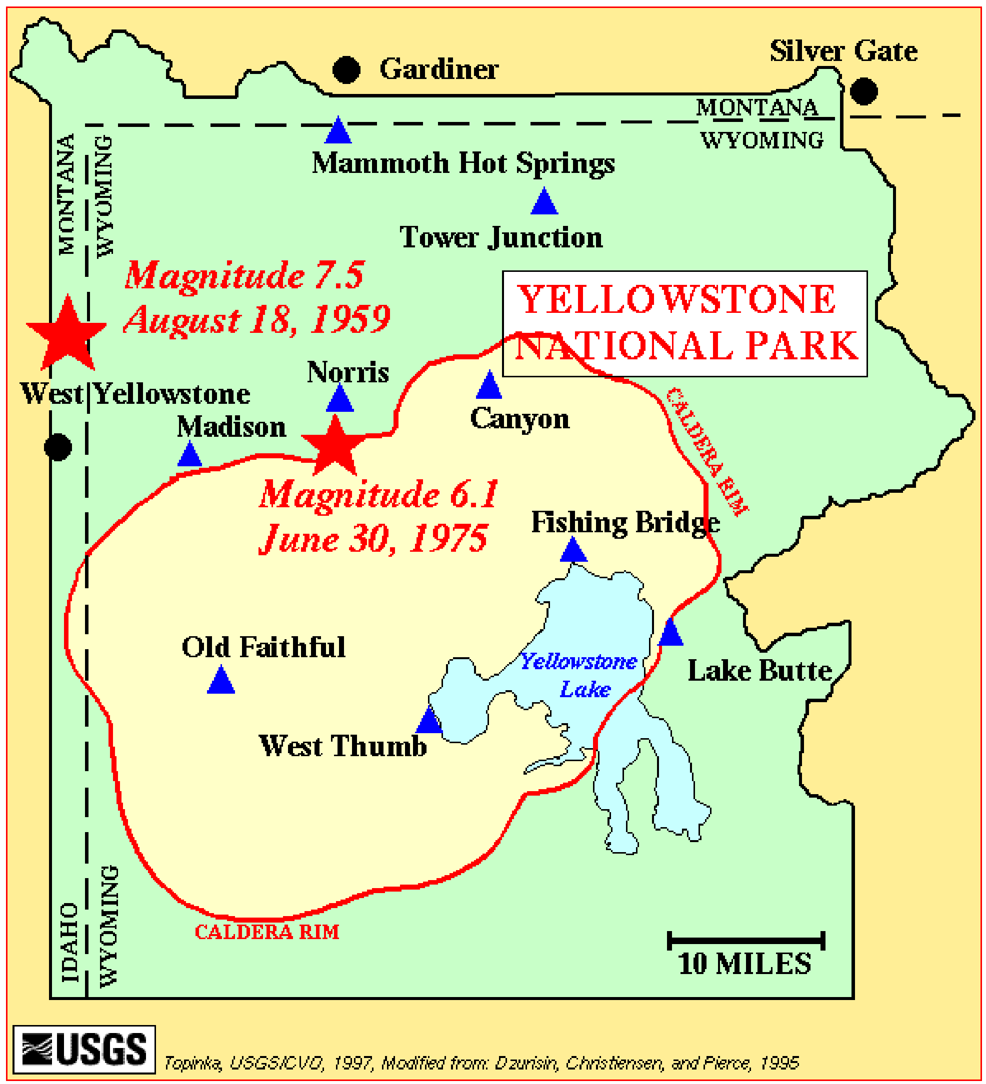
# Crater Lake caldera

- Crater lake is a medium-sized caldera, about 10 km in diameter
- The upper parts of a big stratovolcano (Mt. Mazama) once rested on top
- Mt. Mazama is now at the bottom of Crater Lake

# Crater Lake fills caldera formed by collapse during massive eruption of Mt. Mazama 6600 years ago.

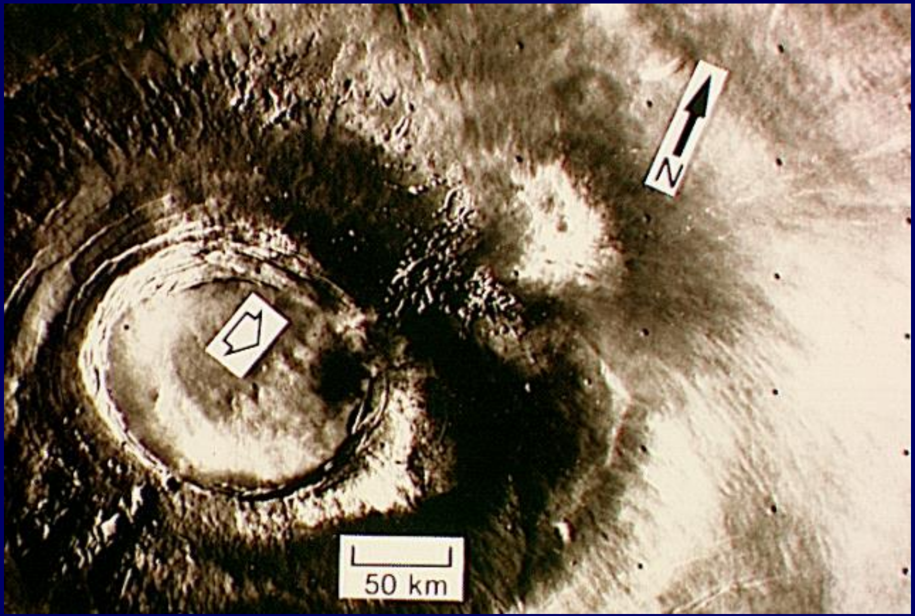
# Yellowstone caldera

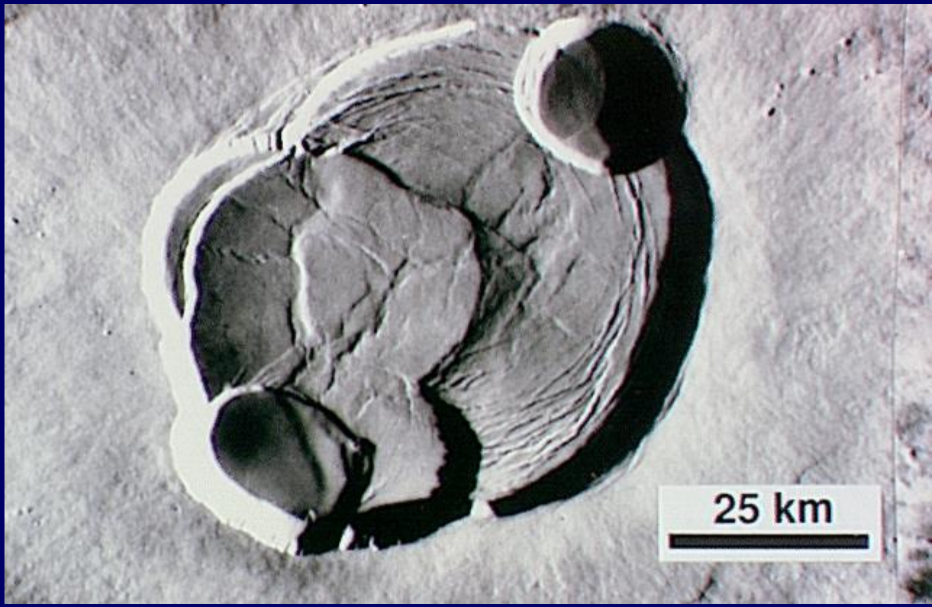
- Yellowstone is a good example of a **big** continental caldera
- It is rhyolitic in composition and formed about 600,000 years ago
- It actually sits within an older, much larger caldera extending west into Idaho



# Martian calderas

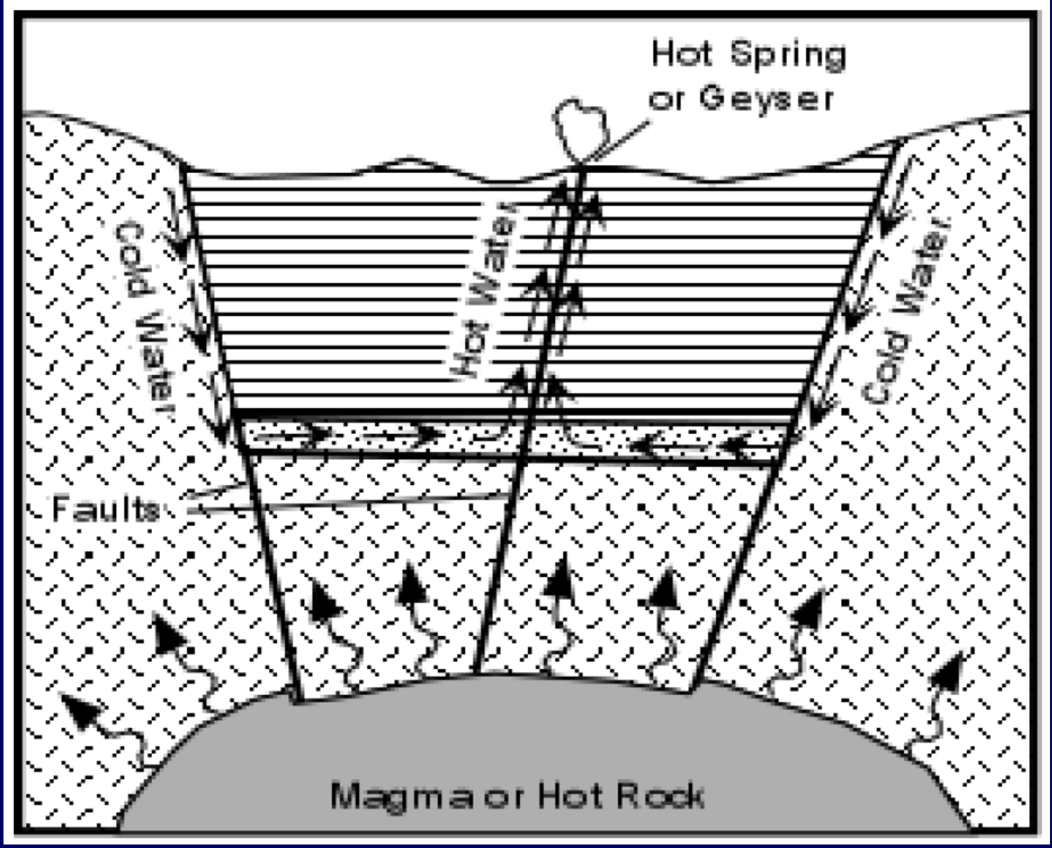
- Here are two Martian calderas. Again, you should appreciate the difference in scale between these structures and those on Earth



# Geysers, Fumaroles and Hot Springs

**A fumarole is vent where gases, either from a magma body at depth, or steam from heated groundwater, emerges at the surface of the Earth. Since most magmatic gas is H2O vapor, and since heated groundwater will produce H2O vapor, fumaroles will only be visible if the water condenses. (H2O vapor is invisible, unless droplets of liquid water have condensed)**



**Hot springs or thermal springs are areas where hot water comes to the surface of the Earth. Cool groundwater moves downward and is heated by a body of magma or hot rock. A hot spring results if this hot water can find its way back to the surface, usually along fault zones.**

**A geyser results if the hot spring has a plumbing system that allows for the accumulation of steam from the boiling water. When the steam pressure builds so that it is higher than the pressure of the overlying water in the system, the steam will move rapidly toward the surface, causing the eruption of the overlying water.**

**Some geysers, like Old Faithful in Yellowstone Park, erupt at regular intervals. The time between eruptions is controlled by the time it takes for the steam pressure to build in the underlying plumbing system.**

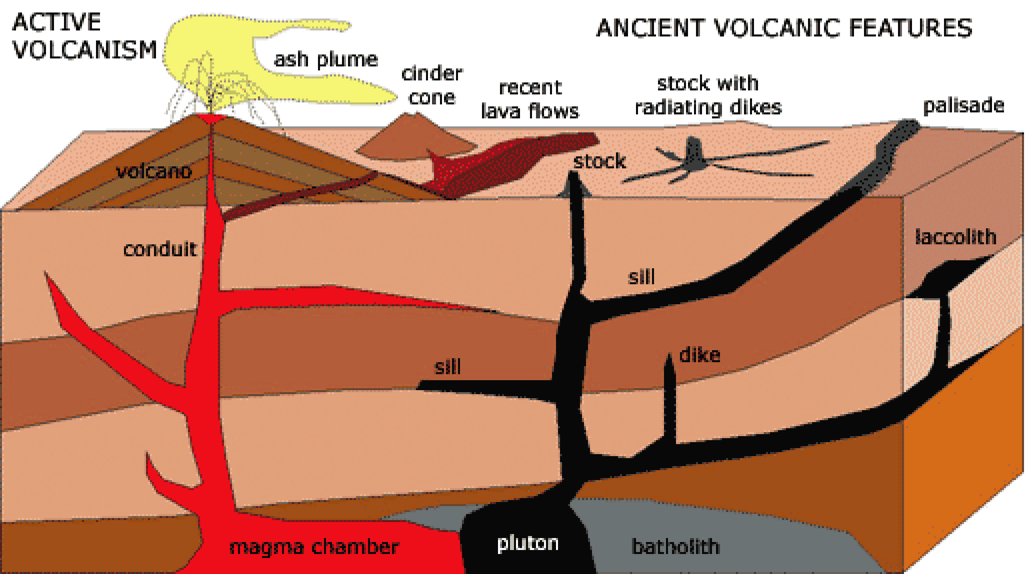
# Plateau Basalts or Flood Basalts

## Lava plateaus

**Sometimes, plate tectonics results in a long, narrow crack (fissure) in Earth's surface**

**Basaltic lava pouring from the fissure spreads across the land, forming a lava plateau**

**Due to erosional processes the plateau gives Mesa and Buteau**




# Flood basalt, Columbia Plateau,Washington


Figure 12-16 part 1
*Understanding Earth, Fifth Edition*


Figure 12-16 part 2
*Understanding Earth, Fifth Edition*


# Columbia Plateau basalts

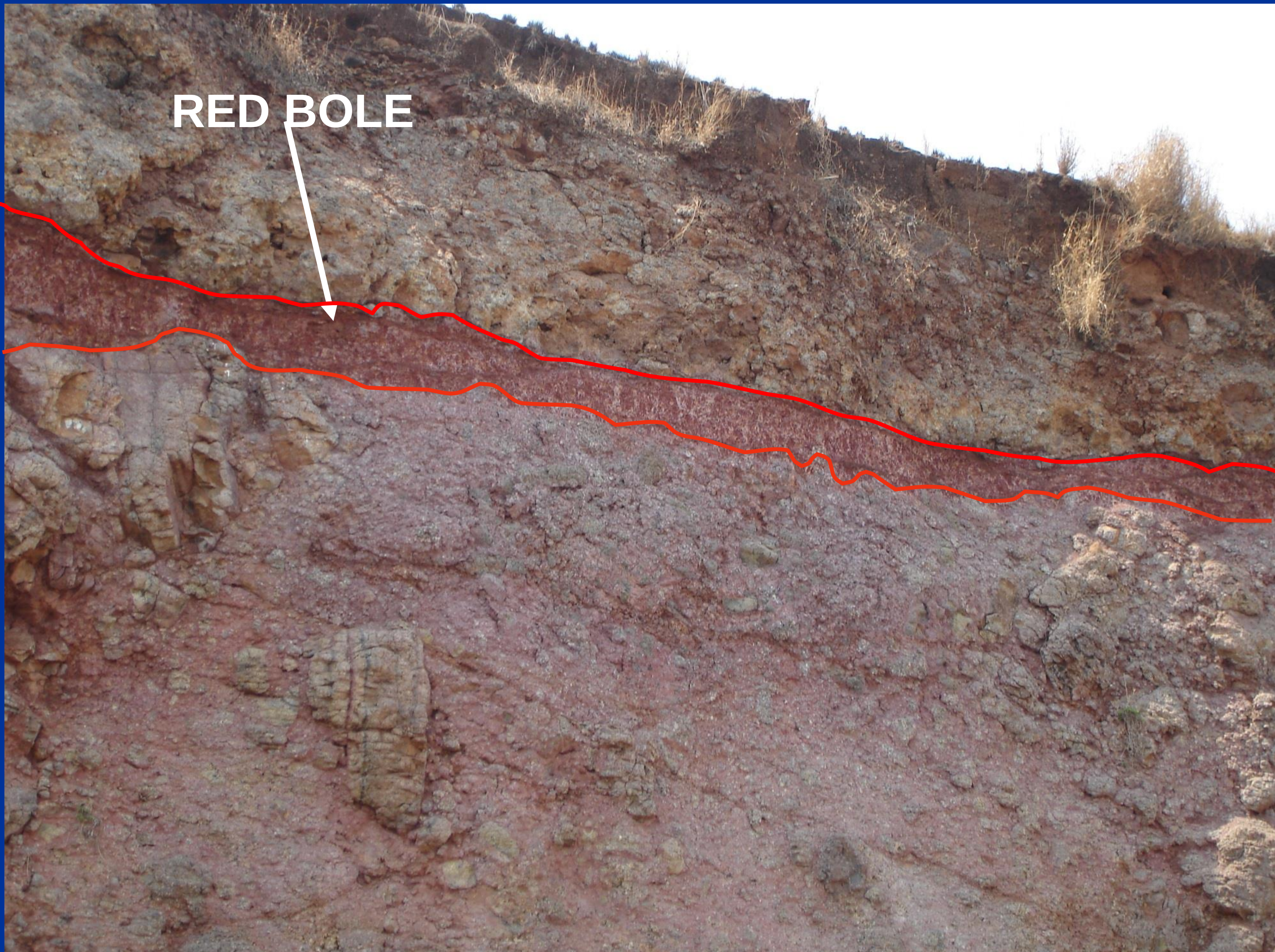
Western Edge,Columbia Plateau
West of Quincy, WA - M. Mustoe

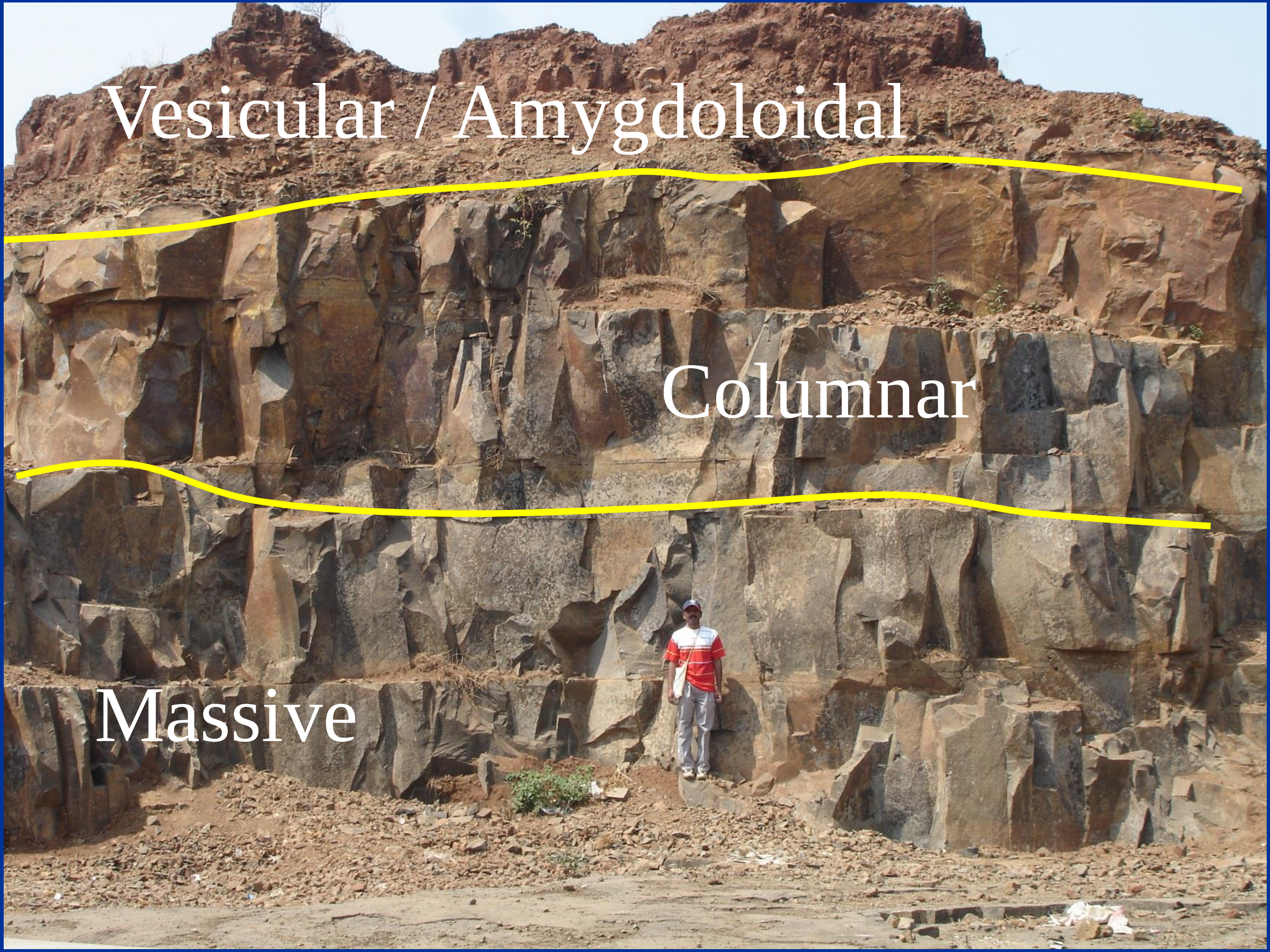
The Anatomy of a Basalt Flow

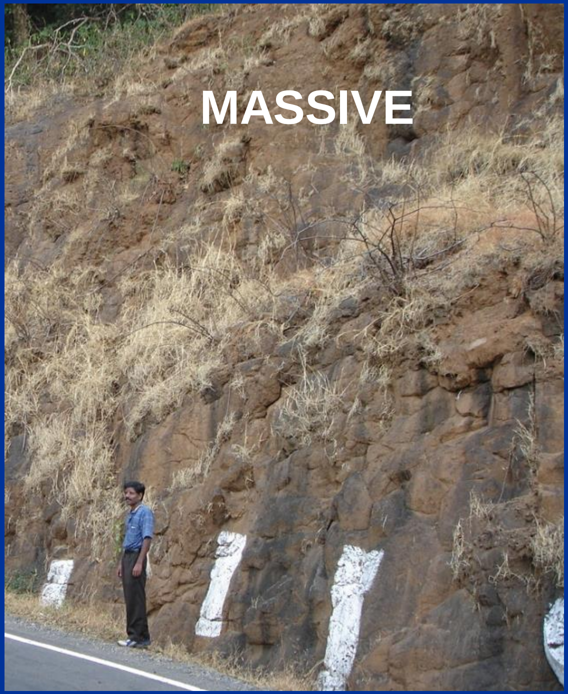

Basalt Layering

In western India are the Deccan plateau basalts, whose extrusions for more than 70 million years are related to the collision of India against the southern margin of the Asian plate.

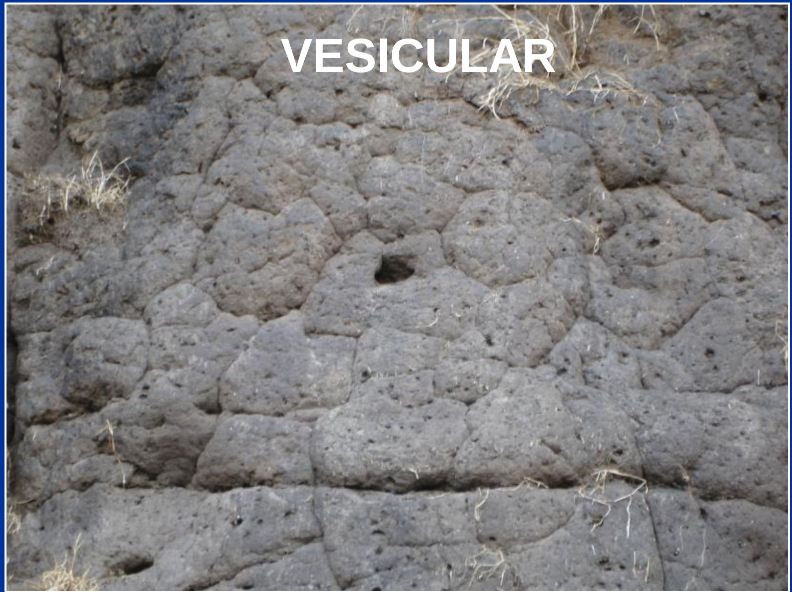
- Deccan trap forms unique and self styled geological formation with rhythmic and repetitive layers of volcanic flows numbering over 40 – 50
- These 40 – 50 flows have repetitively erupted intermittently
- Each flow contains
  - Red bole / flow breccia in the bottom followed on the top by Massive flow
  - Columnar flow
  - Vesicular and Amygdaloidal basalt on the top
  - These multiple flows are intensively dissected and hence depending upon the levels of dissection and erosion different flows are spatially exposed in different locations


RED BOLE

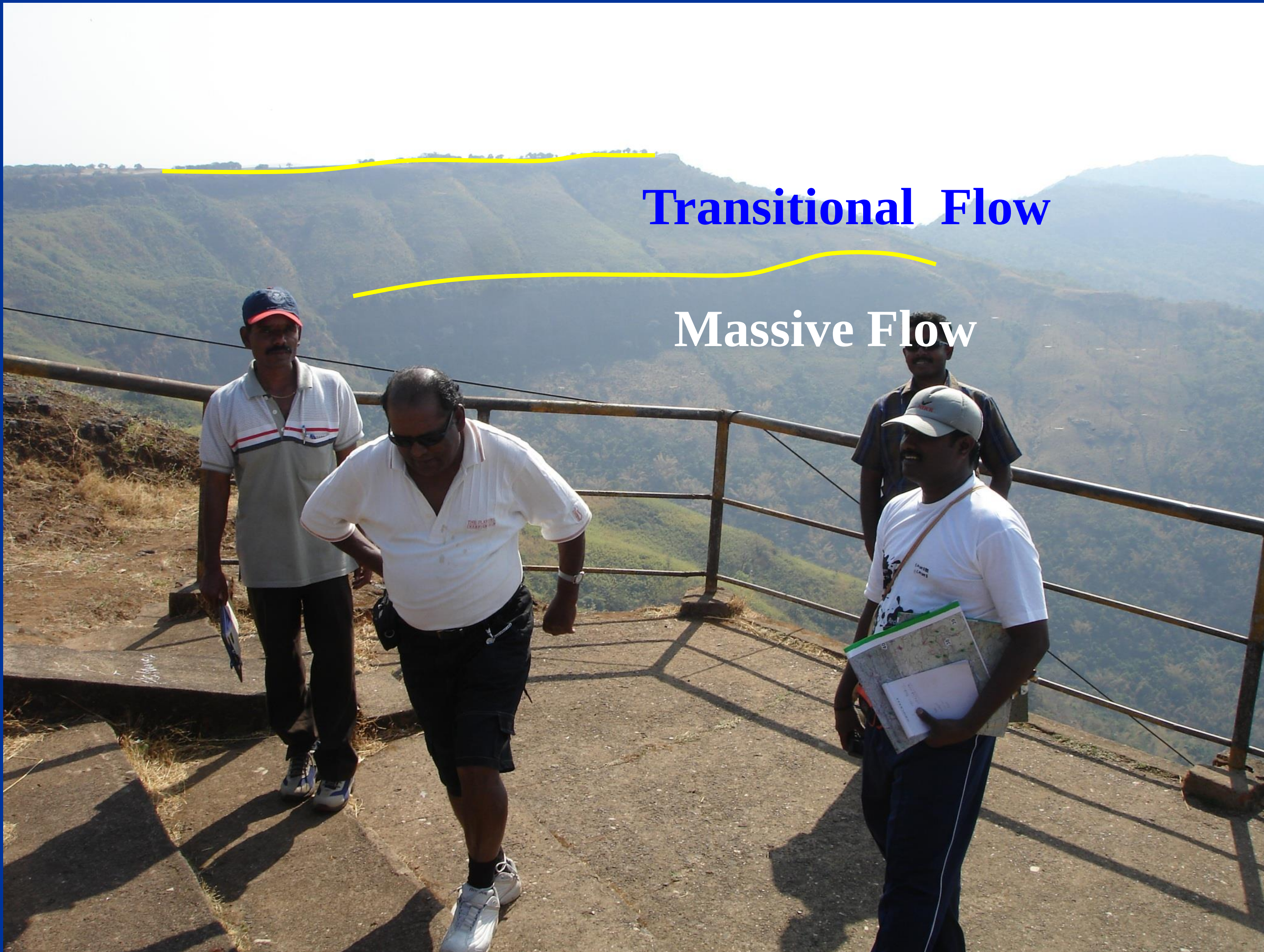

Vesicular / Amygdoloidal
Columnar
Massive


MASSIVE


COLUMNAR

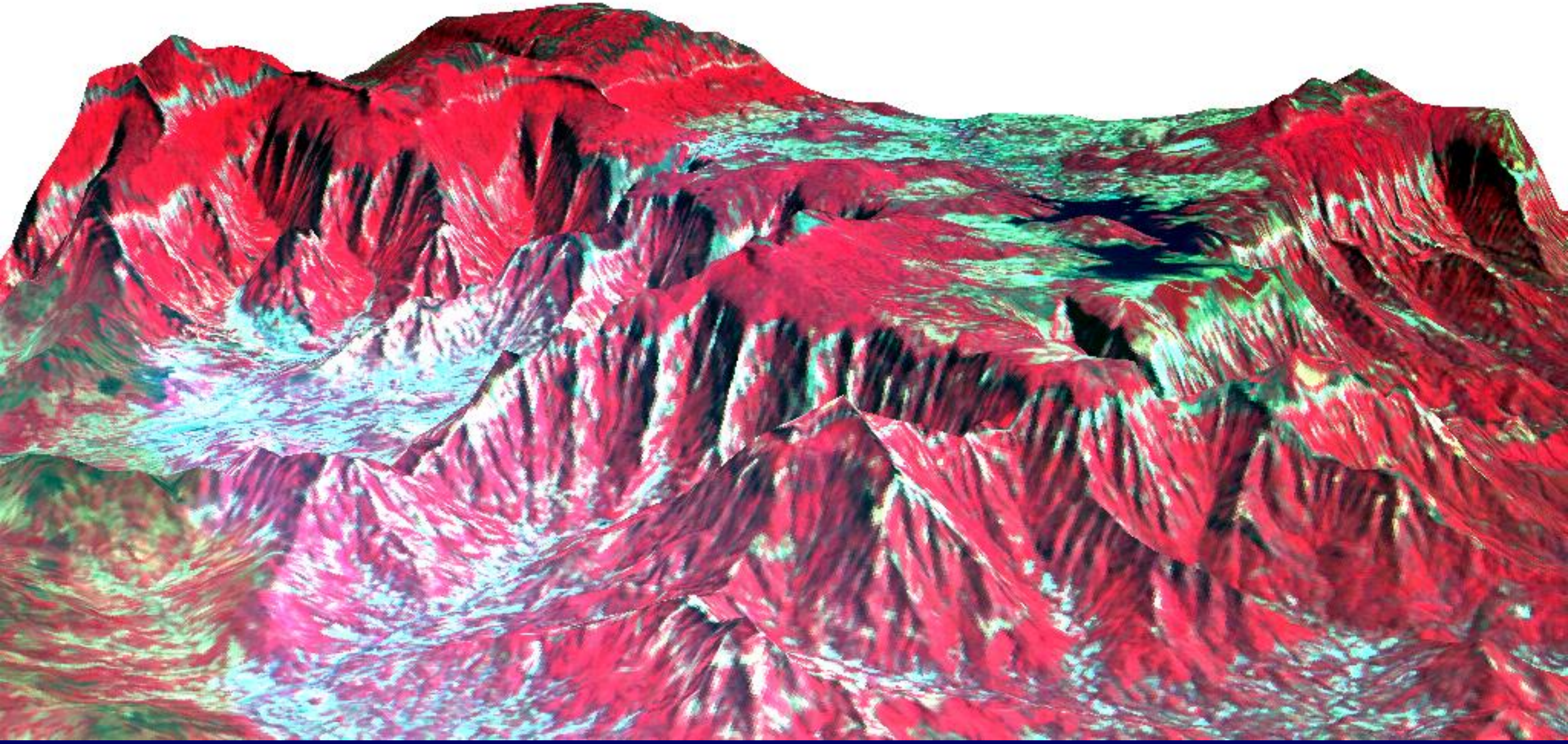

VESICULAR


AMYGDALOIDAL

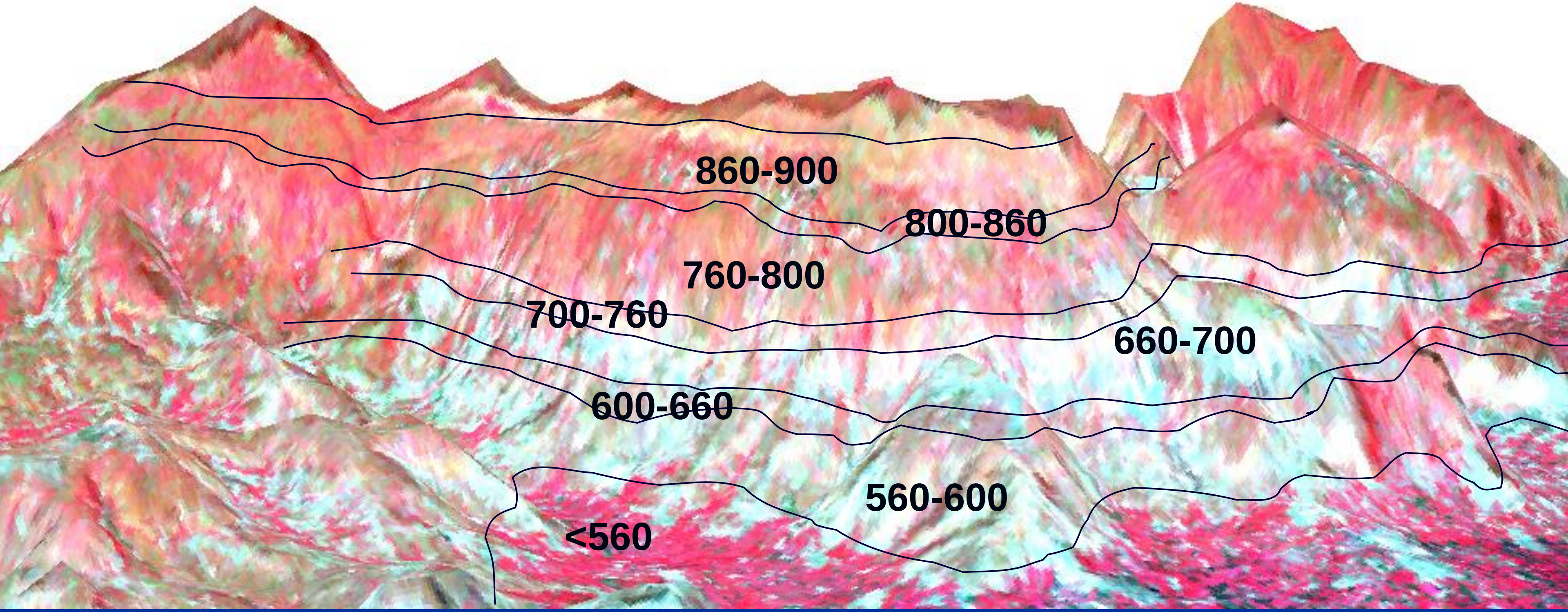

Transitional Flow
Massive Flow

# Multiple flows

5TH FLOW
ESCARPMENT
4TH FLOW
ESCARPMENT
3RD FLOW
2ND FLOW
1ST FLOW



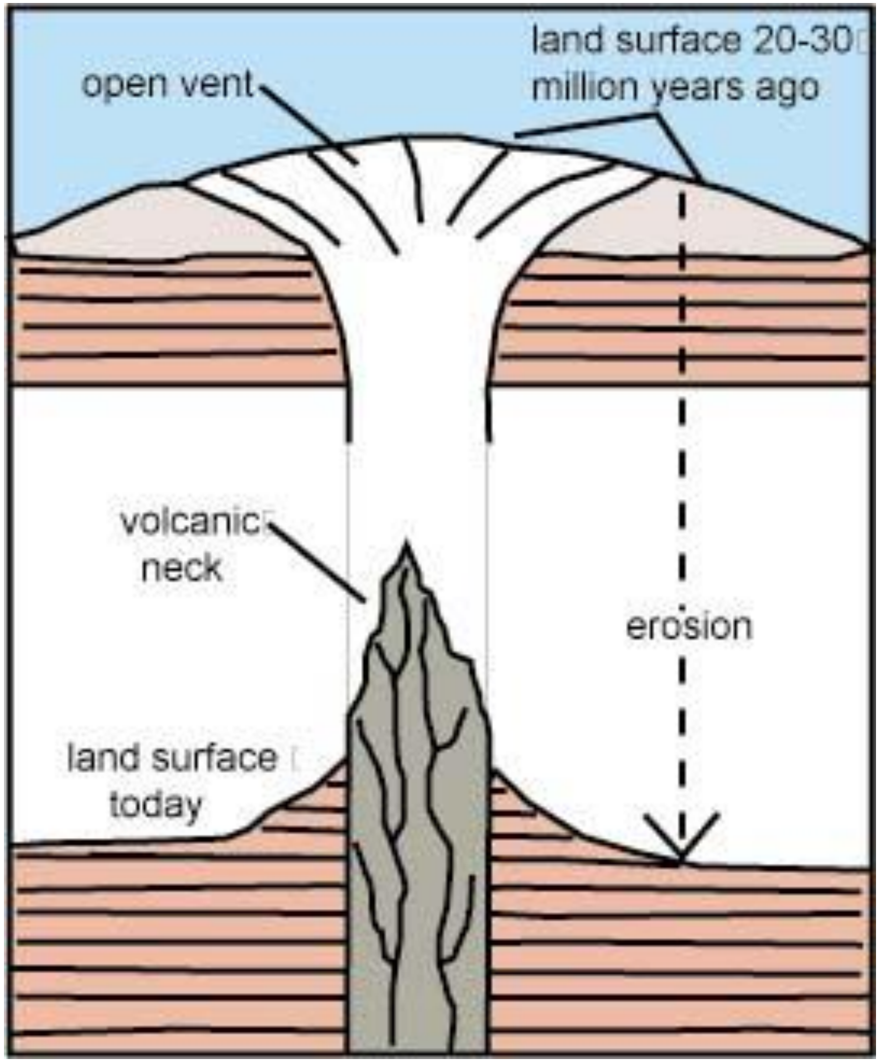
# DEM Wrapped FCC image showing different level of flow elevation



- Sometimes magma rises upward through cracks in the crust but does not reach Earth's surface.
- The magma cools and hardens into rock beneath the surface
- Features formed by magma include volcanic necks, dikes, and sills, as well as batholiths and dome mountains.

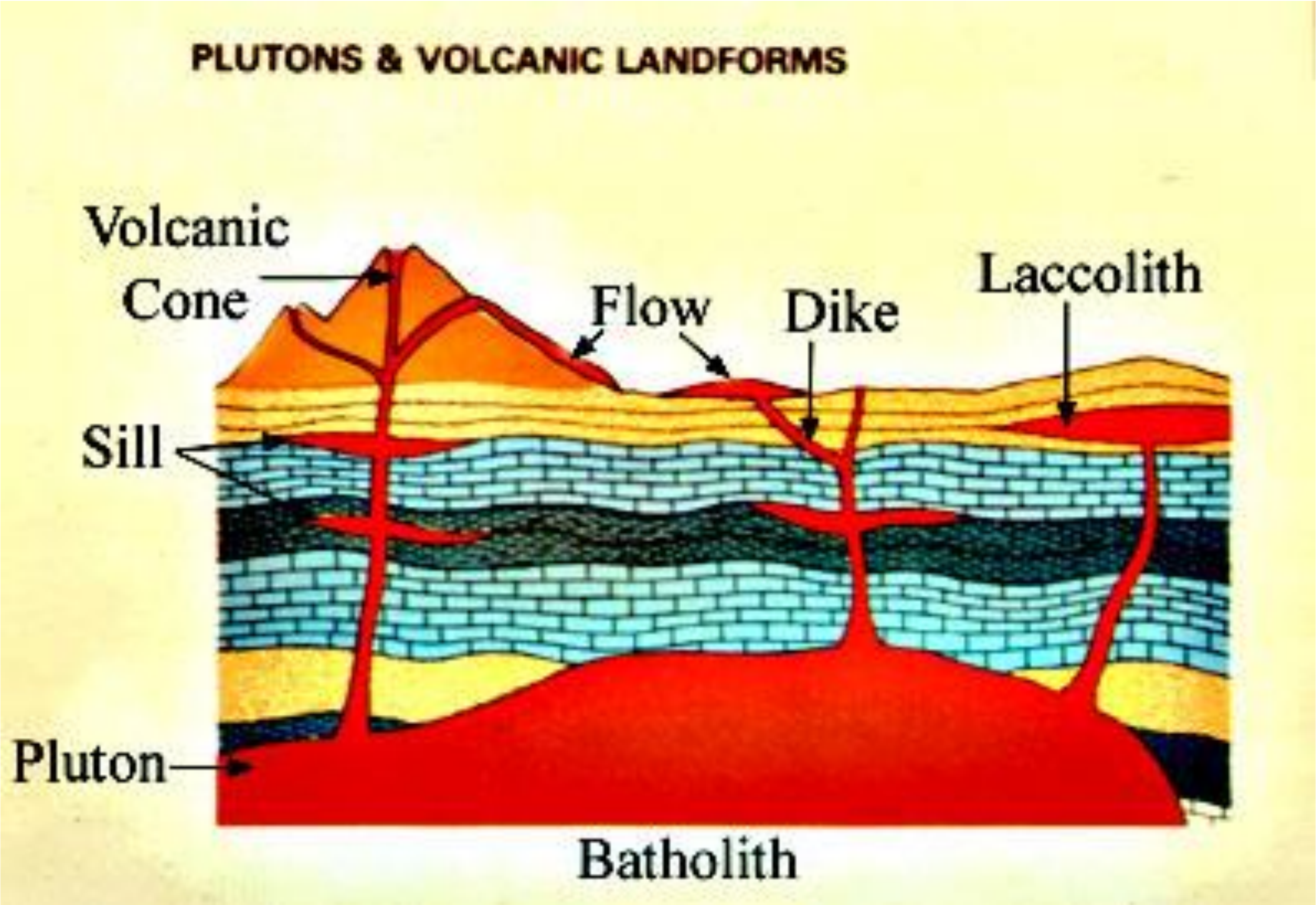
- **A volcanic neck forms when magma hardens in a volcano's pipe.**

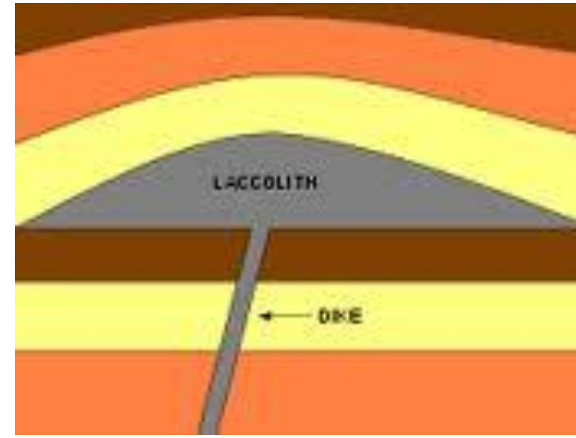
- **The softer rock around the pipe wears away, exposing the hard rock of the volcanic neck.**



- A **dike forms when magma forces itself across rock layers** and hardens.

- A **sill forms when magma squeezes between layers of rock** and hardens.





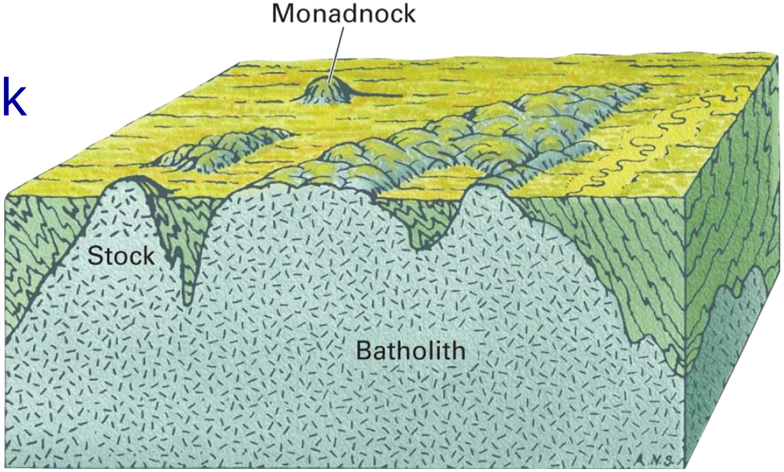

**Laccolith:** **A laccolith (also called a plutonic formation or an igneous intrusion) is a formation in which magma (molten rock) is trapped beneath the surface of the Earth and pushes the rock located above it into a dome shape. It has a flat base and a convex upper surface. The magma cools and solidifies, and eventually, it is exposed (as the fractured sedimentary rock above it erodes away). Laccolith means "cistern stone" in Greek.**

- When a large body of magma cools inside the crust, a mass of rock called a **batholith forms.** Because of erosion, it will be exposed in the surface

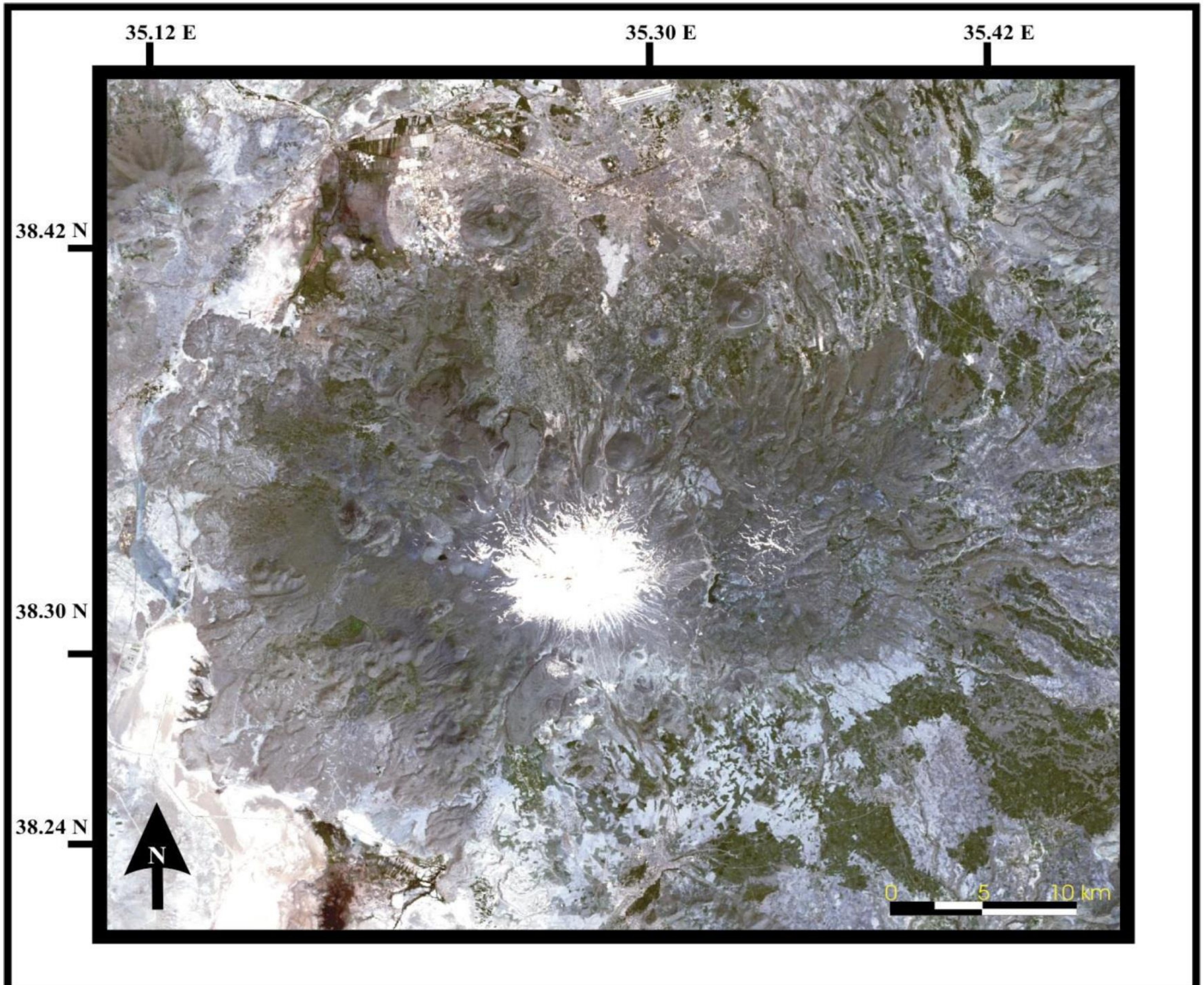
# Exposed Batholiths and Monadnocks

*Batholiths:* huge bodies of intrusive igneous rock

- Form hilly or mountainous uplands
- *Monadnock*: a mountain that rises out of a surrounding plain and that develops because it consists of more resistant rock than the bedrock of the surrounding region




- **Smaller bodies of hardened magma can** form dome mountains.




gure 1. Landsat ETM image of Erciyes Stratovolcano
omplex

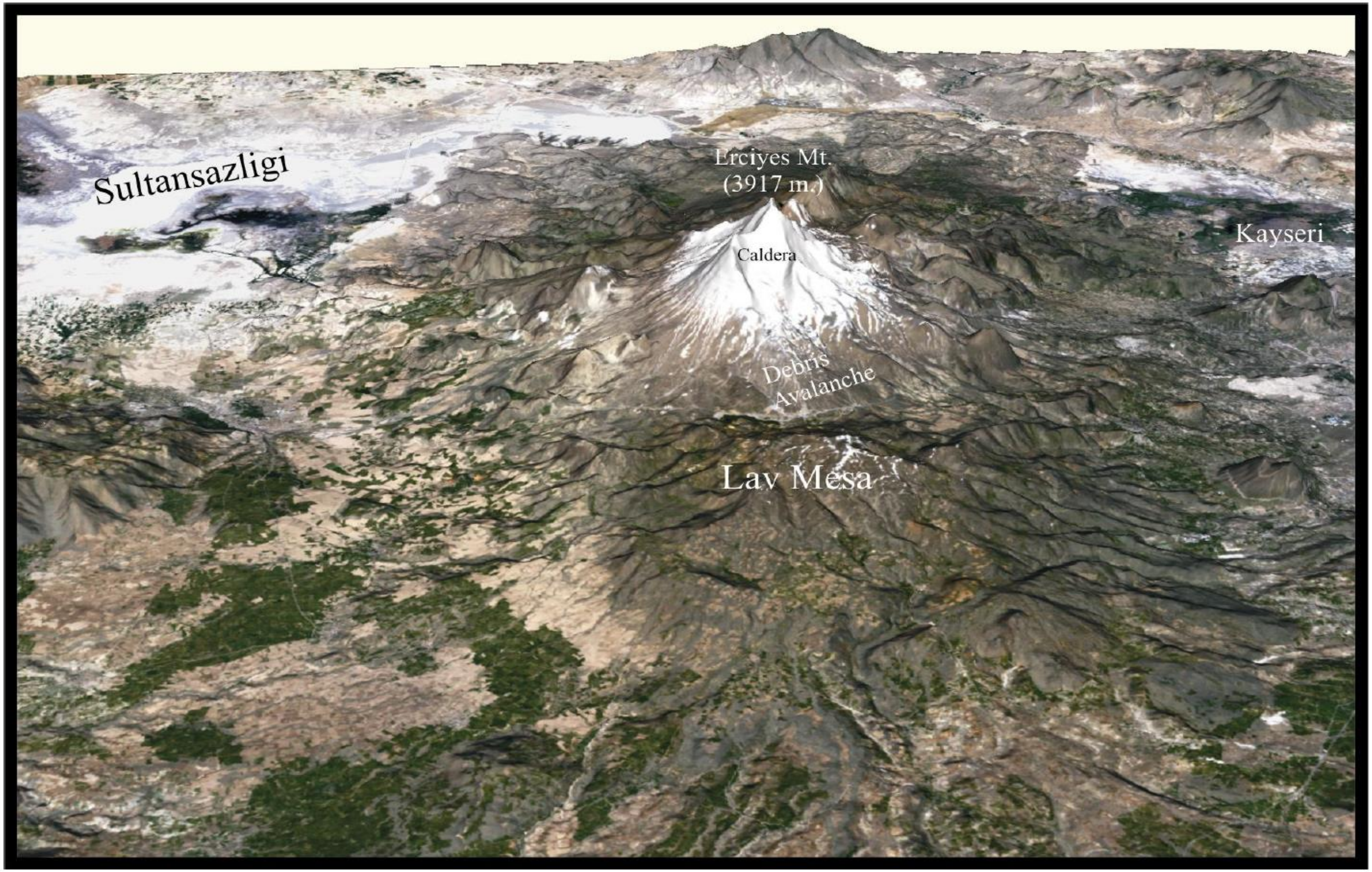
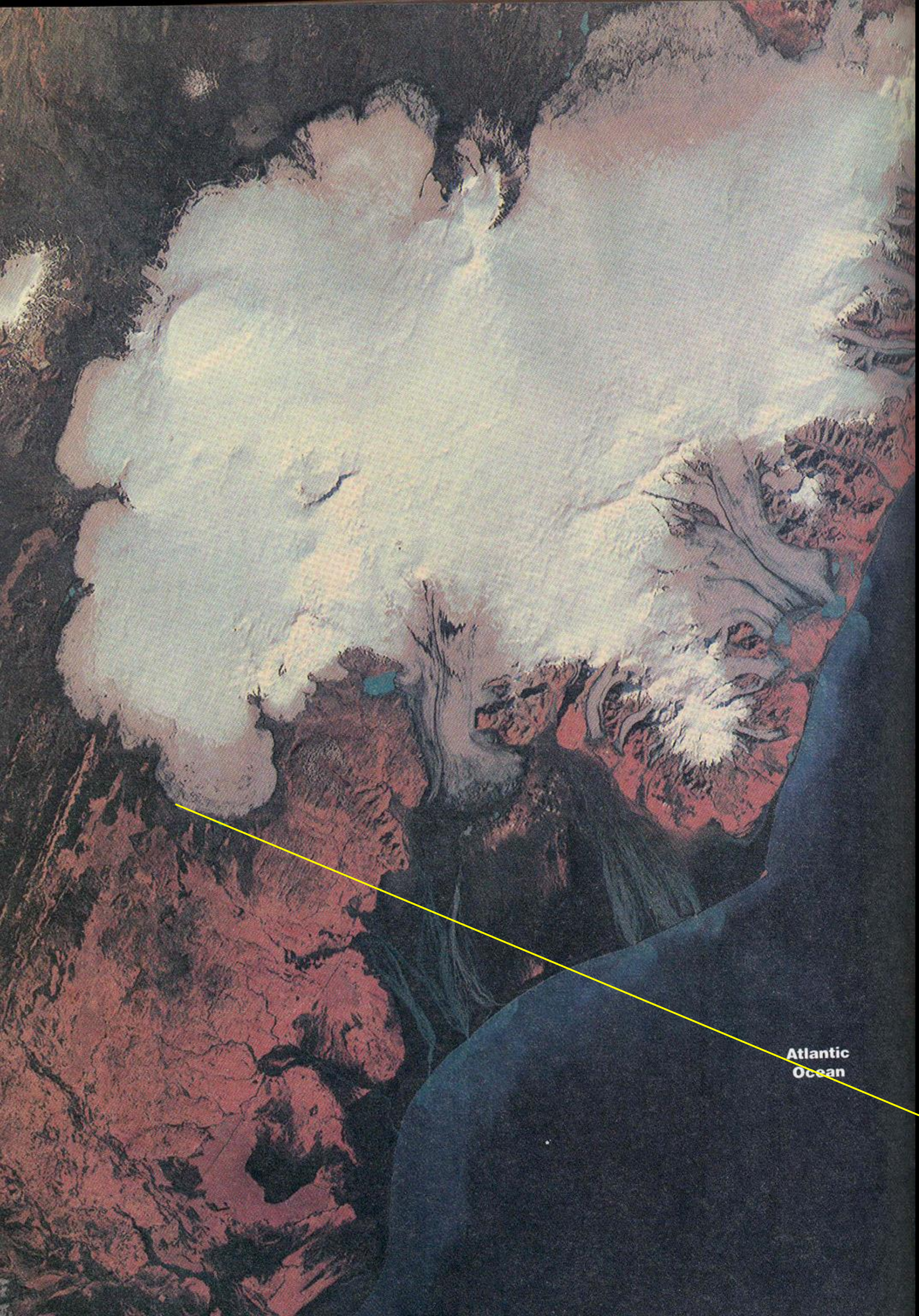



Figure 3. Perspective view of Erciyes Stratovolcano Complex.

## Glaciers

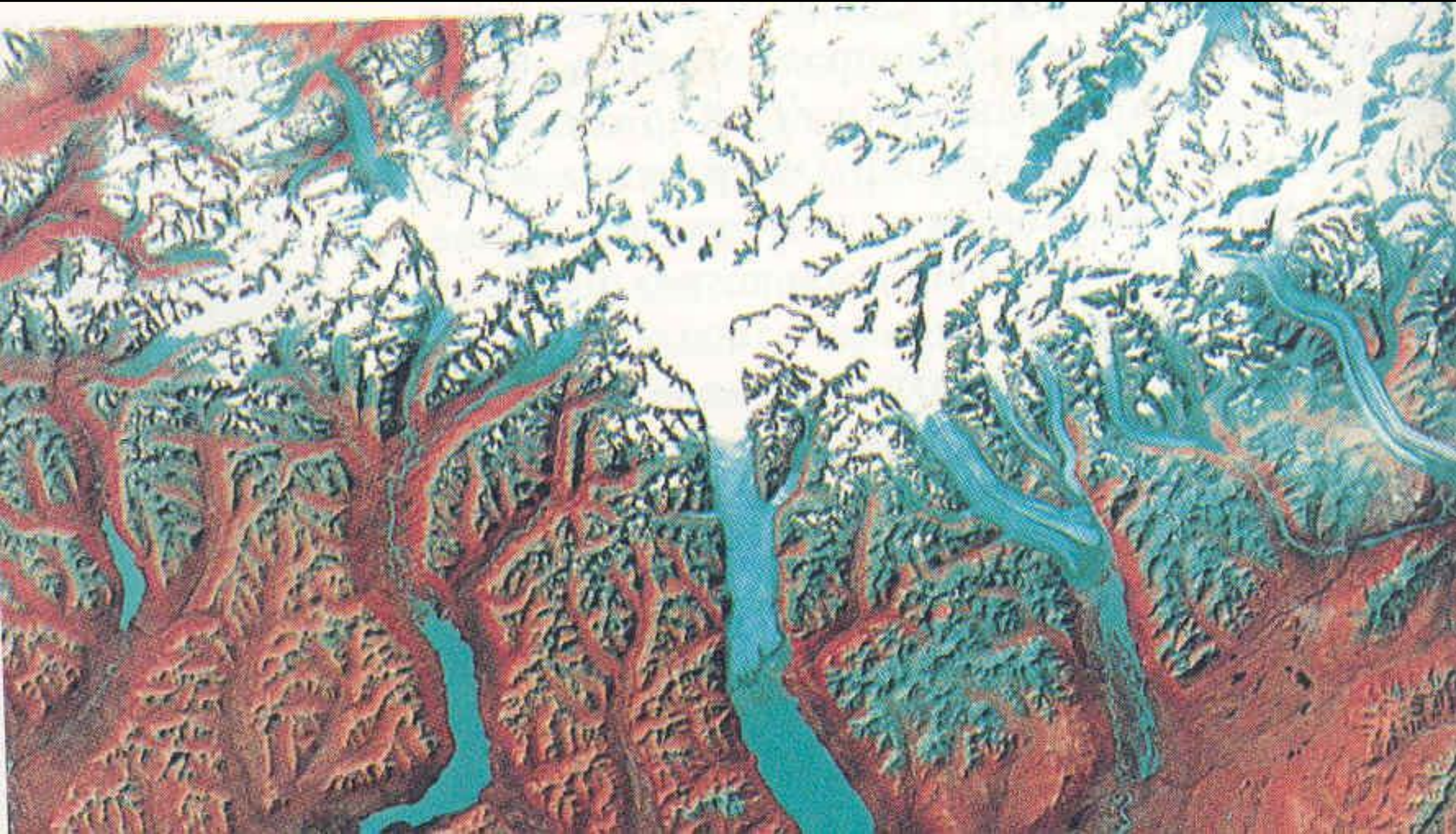
**Glaciers are rivers or sheets of recrystalised Ice that survive all year along and move in response to their own weight and slope. They carve beautiful landscapes and deposits hills of sediment**




# Vatnajokull Glacier, Iceland

# Valley glacier on Bylot Island

It is just off the northern end of Canada’s Baffin island originate in the snow fields that almost completely cover the mountain peaks. Note that the snowline extends down almost to sea level. The main glaciers extend down from the highland as tongues of ice (blue). Note the glaciers, like river systems, consist of a main trunk stream and an intricate system of branching tributaries



Glaciers in the Himalayas show this continuing condition of retreat. The mountain glaciers in Bhutan shown here are shrinking and developing new lakes at their terminal - solid indications of diminishing glacial active in that region.

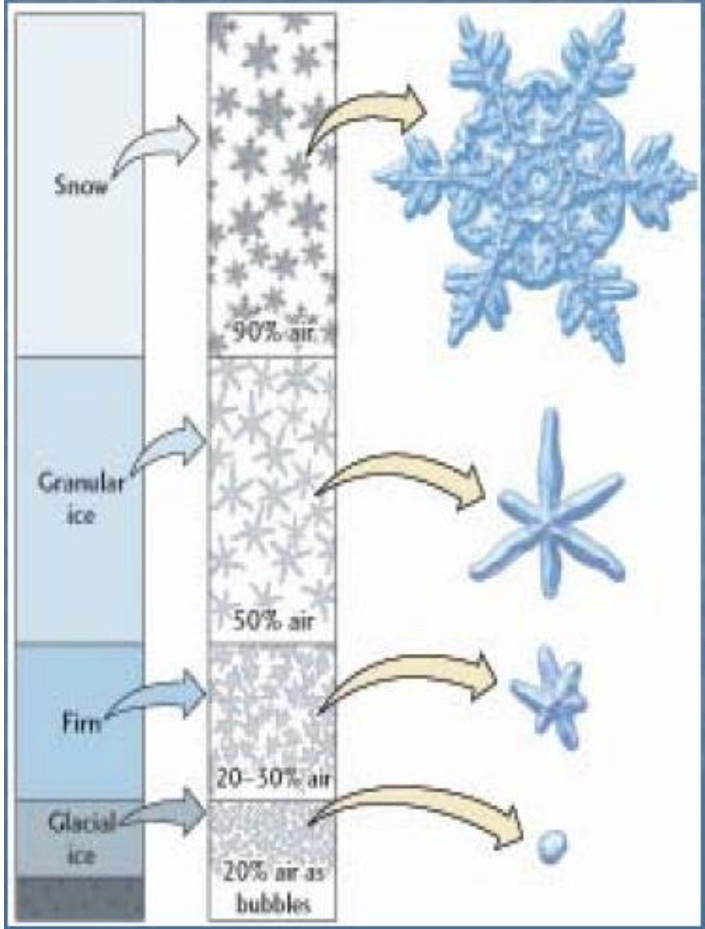
The image is a special, false-color image, using yellow, red, and blue filters, to enhance various types of ice and glacial zones.

It shows the thick ice cap (defined as a dome-shaped ice mass with radial flow) known as Vatnajökull, in south-central Iceland which has 43 outlet glaciers (light blue), many with lobate termini.

Areas in yellow-orange are vegetated, while reds associate with basaltic rocks and sparse vegetation.
Green in the ocean is sediment, and

black around the ice cap is a zone of ground soaking from glacial meltwater.

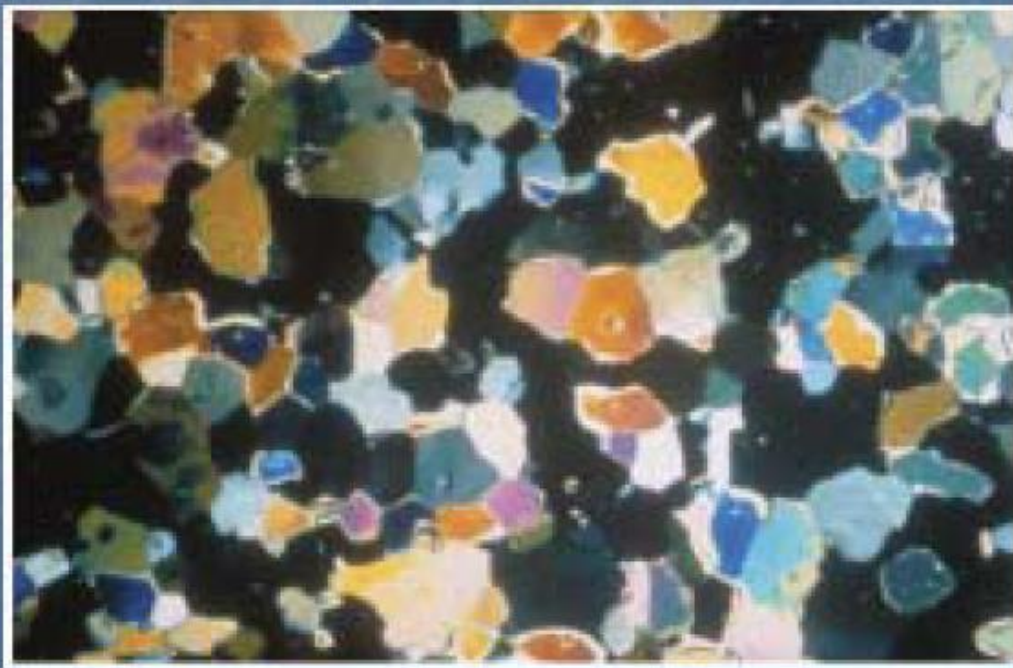
# Glacial Ice




- Accumulates where snowfall in winter exceeds melting in summer
- When snow is greater than several meters thick it is compressed into a more compact form termed firn
- When the snow/firn layer is > 30m thick the material is compacted into pure ice

# Glacial Ice

- Glacial ice will recrystallize under the pressure of the overlying snow/firn to form a polygonal texture (similar to granoblastic metamorphic rocks)



## Glacier Formation

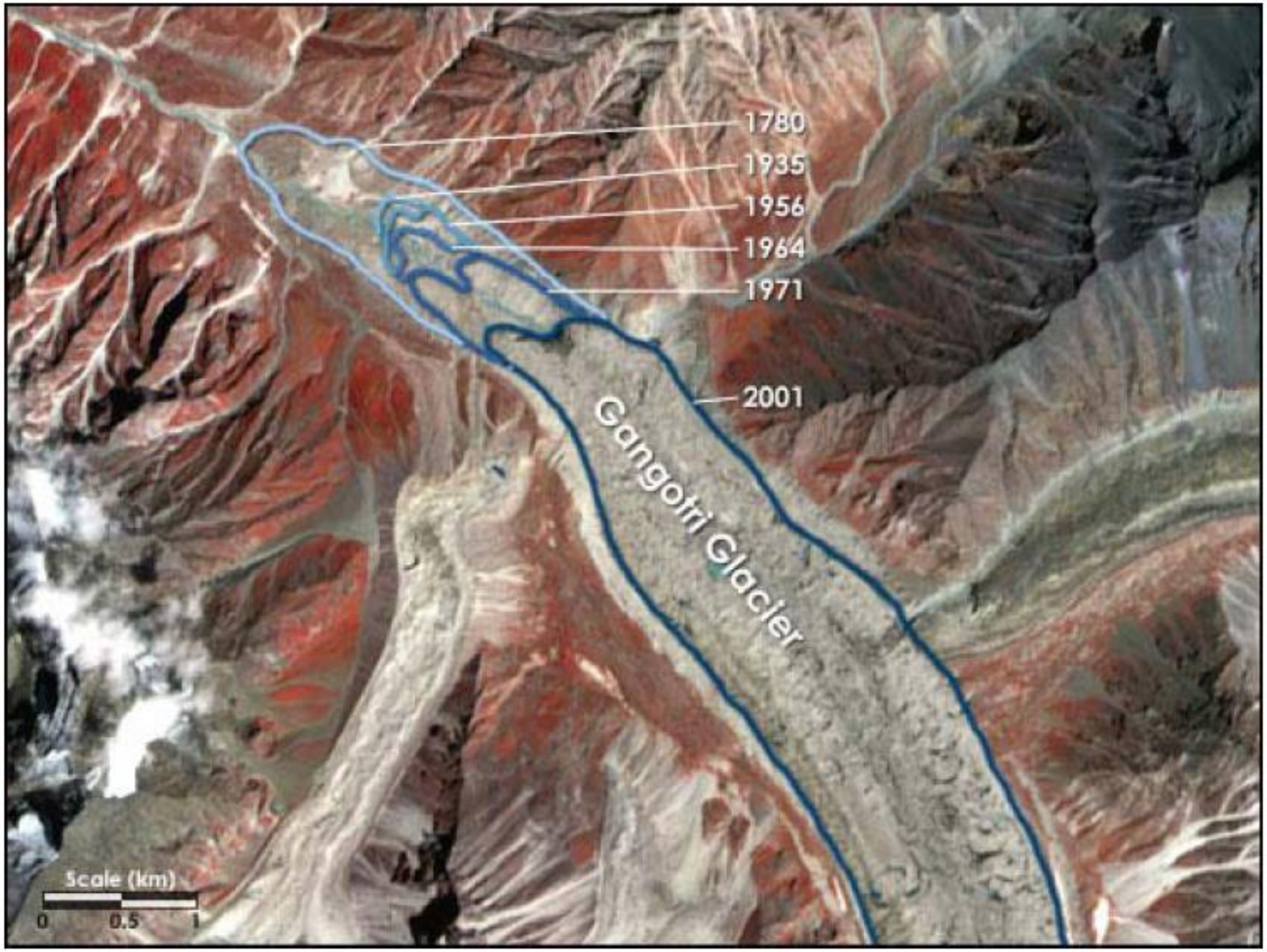
**Large, long-lasting accumulation of snow & ice that develop on land**

**Time passes –ice mass begins moving due to pull of gravity**

**Periods of…**

- **ADVANCING (cold temps + moisture = accumulation)**
- **RETREATING (warm temps = melting)**

# Movement: Advancing & Retreating



# Zones of Accumulation & Ablation

## Zone of Accumulation

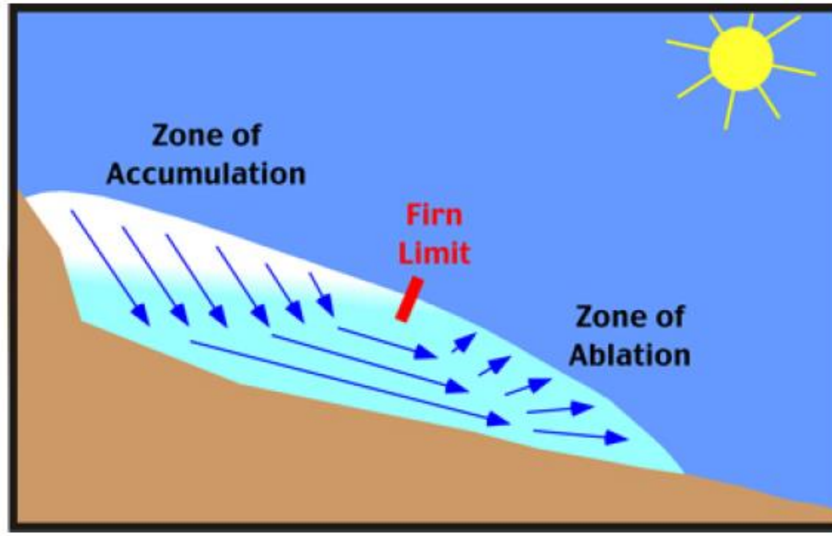
- ❖Area where glacier is gaining precipitation
- ❖Upslope –higher elevations

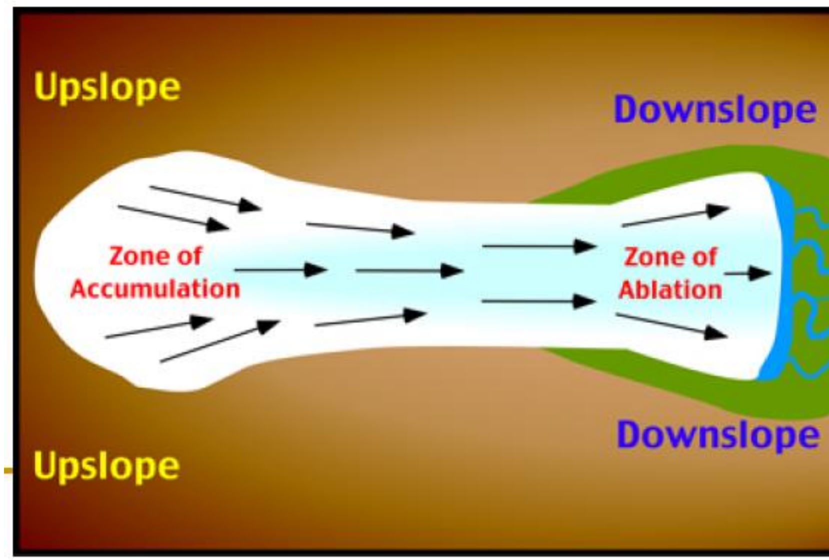
## Zone of Ablation

- ❖Area where glacier is melting
- ❖Downslope–lower elevations

## Sublimation

- ❖Occurs when ice is directly changed into water vapor



# Glacier Zones

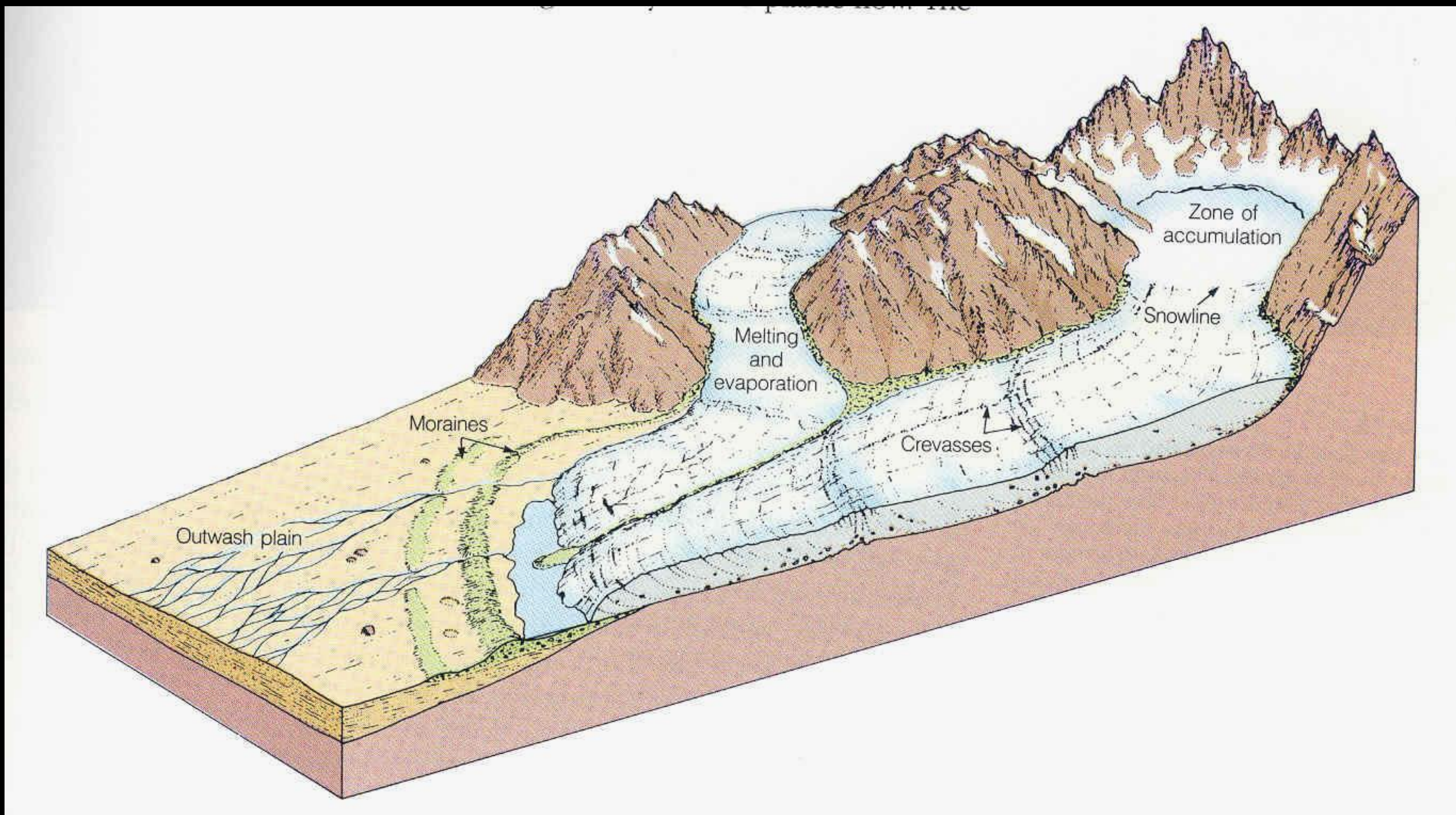



Southwestern coast of Greenland

# Ablation

Matanuska Glacier, AK. Foto: Lachniet (1997)

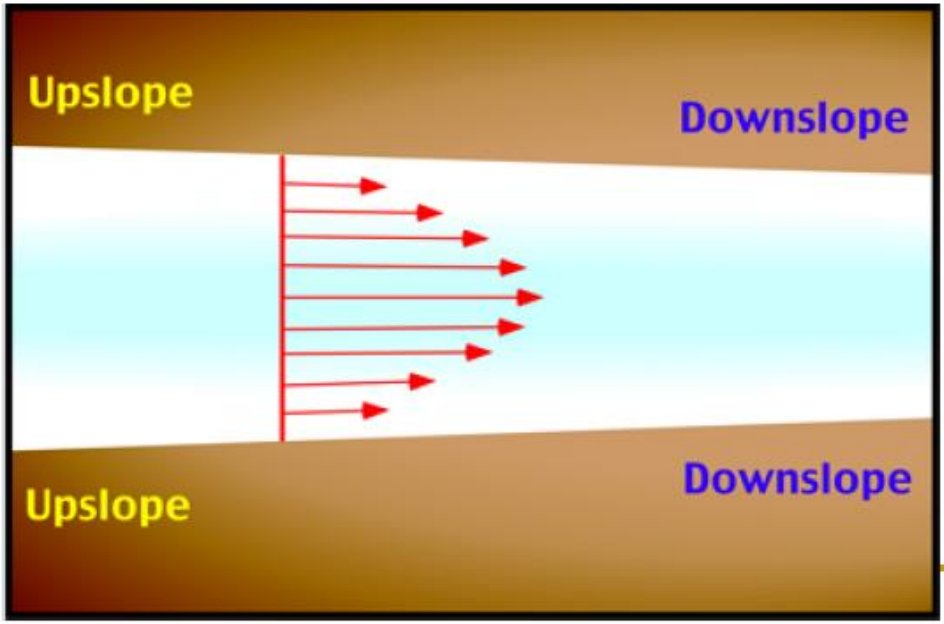
# A Glacial system

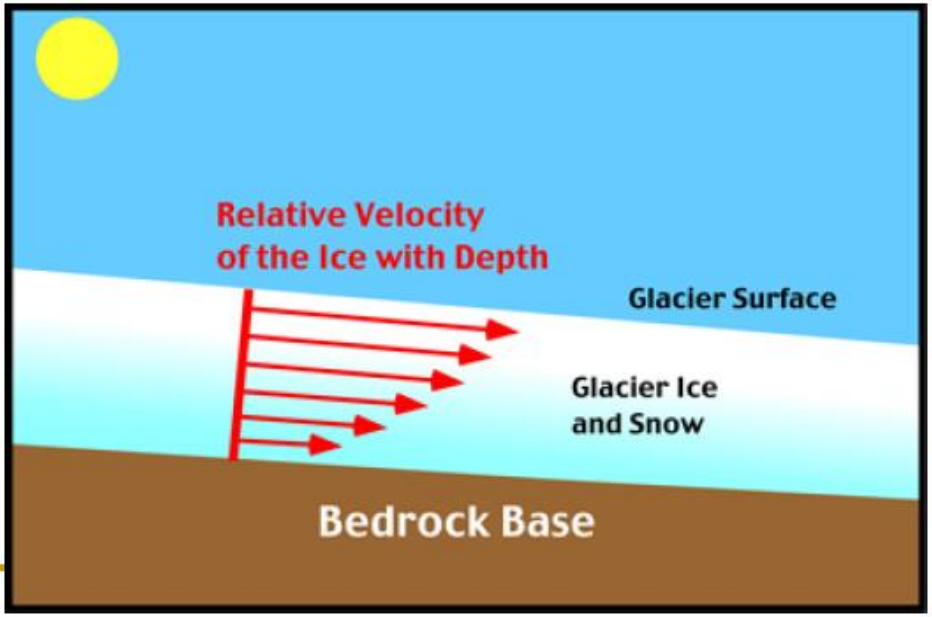


# Movement of Glaciers

To be called "glacier", mass of ice must be capable of MOVEMENT

- Movement within glacier is not uniform.
- Middle and top of glacier moves faster than sides and bottom.



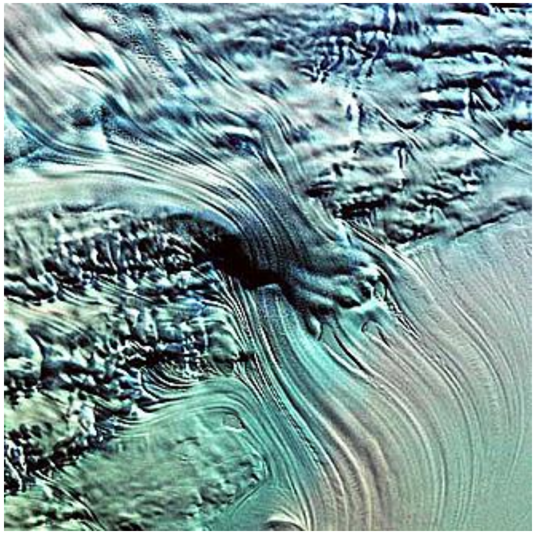



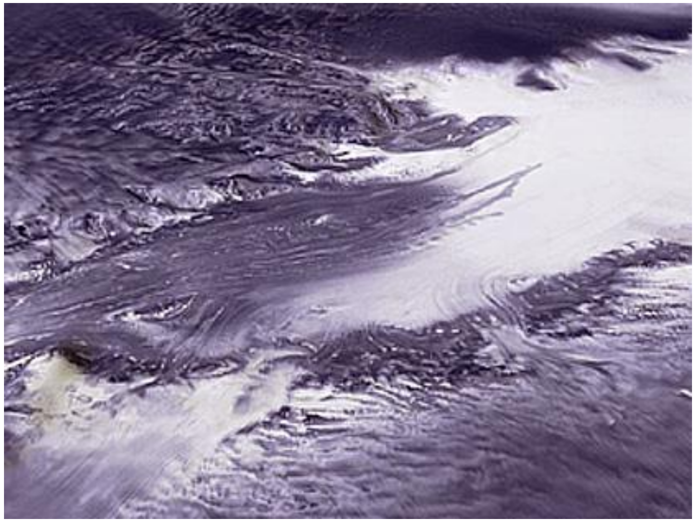
## Glacial Movement

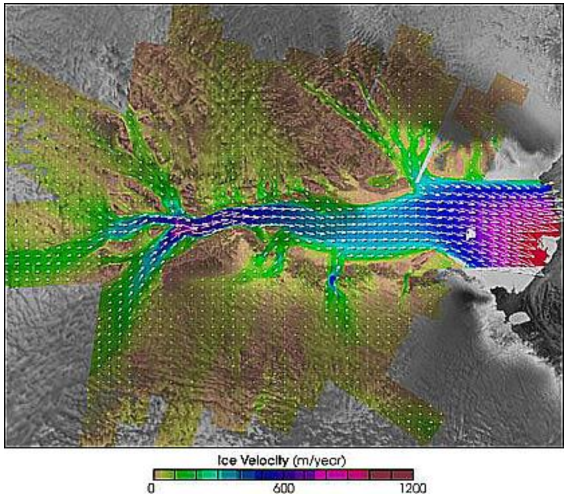
**Plastic flow:** **under the influence of gravity glacial ice will undergo plastic flow as much as several meters per year**

**Basal slip:** **under sufficient pressure the basal ice in a glacier will melt allowing the entire glacier to undergo basal slip up to a kilometer per year**

The largest and longest glacier in the world is the Lambert Glacier, in northeastern Antarctica (Australian sector), which meets the sea at the Amery Ice Shelf. Its length is given as 403 km (250 miles); it width reaches to 64 km (40 miles).







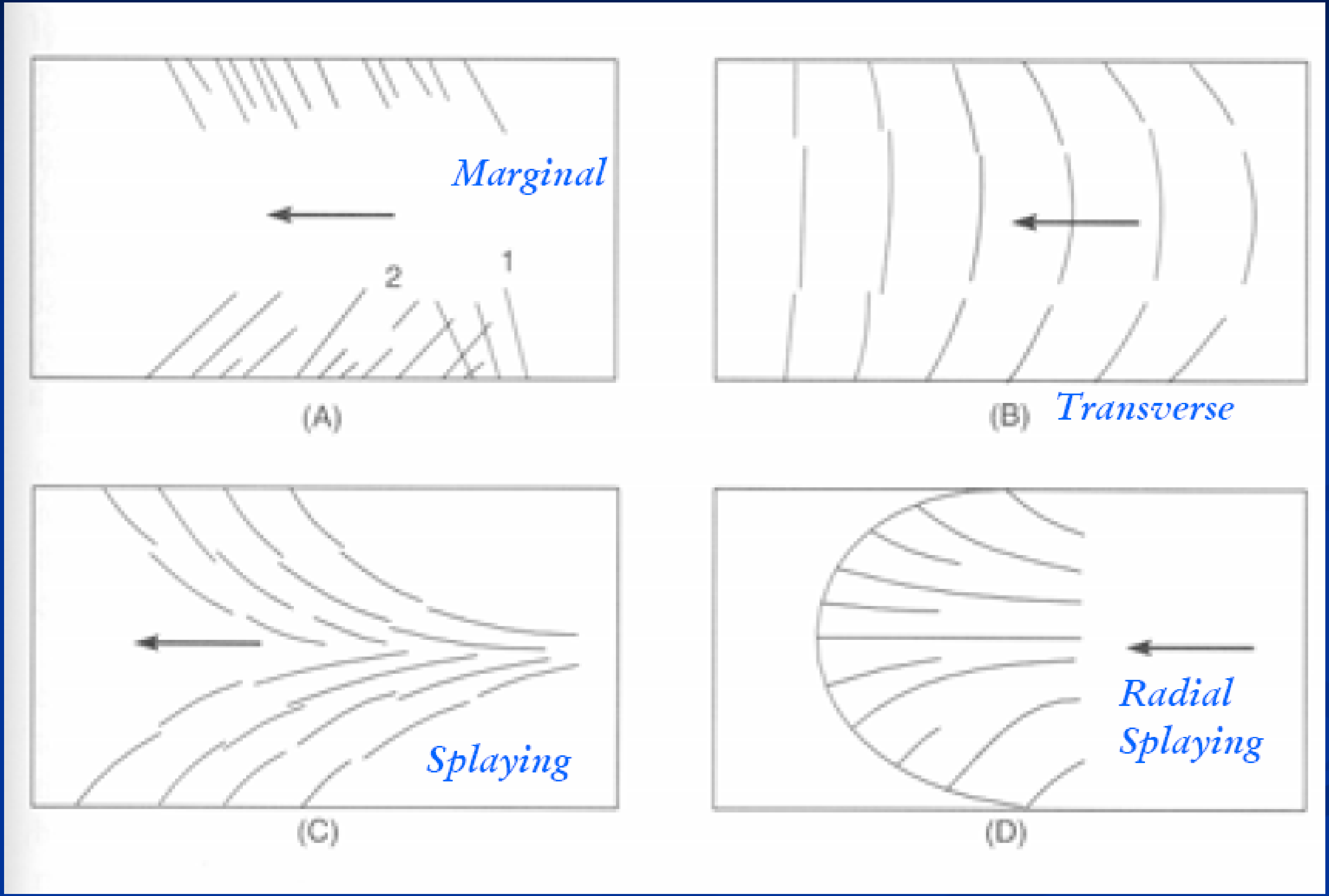

Three space images: the first shows part of the glacier in a Landsat image; the center is a perspective view made using DEM data; the third displays rates of flow determined from radar data taken over an extended period:

# Crevasses

- **Crevasses are cracks in the glacier ice**
- **Form at low confining pressures**
- **near the glacier surface ice is brittle**
- **Seracs are a form of crevasses that commonly form at icefalls**

- Longitudinal crevasses develop in areas of compressive stress
- Transverse crevasses develop in areas of tensile stress
- Marginal crevasses occur when the central portion of the glacier flows faster than the outer edges.

# Crevasses

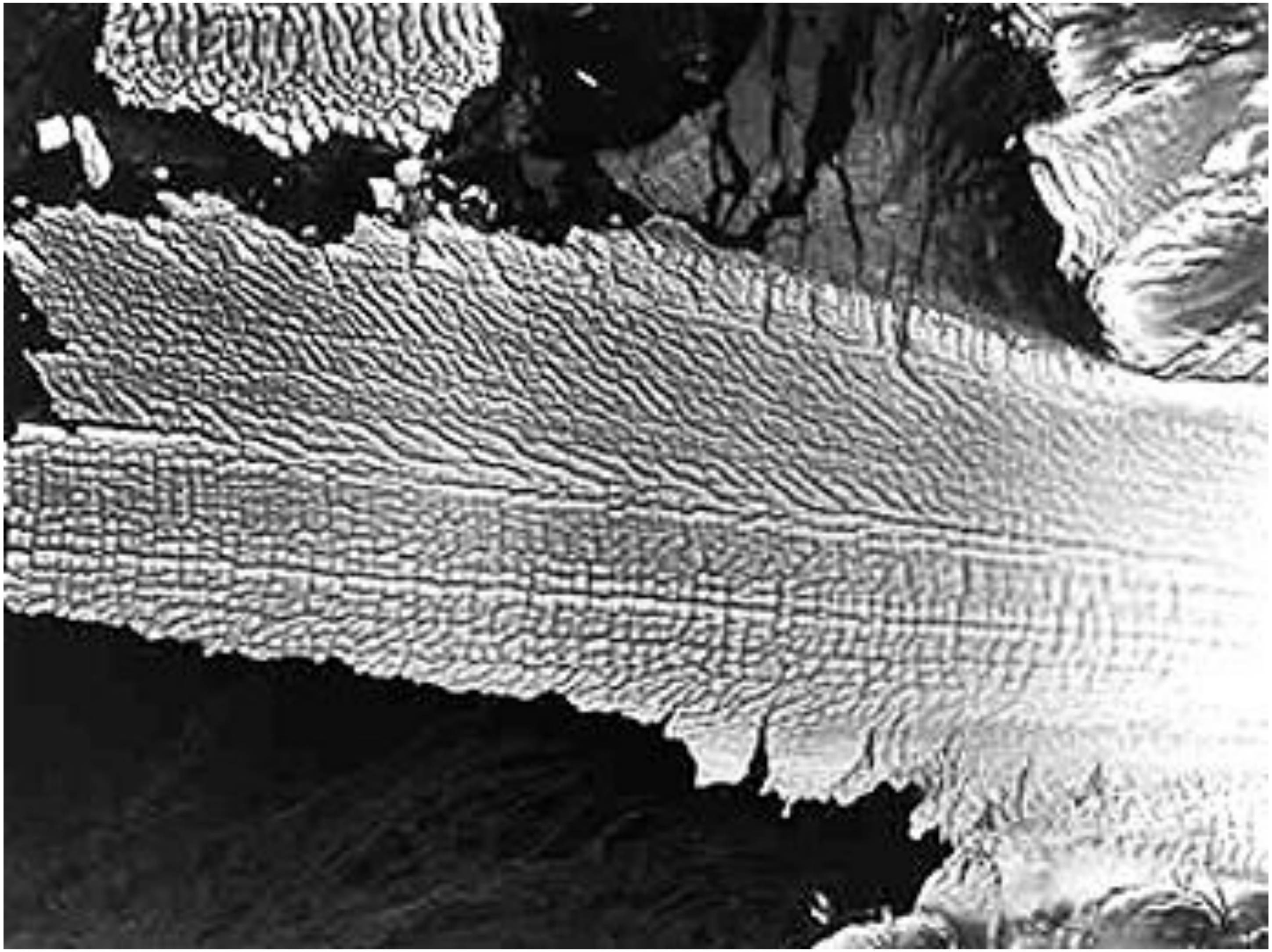



From Ritter et al., 2002. Process Geomorphology, Fourth Edition

# Crevasses in a glacier, Alaska

Crack or fissure in a glacier resulting from stress due to movement, Glacial crevasses may be 20 m wide, 45 m deep and several hundred meters long. Longitudinal crevasses develop in areas of compressive stress, transverse crevasses develop in areas of tensile stress, marginal crevasses occur when the central portion of the glacier flows faster than the outer edges. Jagged ice pinnacles may form where crevasses intersect at the glacier terminus

**This JERS-1 SAR (radar) image of an Alaskan glacier brings out the details in the cracking of the ice as the entire mass moves slowly down gradient.**

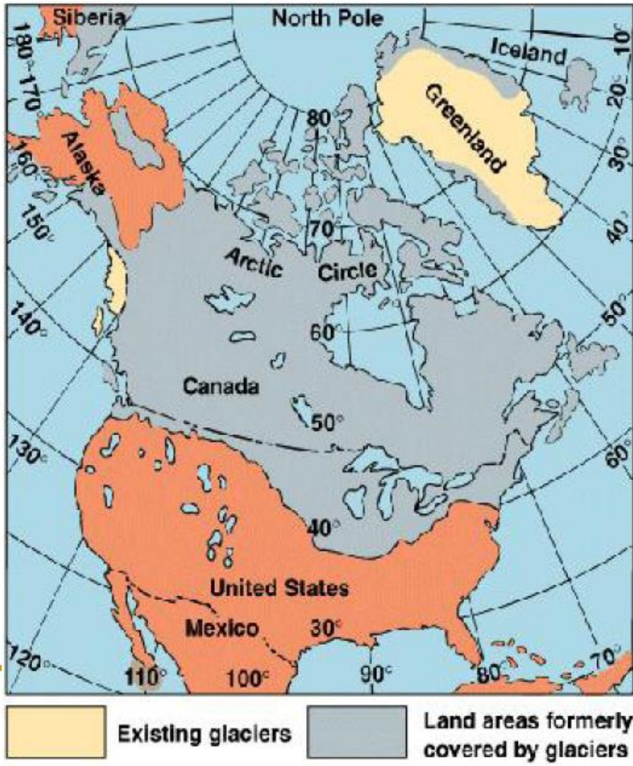


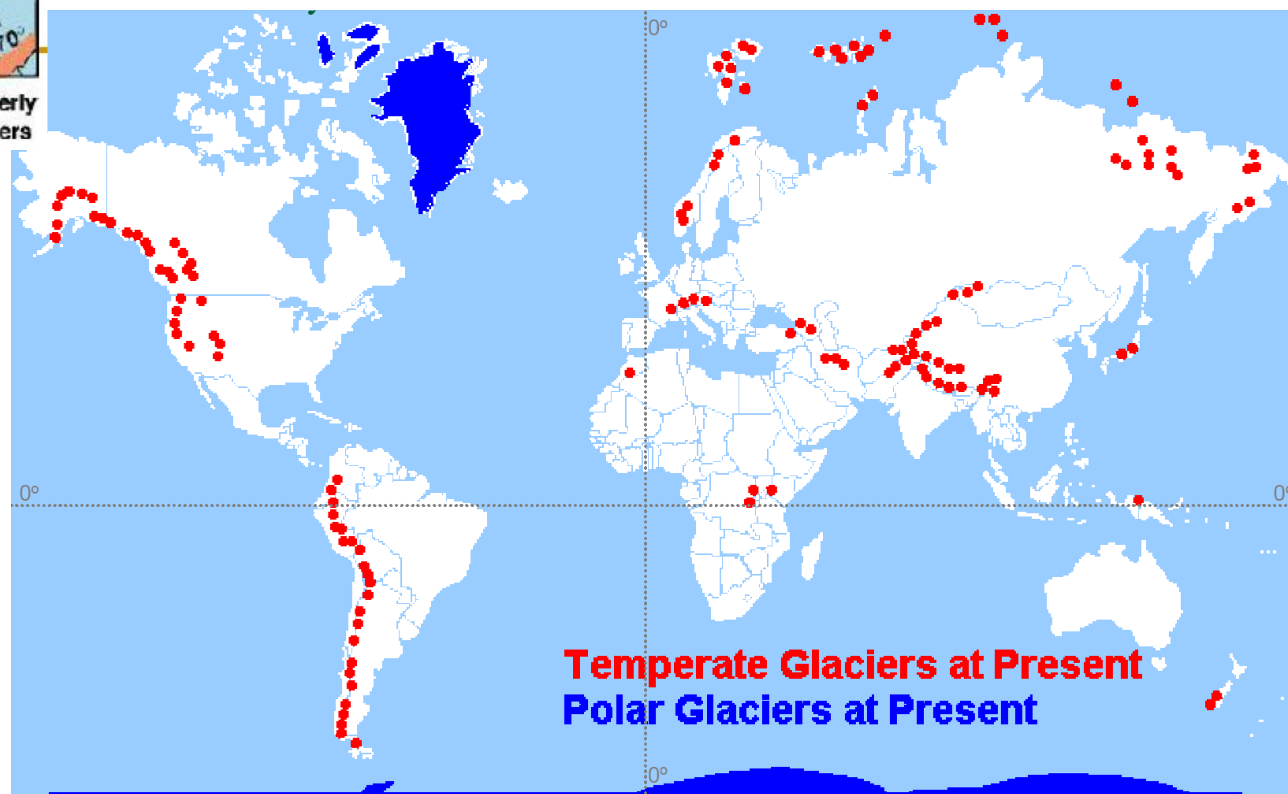
# Glacial Mass Balance


**Calculated by the difference in amount of snow accumulated (winter) and the snow melted (summer).**

**Snow accumulated is less than Melted snow, mass balance is positive and the glacier has increased in volume.**

**Melted snow is more than Snow accumulated, mass balance is negative and the glacier volume decreased.**


Siberia
North Pole
Iceland
Greenland
Alaska
Arctic Circle
Canada
United States
Mexico
Existing glaciers
Land areas formerly covered by glaciers


Temperate Glaciers at Present
Polar Glaciers at Present

# Categories of Glaciers

## Continental Glacier:

- ❖ Large ice masses that cover significant portions of continents and are a mile or more thick

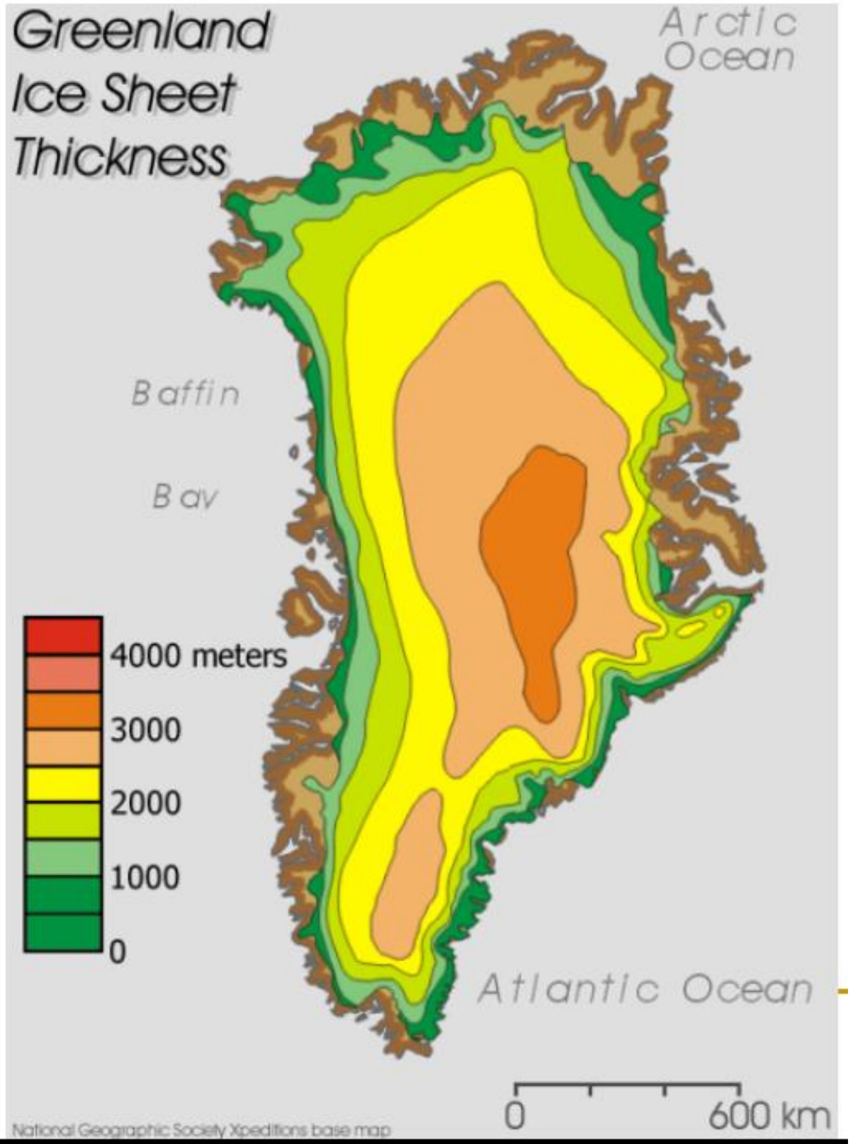
Largest type: only 2 exist

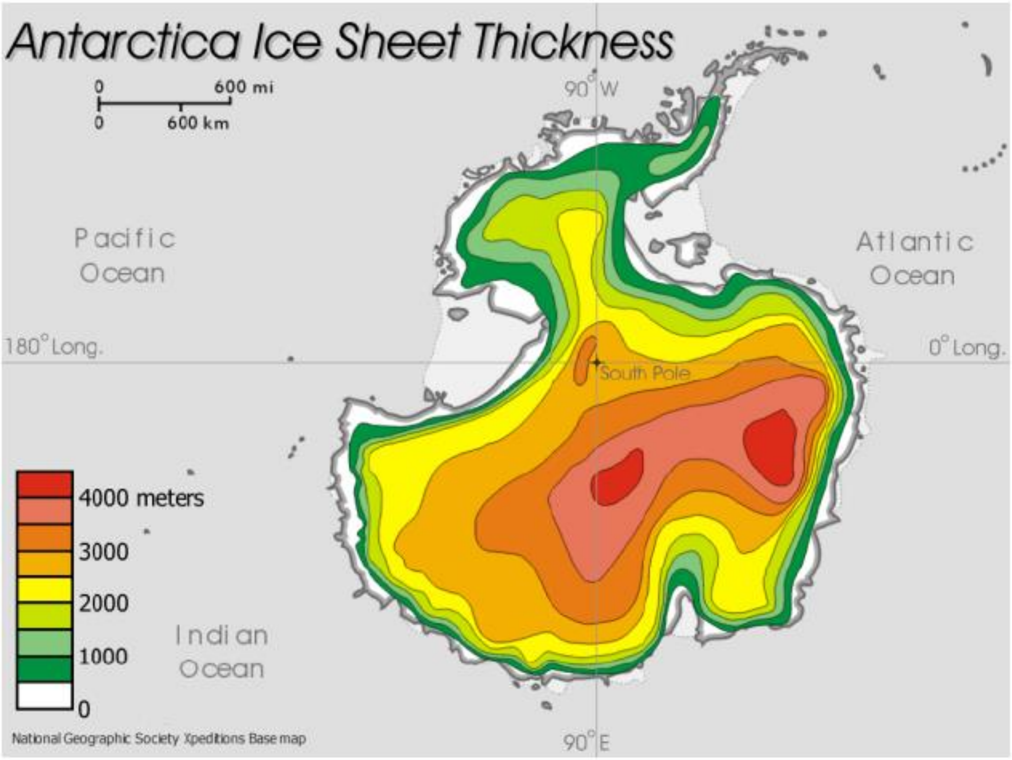
- ❖ANTARCTICA and GREENLAND
- ❖Surface coverage of at least 2Million sq. miles

## Mountain/Alpine Glacier

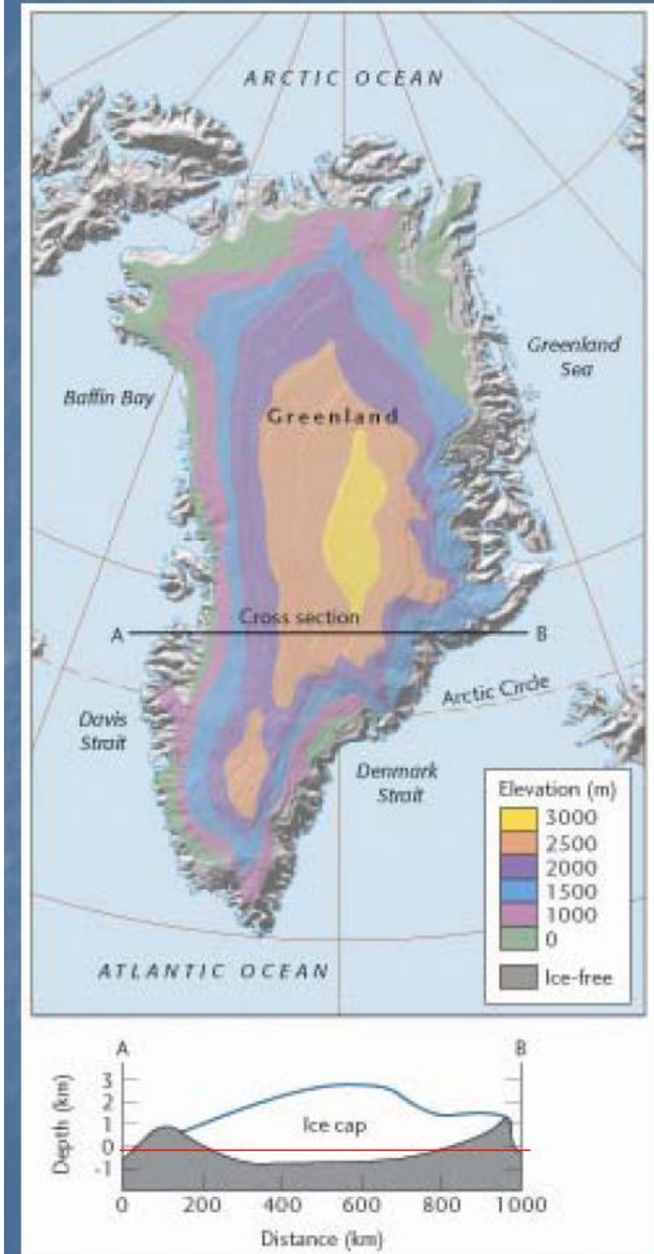
- ❖Occupies a U-shaped valley on a mountain
  - ❖ 2 MYA (Pleistocene), max extent: 1/3 land covered
  - ❖ Now: 10% land covered
  - ❖ 96% glacial ice is tied up in Antarctica & Greenland

# Continental Glaciers
## Greenland & Antarctica



# Continental Glacier




- Thick ice masses actually depress the lithosphere below sea level

# Glacial Processes

1. **Erosion**

   - **Erosion is possible due to presence of till (Combination of all sizes of sediments (pebbles to boulders) carried within glacier and eventually deposited).**

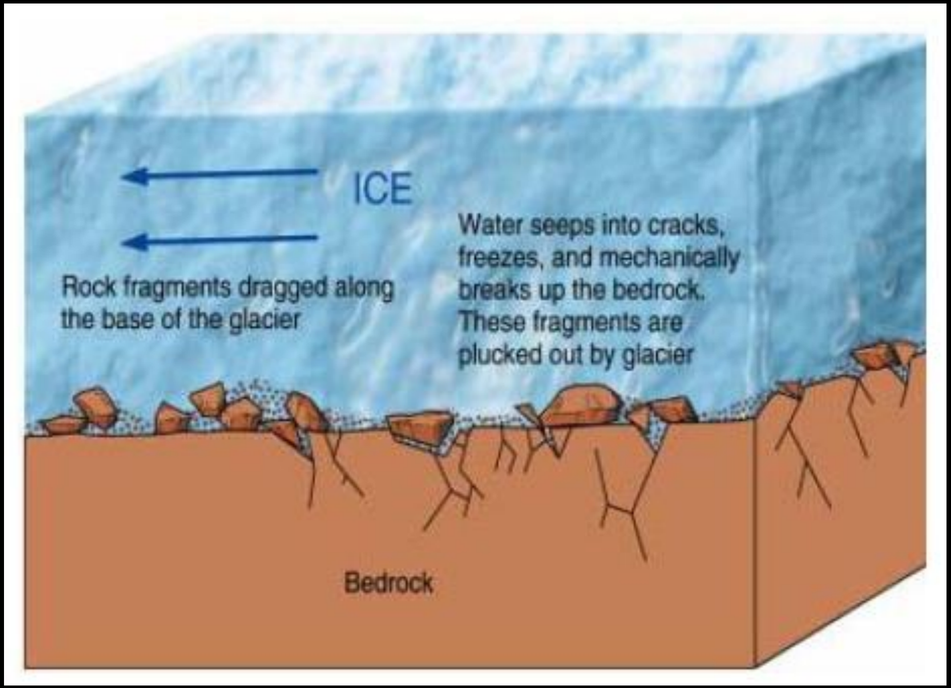
2. **Transportation & Deposition**

3. **Glaciofluvial**

# Glacial Erosion

## ❖ Plucking

- **Water gets in cracks, freezes, lifts up bits of rock and carries them in the glacier itself**
- **Leaves a blocky and irregular surface**




## ❖ Scouring

- **Abrasive action of rocks within glacier as glacier moves over surface**
- **Leaves striated surface**
- **Enough scouring creates a polished surface**

# Glaciofluvial

**Meltwater deposit materials far away from the glacier**

**Braided streams are formed –think of all that till moving inside the glacier, and what happens to it as it is carried by meltwaters.**

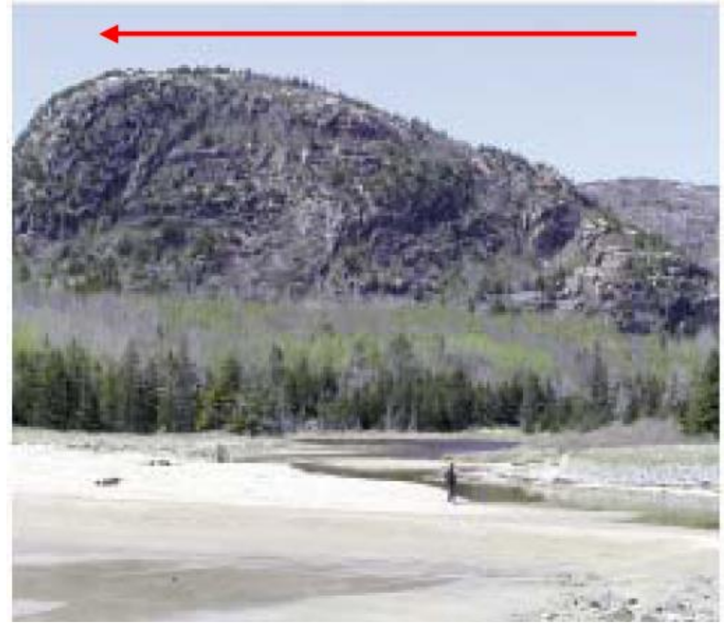
# Glacial Transportation & Deposition

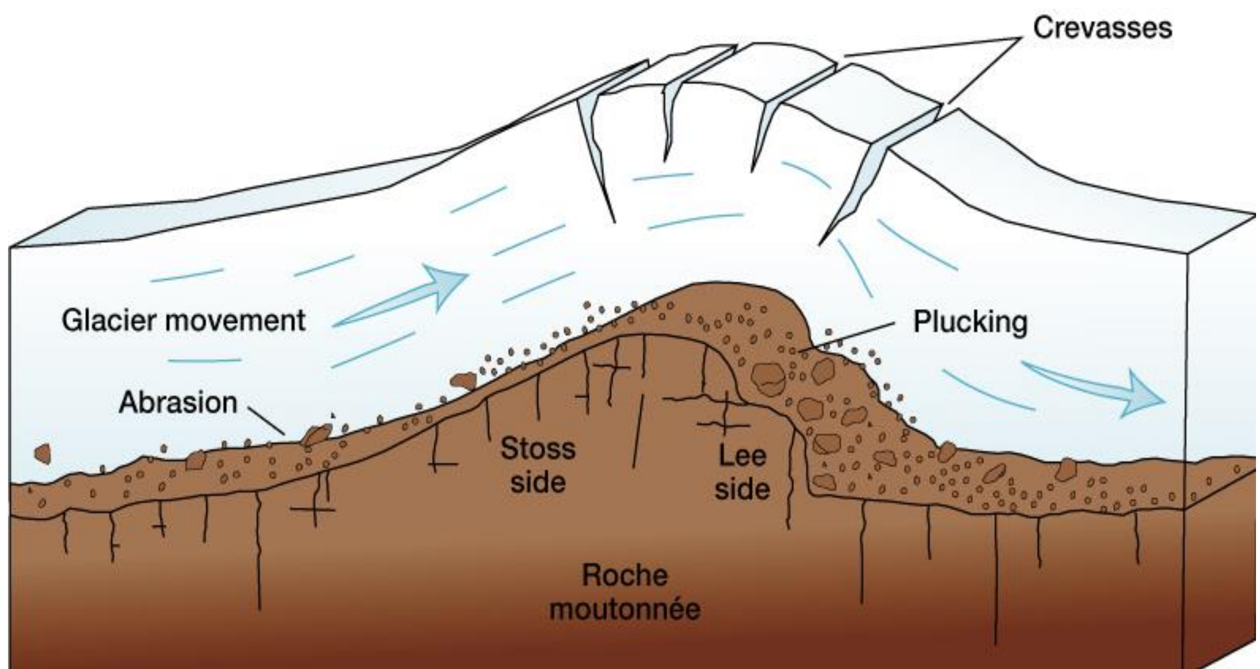
- Debris within glacier = transported
- Debris ahead or to sides of glacier = deposited
- Moraines form when till gets pushed into linear piles (heap) by the movement of a glacier.

# EROSIONAL FEATURES OF GLACIERS

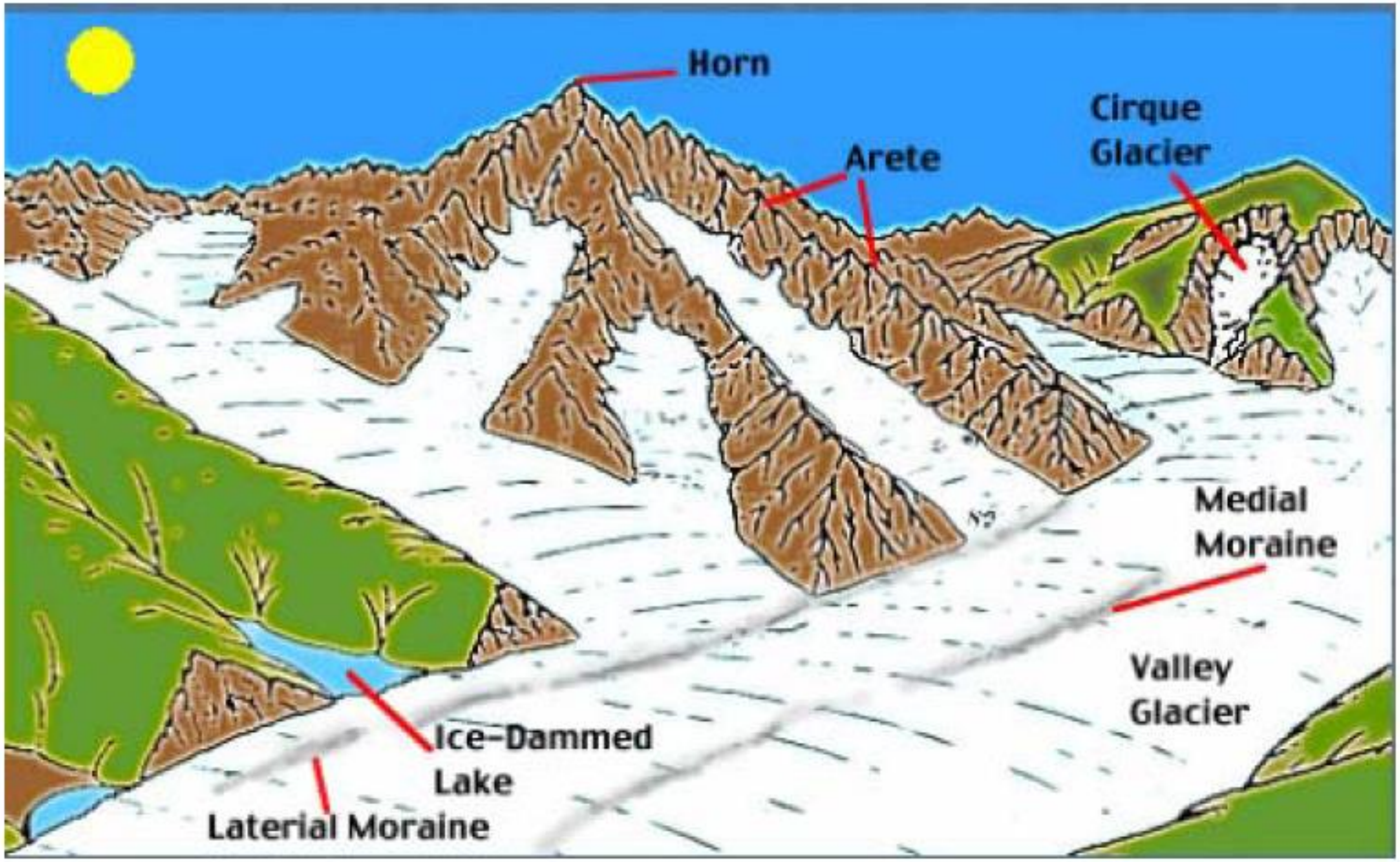
# Roche moutonee

**A glacially eroded hill that becomes elongate in the direction of flow and asymmetric; glacial rasping smoothes the upstream part of the hill into a gentle slope, while glacial plucking erodes the downstream edge into a steep slope.**





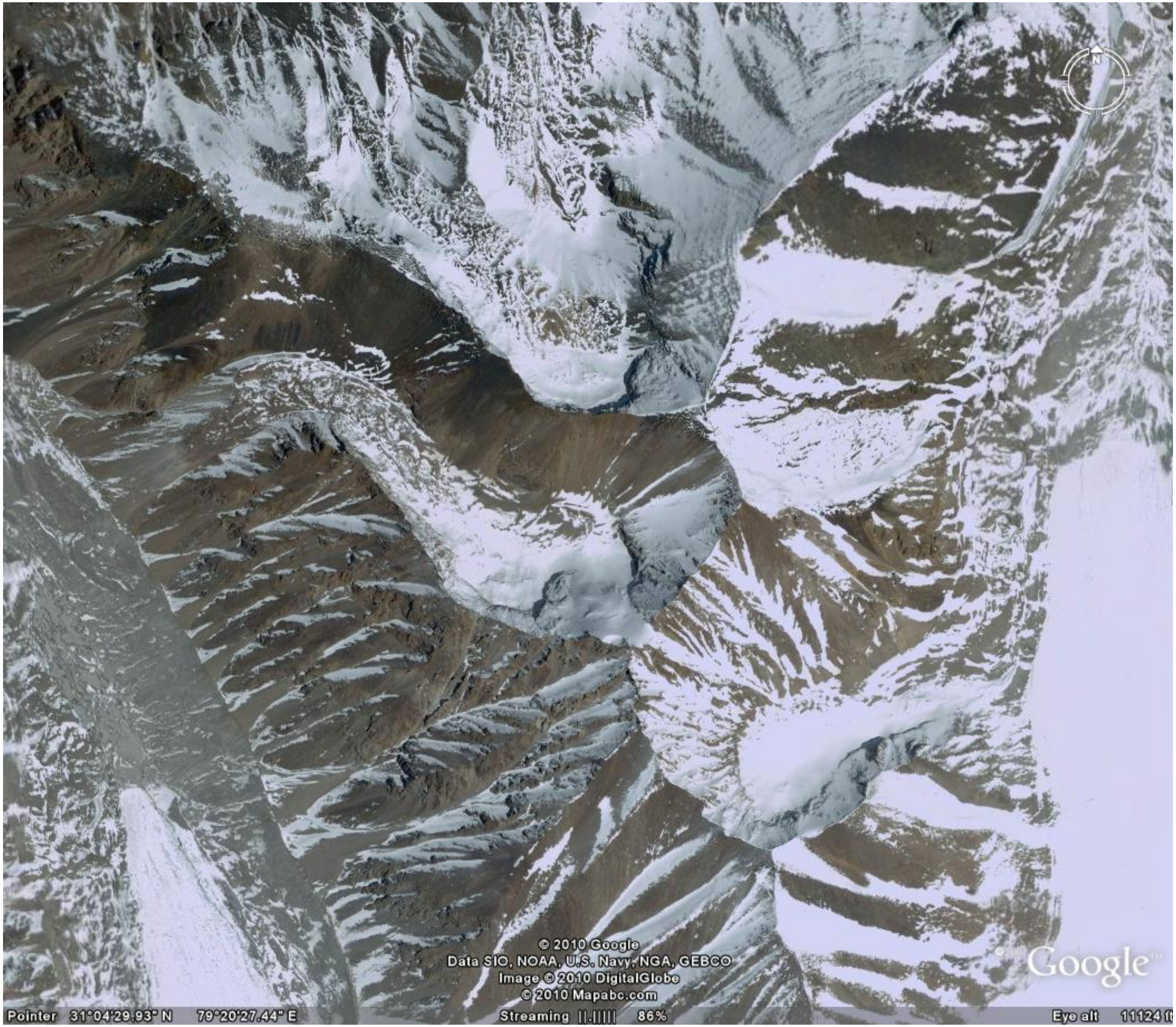
# Landforms due to Erosion in Mountain (Valley) Glaciers




- Cirque
- Tarn
- Horn
- Arete
- Glacial Valley
- Hanging Valley
- Paternoster Lakes

© 2010 Google
US Dept of State Geographer
Image © 2010 DigitalGlobe
© 2010 Mapabc.com
Google
Pointer 31°03'59.20" N 79°21'08.67" E
Streaming 100%
Eye alt 14155 ft

© 2010 Google
© 2010 Cnes/Spot Image
Image © 2010 DigitalGlobe
US Dept of State Geographer
Google
Pointer 31°03'08.07" N 79°08'18.97" E
Streaming |||||||||| 100%
Eye alt 11.00 mi


© 2010 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2010 DigitalGlobe
© 2010 Mapabc.com
Google
Pointer 31°04'29.93" N 79°20'27.44" E
Streaming
86%
Eye alt 11124 ft

# Erosional Features: Cirques

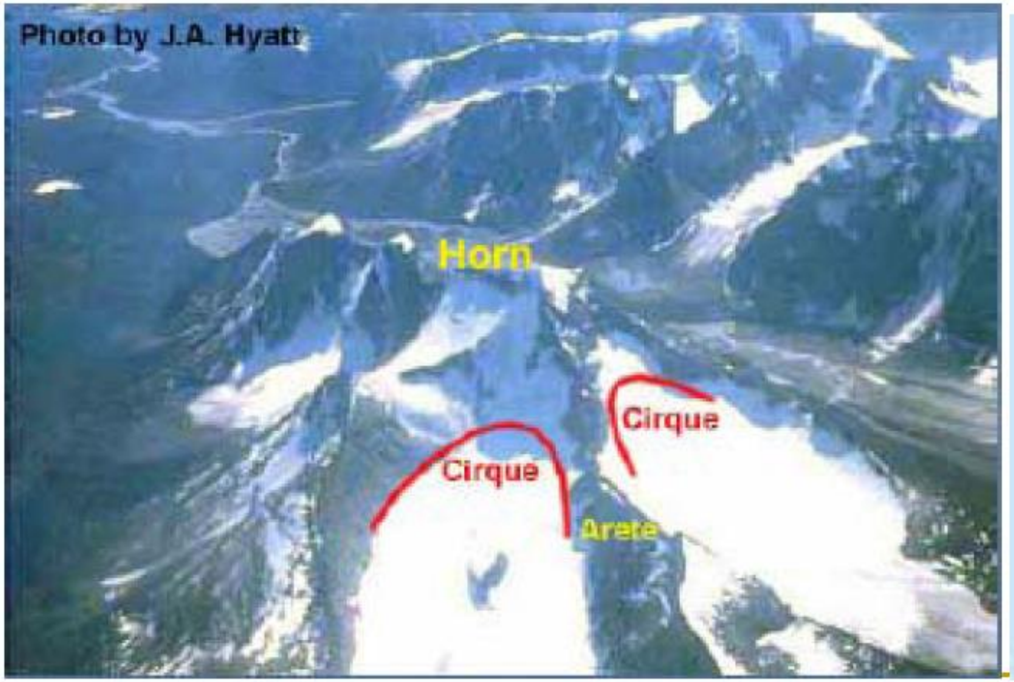
- Bowl-shaped depression
- Area where snow first accumulates and modifies into glacial ice (called Cirques Glacier)

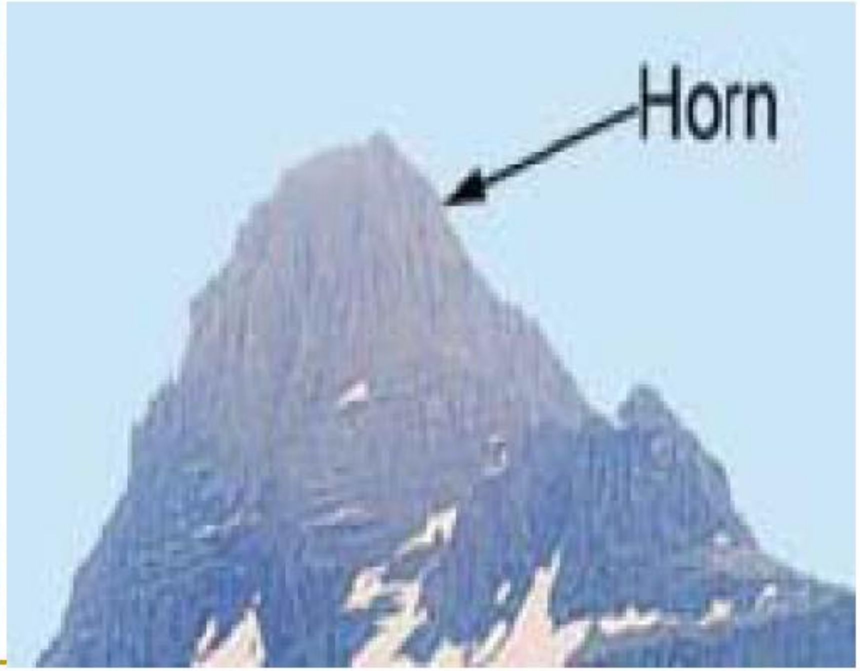
# Erosional Features: Tarns

- After a glacier is no longer present, a lake may form in a cirque

## Erosional Features: Horns

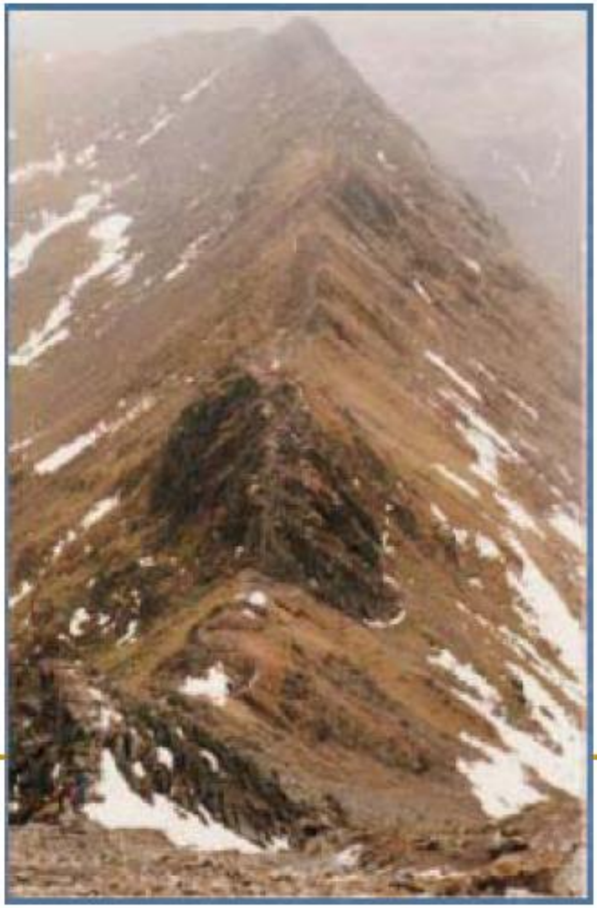
- Pyramidal peak that forms when cirques chisel a mountain from 3+ sides

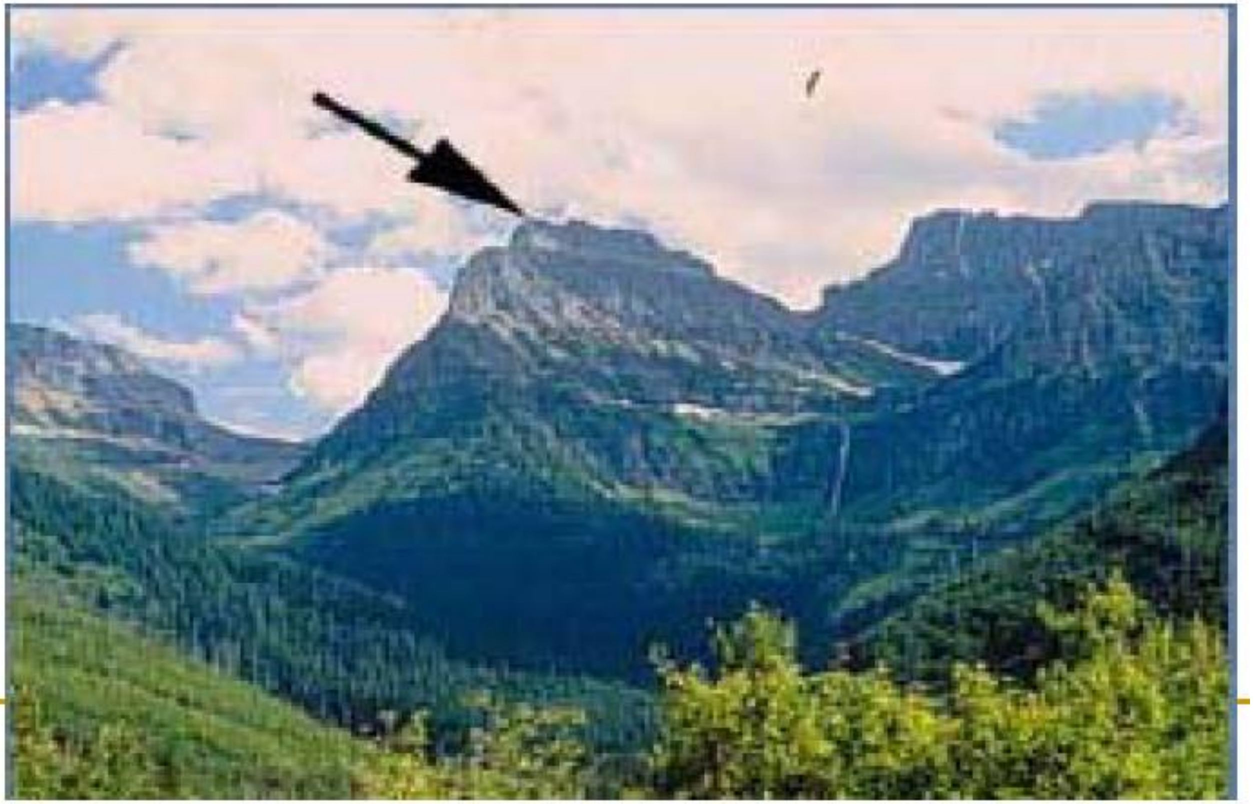


# Erosional Features: Aretes

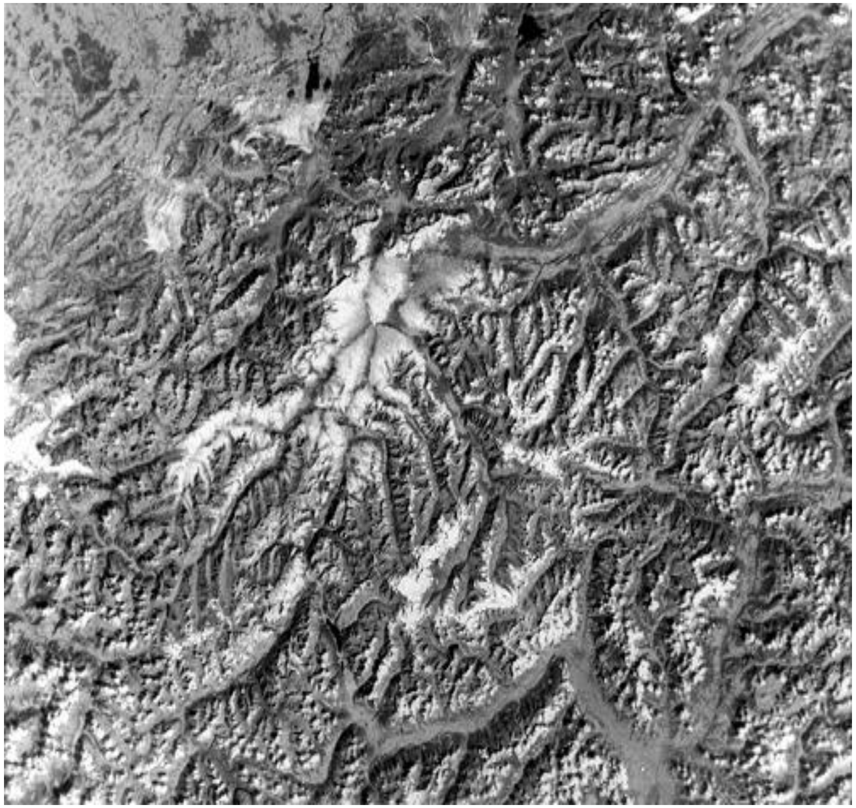
- Narrow ridge : Formed when two glaciers move down valleys and erode the area between them into a ridge





# Erosional Features: Glacial Valley

- ❖ Valleys become deeper & wider over time
- ❖ Guide the path of glacial ice flow
- ❖ U-Shaped



This Landsat scene shows widened valleys in the alpine region of that country

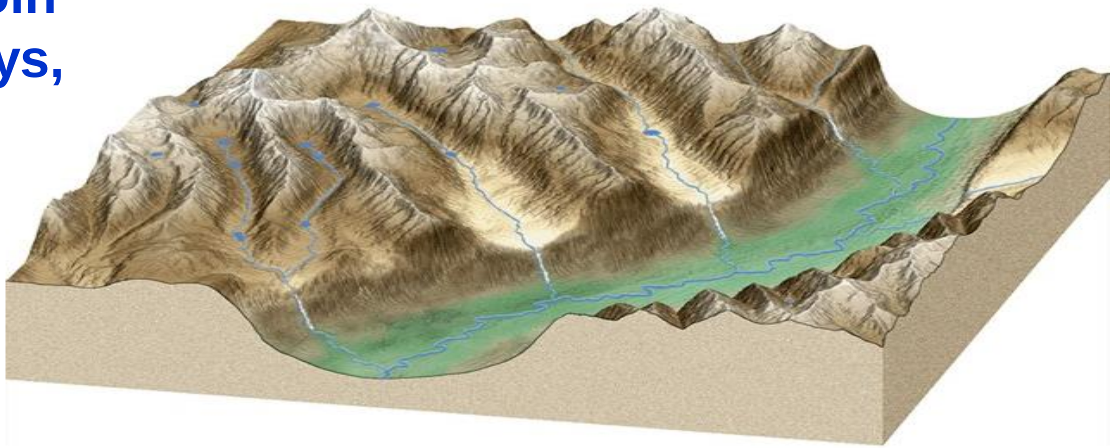
# U-Shaped Valley in Scottish Highland

Photograph: Matthew Lochriet

# Erosional Features: Hanging Valley

- When smaller valleys join with larger glacial valleys, the floors are not at the same elevation

- Waterfalls are often present here




## Fjord : A deep, glacially carved, U-shaped valley flooded by rising sea level.

**This partial Landsat scene in the Trollaskagi region of northwest Iceland provide a post-ice view of an ice-sculpted mountainous area where glaciers, now gone, have left conspicuous troughs (wide valleys) with intervening ridges now sharply creased into aretes.**

**Several large fjords are formed where seawater has encroached into larger glacially-scoured lowlands.**

# Knik Arm - Fjord

Photograph: Matthew Lachniet

# Erosional Features: Paternoster Lakes

- Chain of tarns that are formed when a valley "steps" down
- Lakes are all connected by streams and/or waterfalls

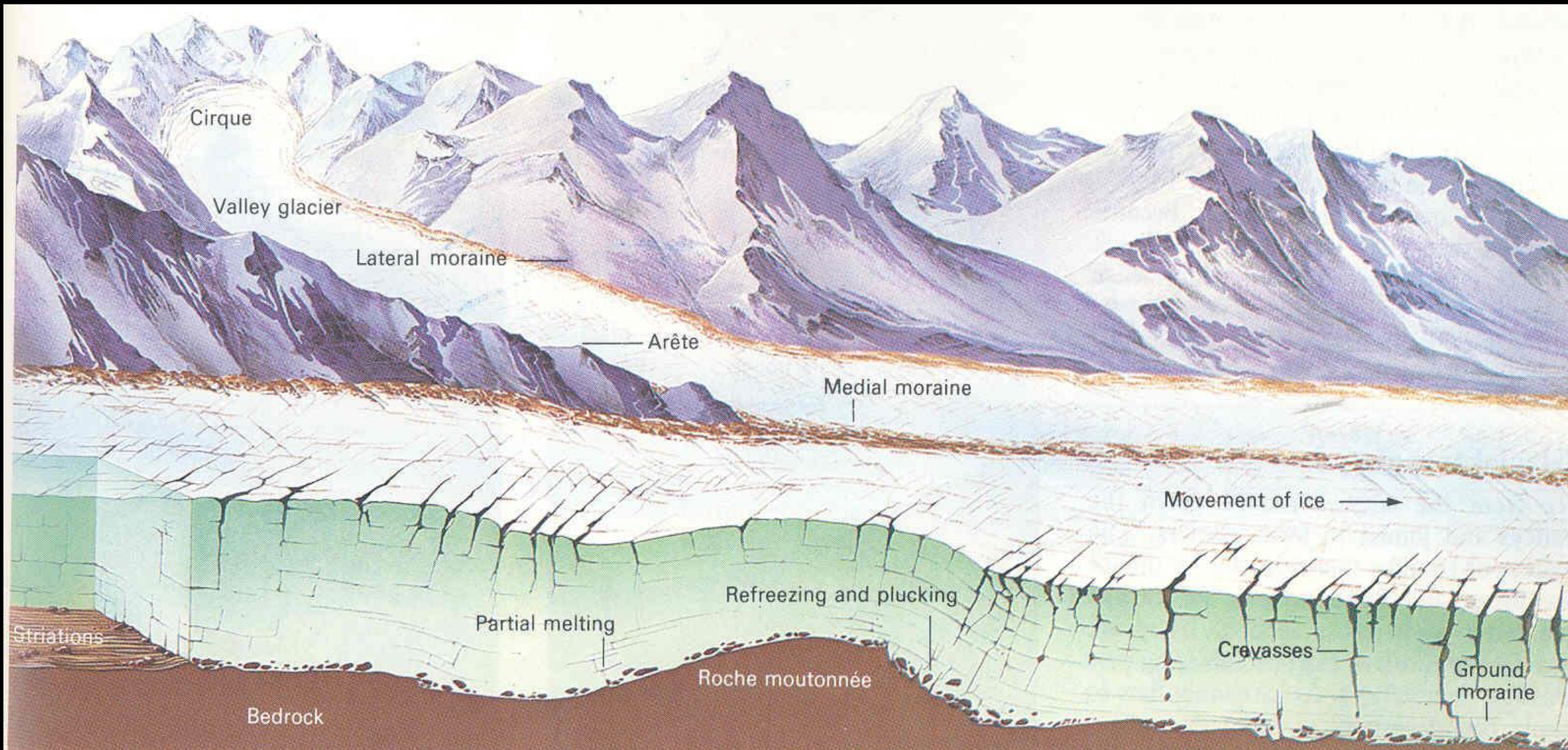
# DEPOSITIONAL FEATURES OF GLACIERS

# Continental Glaciers

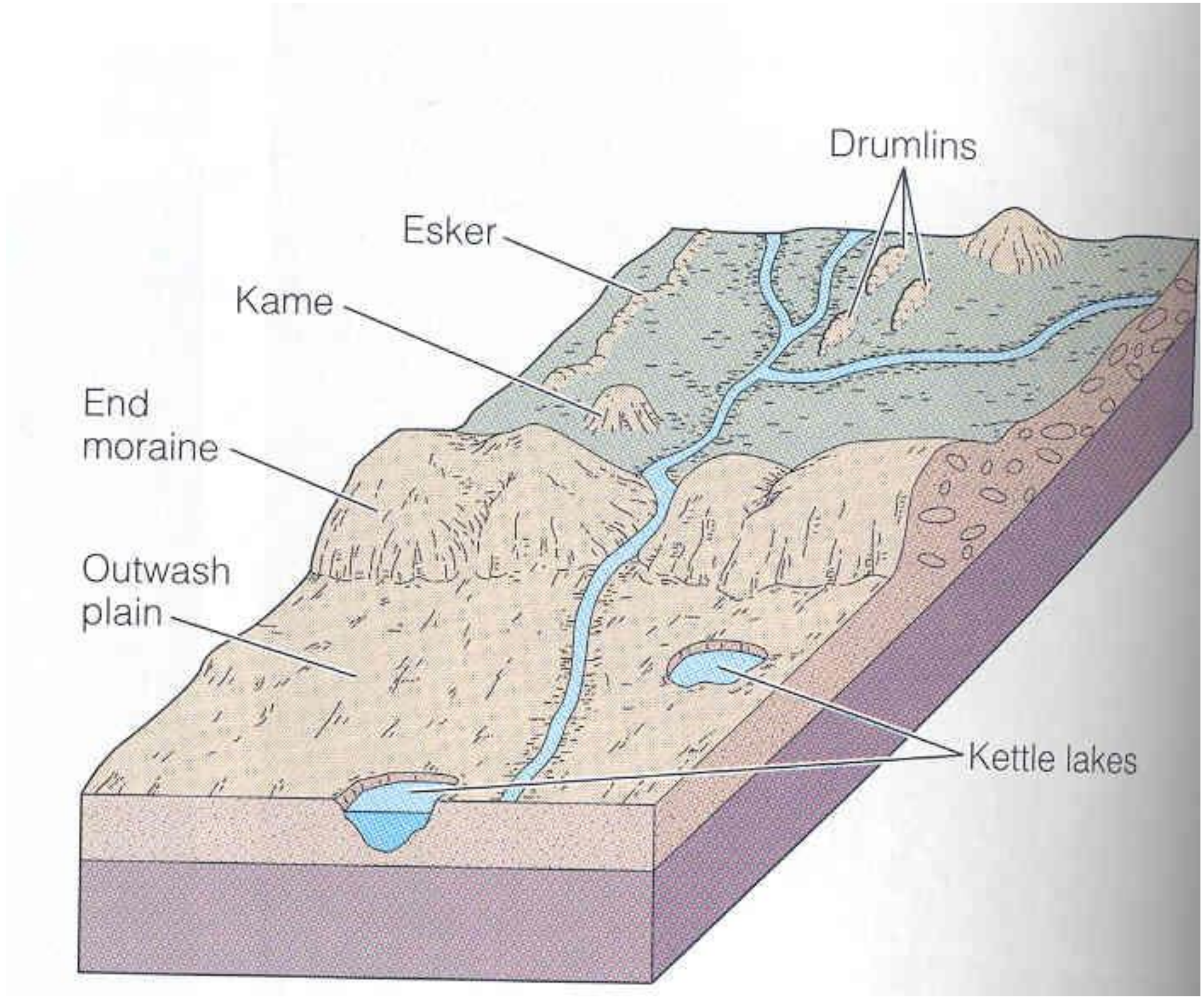
## Landforms

All formed by **deposition** of materials

- **Moraines**
- **Kames**
- **Esker**
- **Kettles/Kettle Ponds**
- **Braided Outwash Streams**



Cirque
Valley glacier
Lateral moraine
Arête
Medial moraine
Movement of ice
Refreezing and plucking
Partial melting
Striations
Crevasses
Ground moraine
Roche moutonnée
Bedrock


Drumlins
Esker
Kame
End
moraine
Outwash
plain
Kettle lakes

**Moraines:** **A strip of debris or linear body of debris formed by the glacier.**

-  **Numerous types of moraines, Two are associated with continental glaciers**

1. **Terminal Moraine**
   marks the maximum extent of the glacier

2. **Recessional Moraine**
   develops behind the terminal moraine as the glacier retreats

# Depositional Features: Moraines

**A strip of debris along the margins of a glacier.**

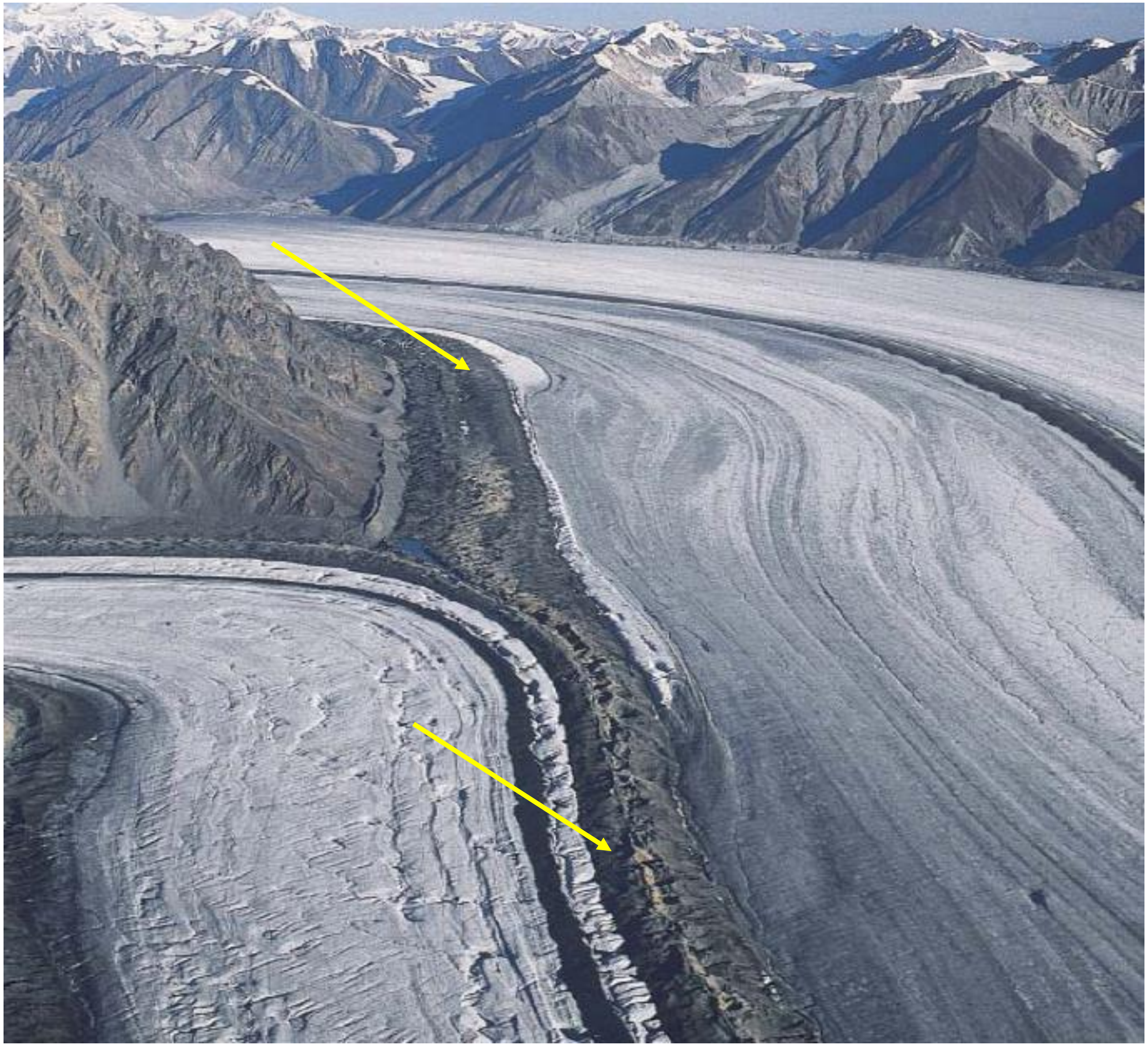
**A strip of sediment in the interior of a glacier, parallel to the flow direction of the glacier, formed by the lateral moraines of two merging glaciers.**

Lateral Moraines

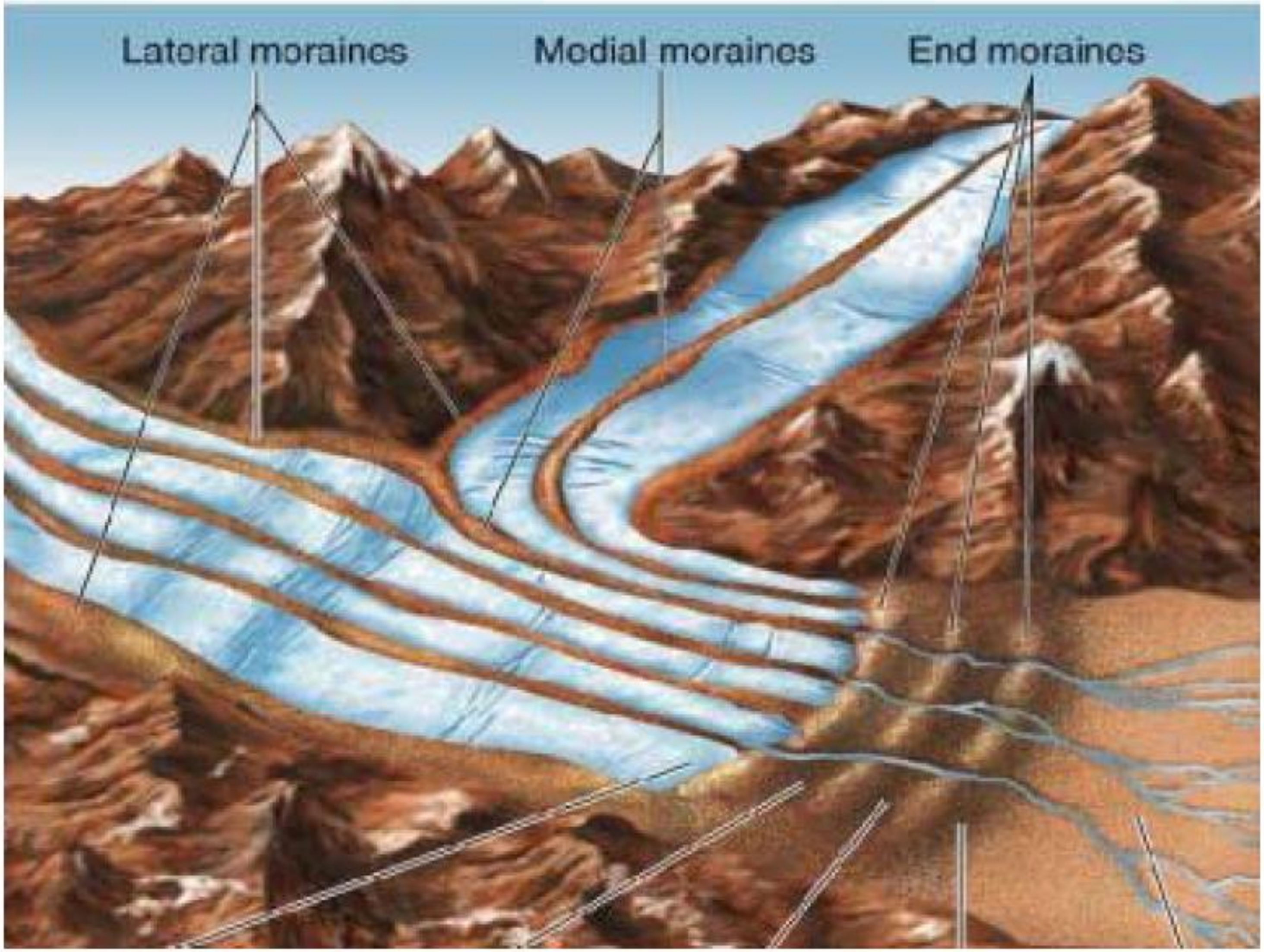
Medial Moraine

Will often form when two glaciers meet and continue down a valley

# Lateral and Medial Moraines



## “End moraines”are more commonly called “Terminal”and “Recessional”moraines.

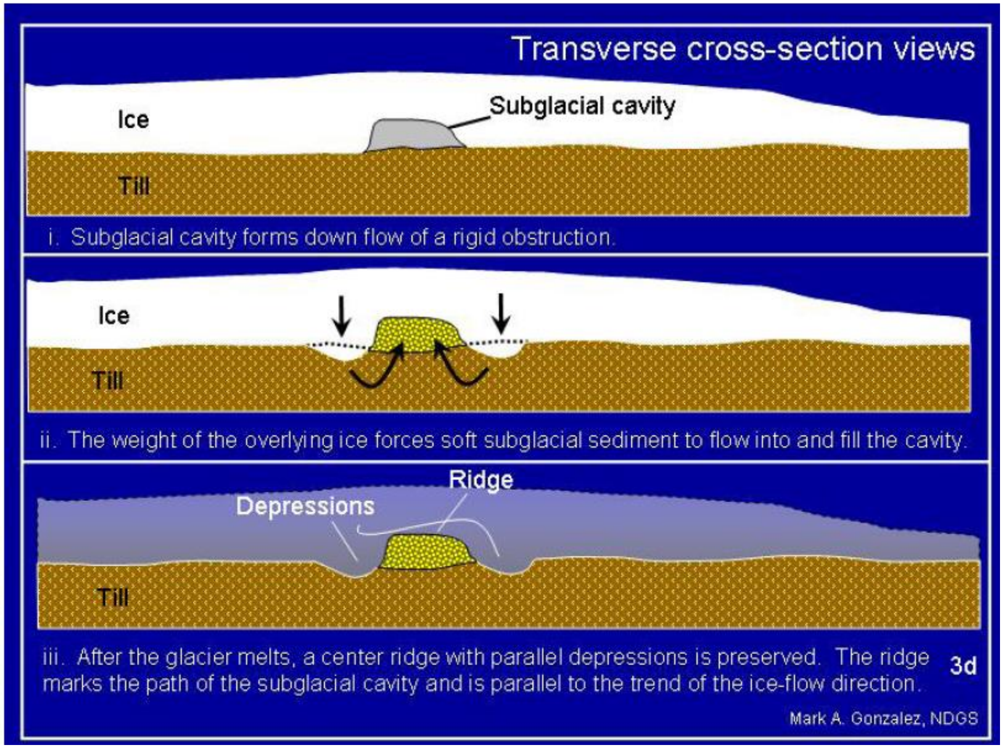


# Glacial Till

- **Sediment transported and deposited by a glacier**
  - **Poor sorting**
  - **bimodal: fines from abrasion; coarse grains from plucking**
- **Usually lacks stratification**
- **Cobbles exhibit striations and facets**

# Depositional Features: Kames

- **Steep-sided, conical hill of debris that originally collected in a hole in the glacier.**



# Depositional Features: Erratics

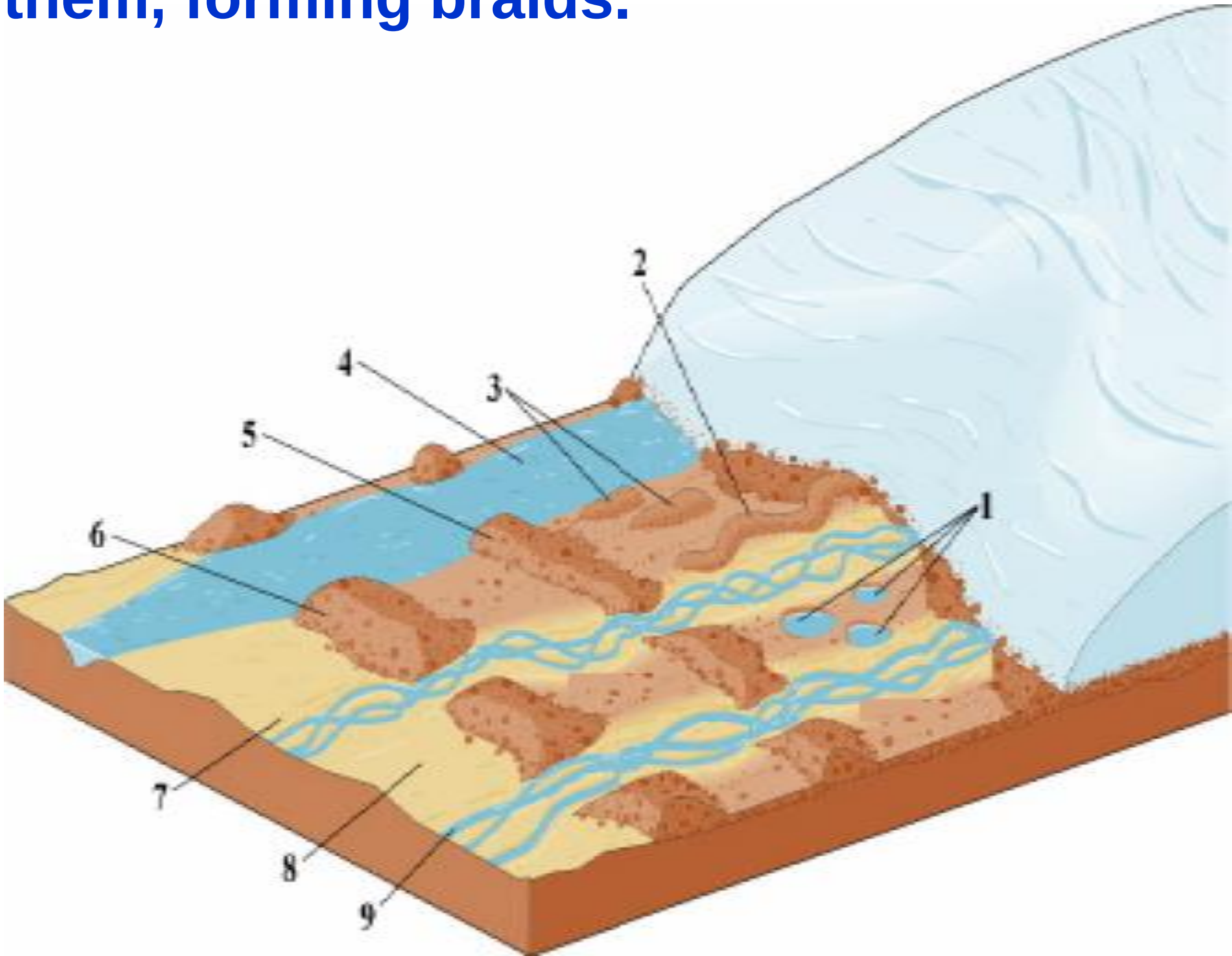
-  Boulders that are carried far from their place of origin by a glacier

# Depositional Features: Kettles

- Large chunks of ice leave a depression in the landscape because
  - Isolated ice is surrounded by till (which becomes part of the landscape). Ice melts – leaving a "depression".
  - If filled with water,called "kettle lakes"

## Depositional Features: Glacial Outwash Meltwater

**Braided streams form when glacial meltwater passes through the moraines and picks up till. It will eventually drop this till into channel bars and begin flowing around them, forming braids.**



# Ice Shelves

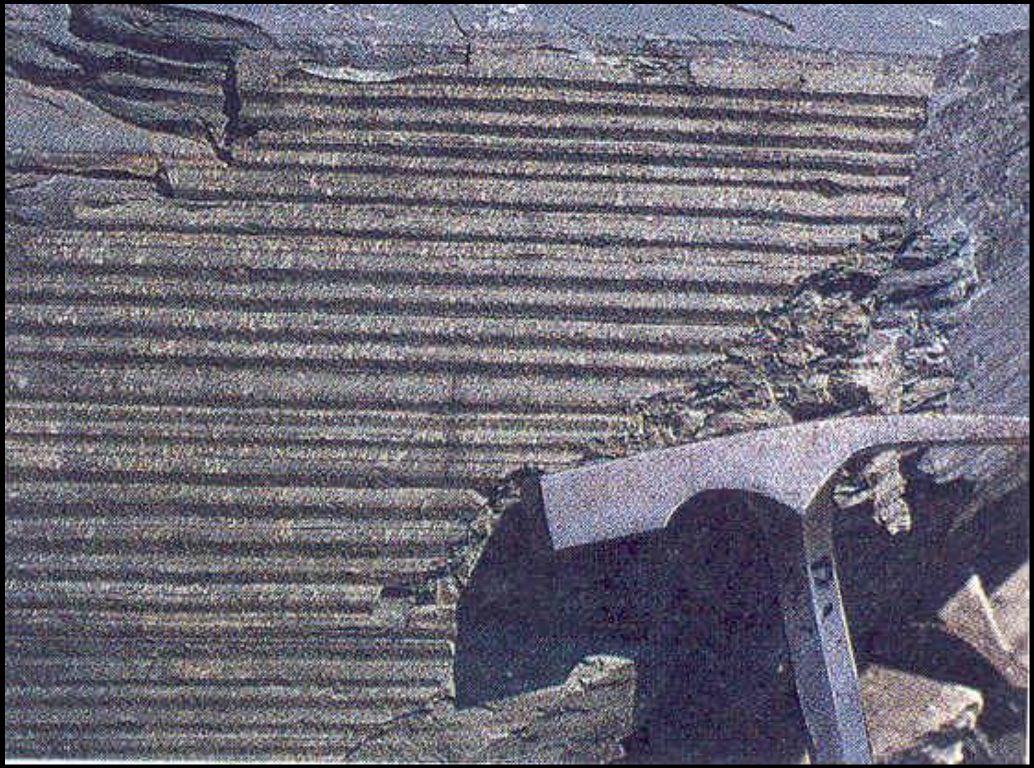
- Large portions of continental glaciers that are floating in the oceans

**Varves :-** are thin, alternating layers of light and dark sediment deposited in a glacial lake.

A layer of relatively coarse grained, light colored sediment accumulates during the spring and summer runoff.

During the winter, when the lake is frozen over, fine, dark mud settles to form a dark layer.

Each set of light and dark layers therefore represents a year's accumulation



# *'Drumlins'*

In areas where continental glaciers have deposited till, the till has been reshaped into elongated hills known as drumlins. Some drumlins measure as much as 50 m high and 1 km long but most are much smaller. From the side, a drumlin looks like an inverted spoon with the steep end on the side from which the glacial ice advanced and the gently sloping end pointing in the direction of ice movement

**(Antrim County, Michigan)**

**DRUMLIN SWARM, Strangford lough, Co. Down**

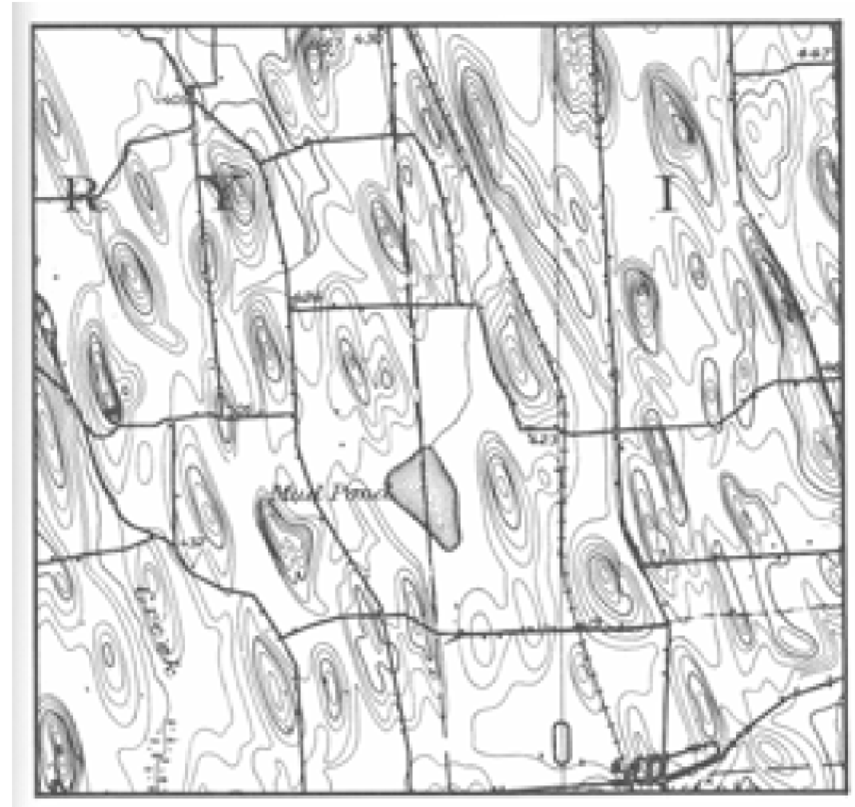
**Drumlins**

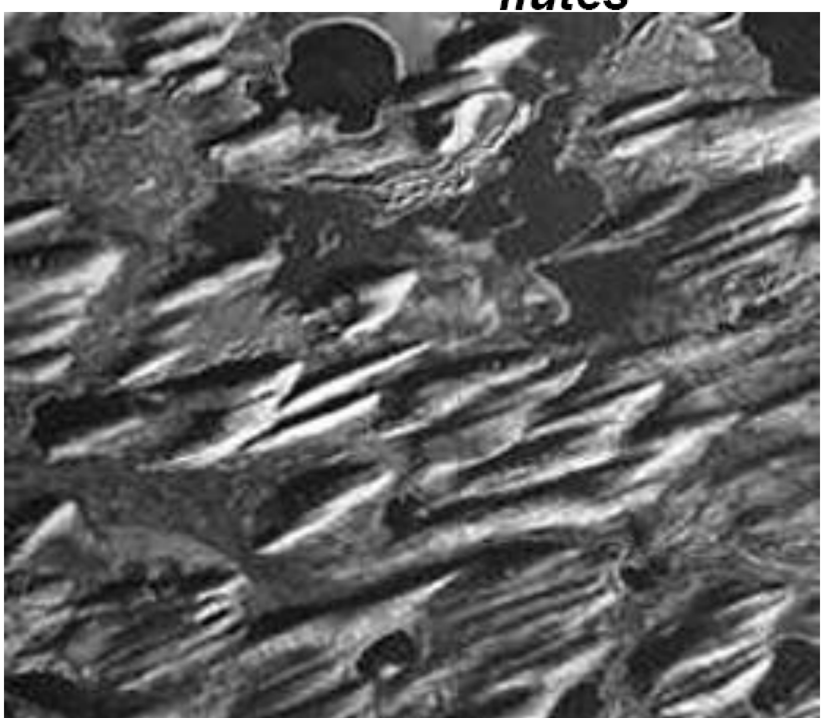
Elliptical hills oriented in the direction of ice movement

Created when a glacier overrides and reshapes preexisting glacial drift

# Drumlins

- Streamlined landform of deformed till oriented parallel to ice flow direction
- Taper downglacier in height and width
- Small-scale (~<1 m) forms are called ***flutes***



**Melt water landforms**

Eskers

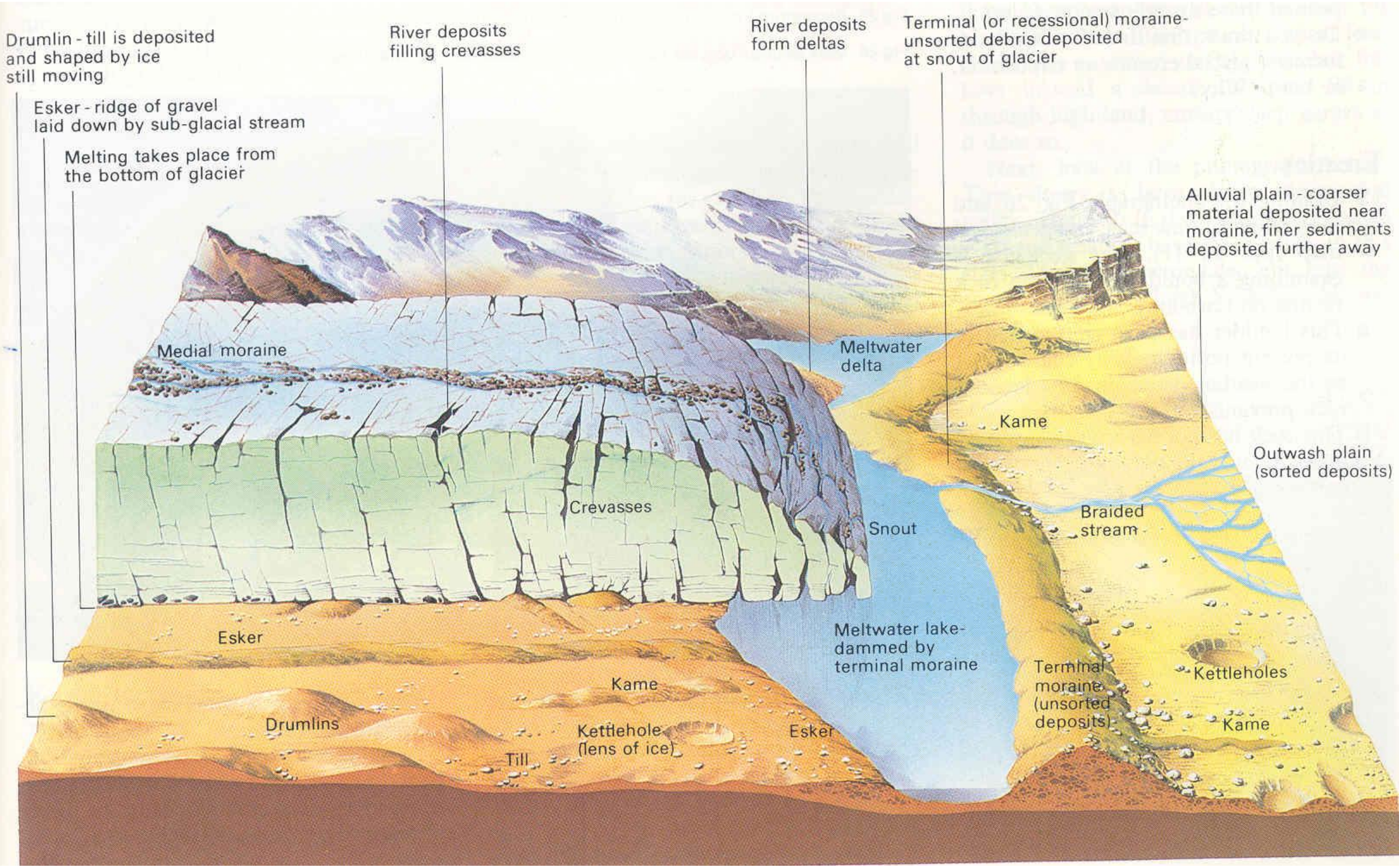
meandering ridges of stratified drift deposited in tunnels in the ice

Eskers - a long, narrow, and often sinuous ridges of stratified drift

- formed by glacial melt streams flowing in tunnels beneath a stagnant glacier

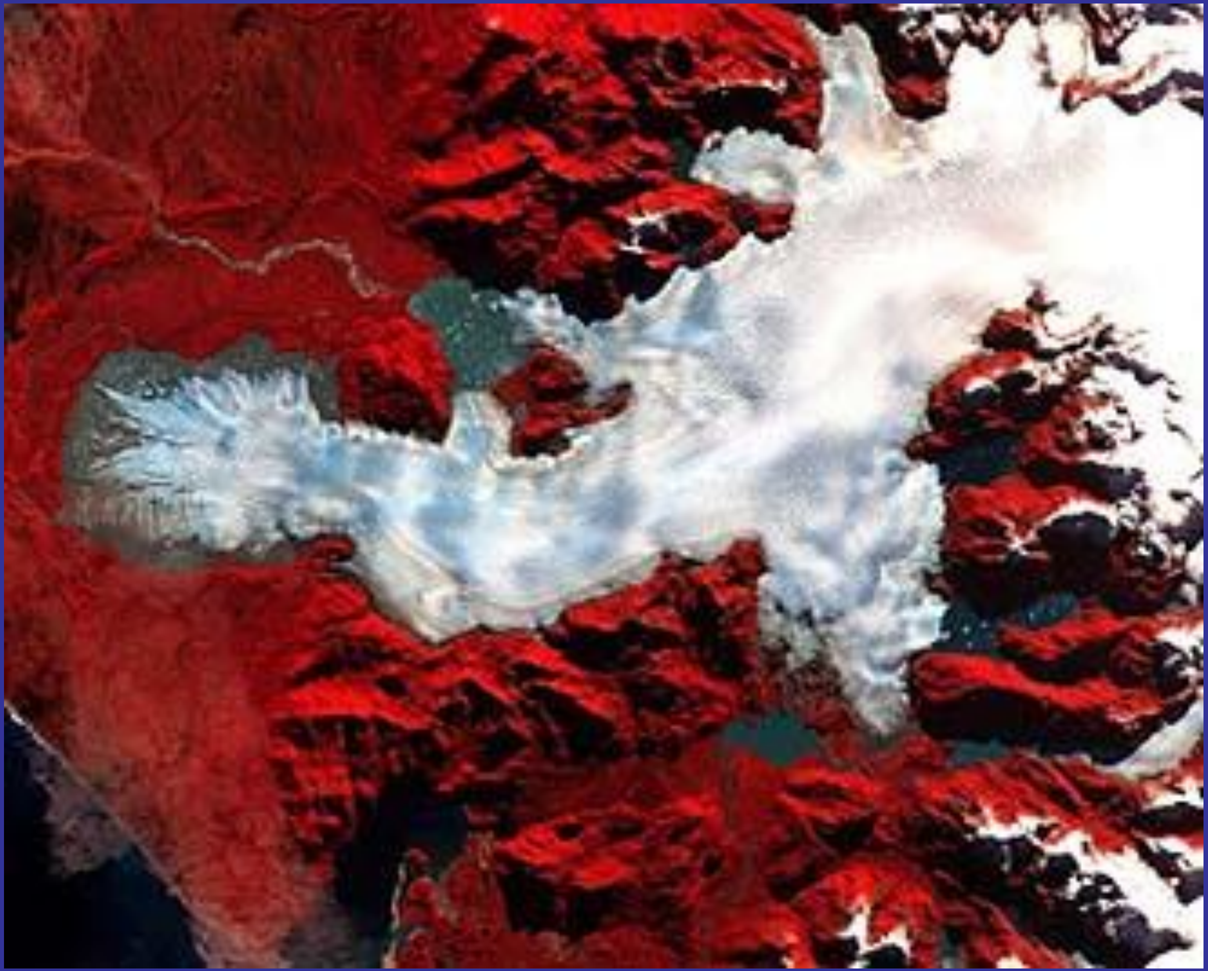
Outwash plain

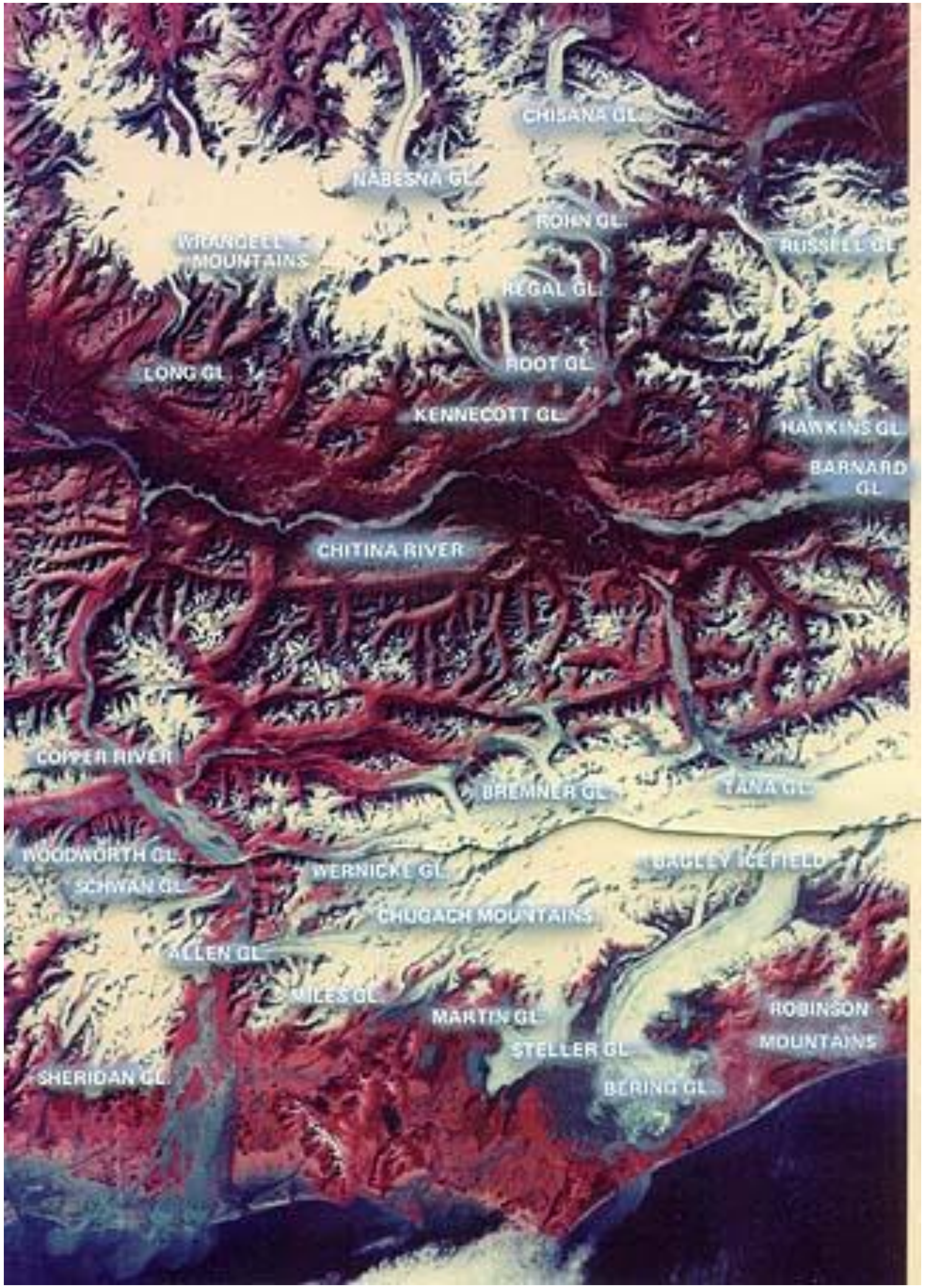
valleys floors and undulating plains formed in outwash, sand and gravel washed out from glaciers by melt water



Drumlin - till is deposited and shaped by ice still moving
Esker - ridge of gravel laid down by sub-glacial stream
Melting takes place from the bottom of glacier
River deposits filling crevasses
River deposits form deltas
Terminal (or recessional) moraine- unsorted debris deposited at snout of glacier
Alluvial plain - coarser material deposited near moraine, finer sediments deposited further away
Medial moraine
Meltwater delta
Kame
Outwash plain (sorted deposits)
Crevasses
Braided stream
Snout
Esker
Meltwater lake- dammed by terminal moraine
Terminal moraine (unsorted deposits)
Kettleholes
Kame
Drumlins
Kettlehole (lens of ice)
Till
Esker
Kame

In the southern hemisphere glaciers occur in New Zealand and in South America, as this ASTER view of a mountain (valley-filling) glacier in the Andes displays so well (the time of the year is the southern summer [around December])





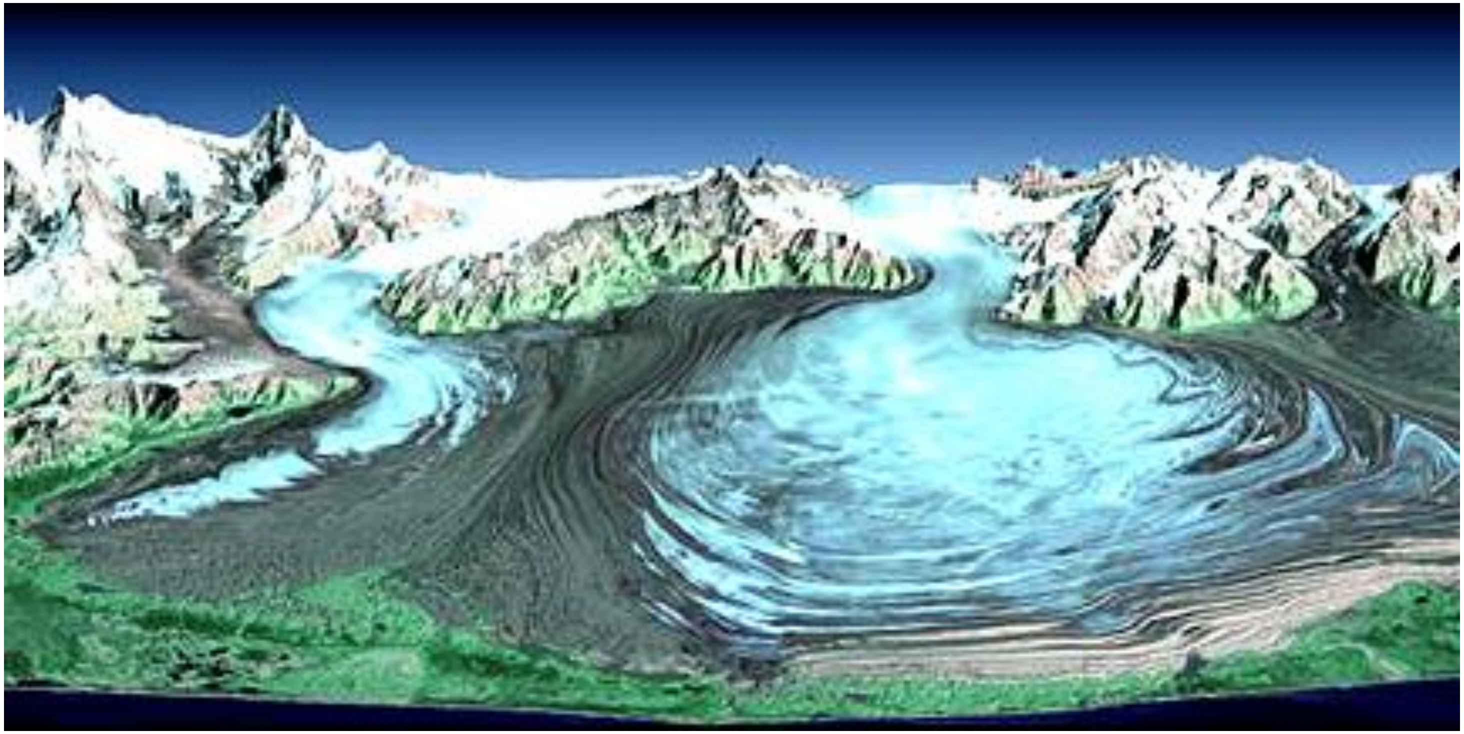

The image mosaic below shows typical alpine or mountain glaciers developed from snow fields covering the higher elevations of parts of the Wrangell and Chugach mountains of southeast Alaska.

Note the dark streaks in some of these piedmont glaciers. These are medial and lateral moraines (glacial debris that may become rock deposits). The reds in the scene are mostly tundra vegetation.

**Along the southern coast of Alaska is a famous active glacier known as the Malaspina Glacier. The Landsat subscene below shows a series of internal moraines on the glacier and a prominent wide lateral moraine to the west (left).**

**The perspective view of this glacier as it creeps towards the Gulf of Alaska, made by combining Landsat and STRM data, shows it in context with its mountain source:**

**Glaciers tend to have black streaks on their surfaces - these are medial moraine deposits formed as rock falls loose at the head of the glacier and continues this process over the years, so that the debris are strung out as streaks that move over the years.**




**The Bear glacier in the Denai Peninsula of Alaska shows a prominent medial moraine.**

**As it reaches an ocean inlet, ice breaks off to form small icebergs that could become a hazard if they reach the open sea.**

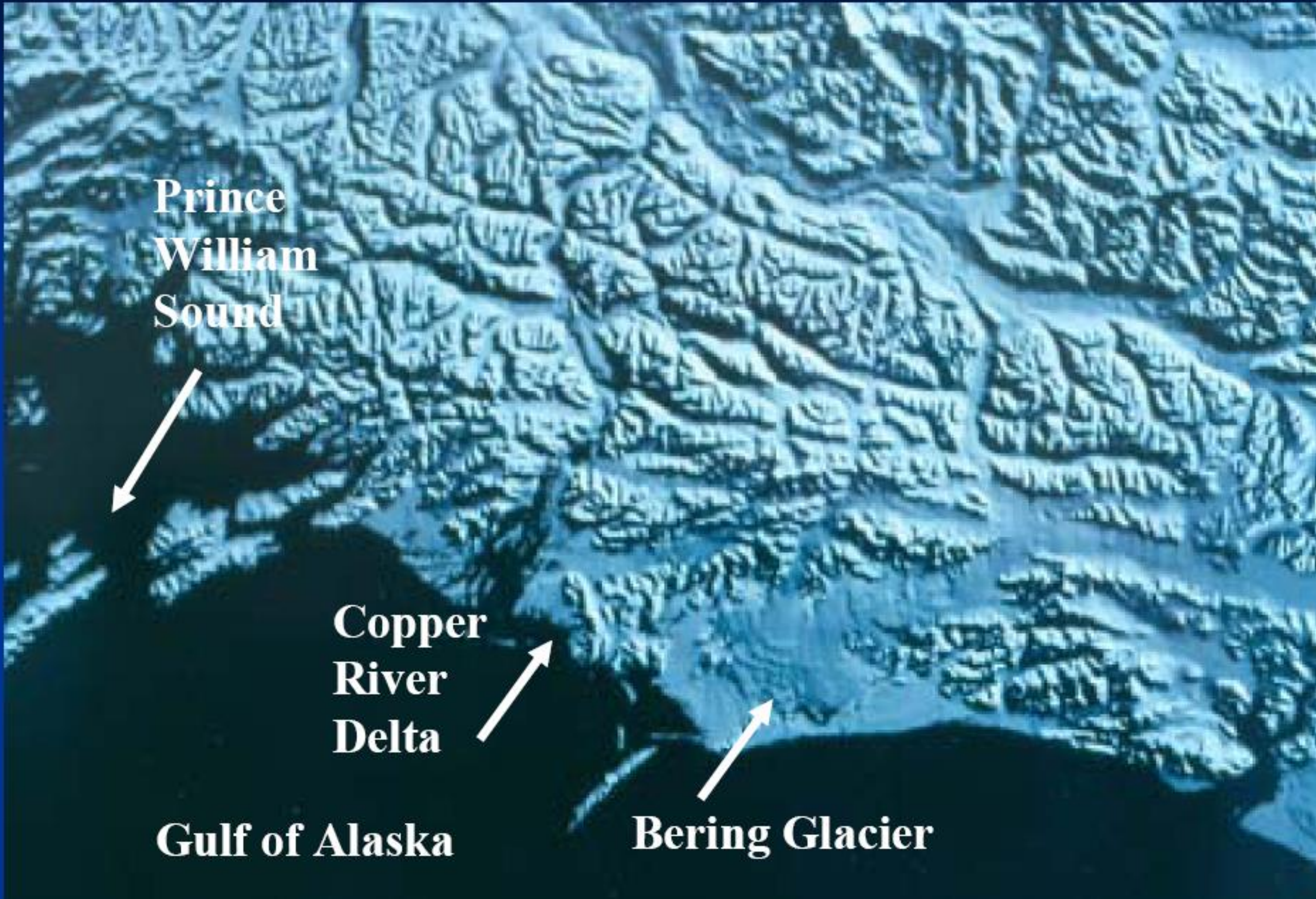
**This IKONOS image has high enough resolution to show crevasses formed by differential movement of the ice mass**

**Piedmont Glaciers:** **Fans or lobes of Ice that form where valley glacier spread out to adjacent plains**

**Fig. 1.23 (Plate 5)** The piedmont lobe of the Malaspina Glacier, Alaska, showing the spectacular fold structures produced by ice flow into the lowlands. (Photo: Michael Hambrey)

*From Benn and Evans. Glaciers and Glaciation, Arnold.*

# Piedmont Glacier



# GLACIAL HAZARDS

# Glacial Hazards

- Glacier floods
- Ice avalanches
- Glacier advance and retreat
- Periglacial debris flows
- Rockfall
- Glacier-clad volcanoes
- Process interactions

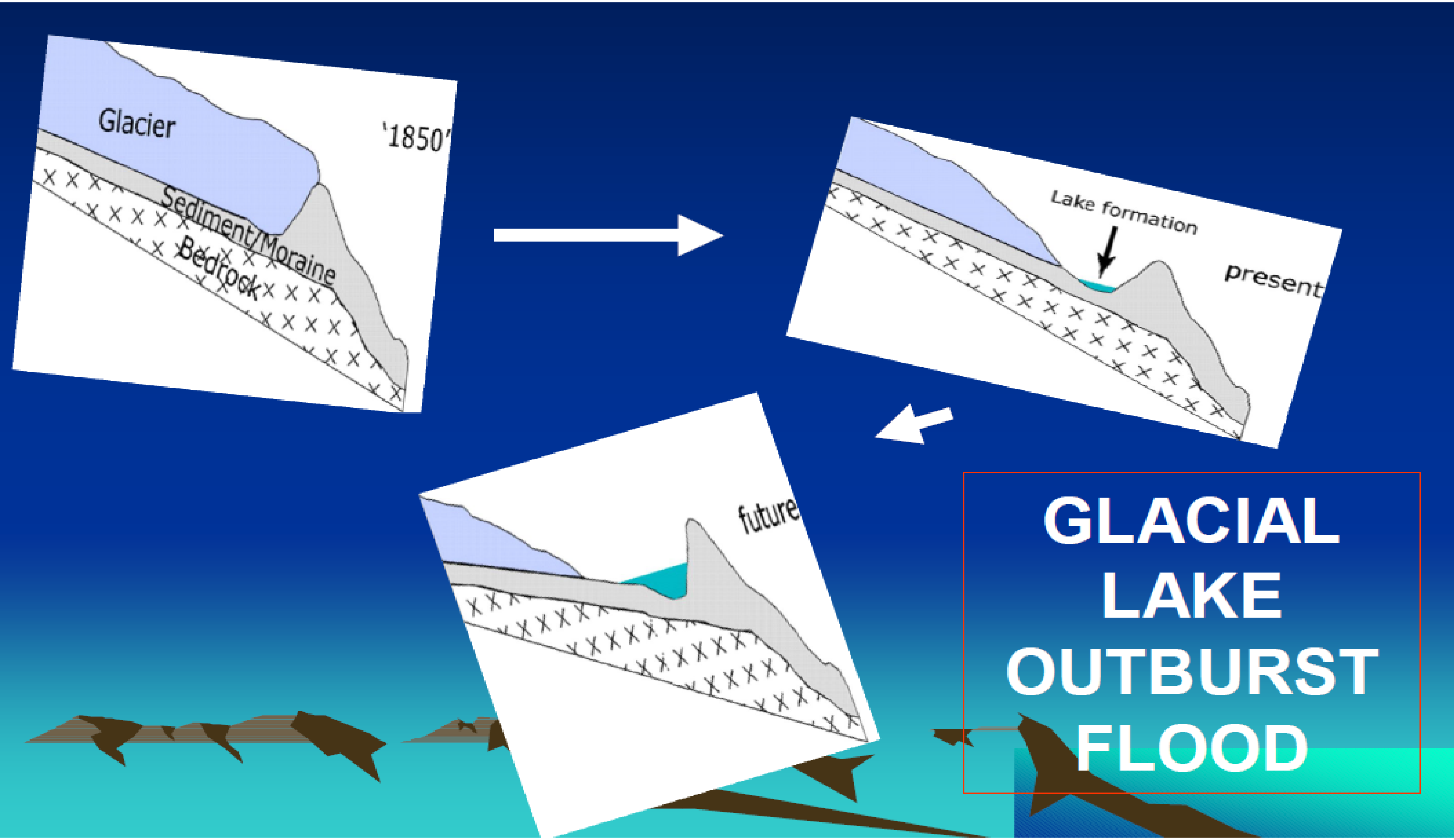
# Glacier floods

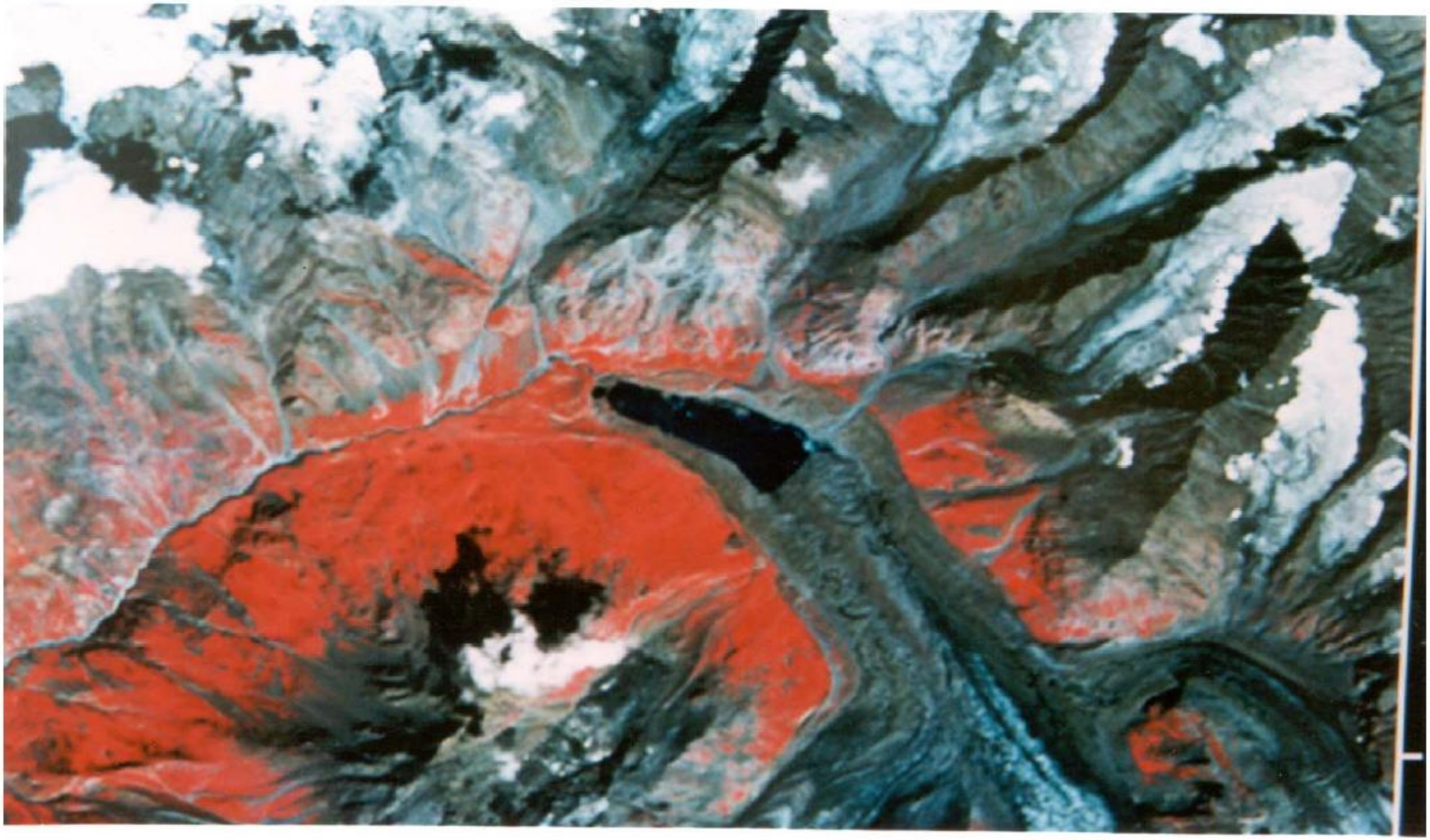
**Generally, glacier floods represent the largest and most extensive glacial hazard, i.e., the hazard with the highest potential for disaster and damage**

**A GLOF (Glacier Lake Outburst Floods, GLOF) is characterized by a sudden release of a huge amount of lake water that rushes along the stream channel downstream in the form of dangerous flood waves.**

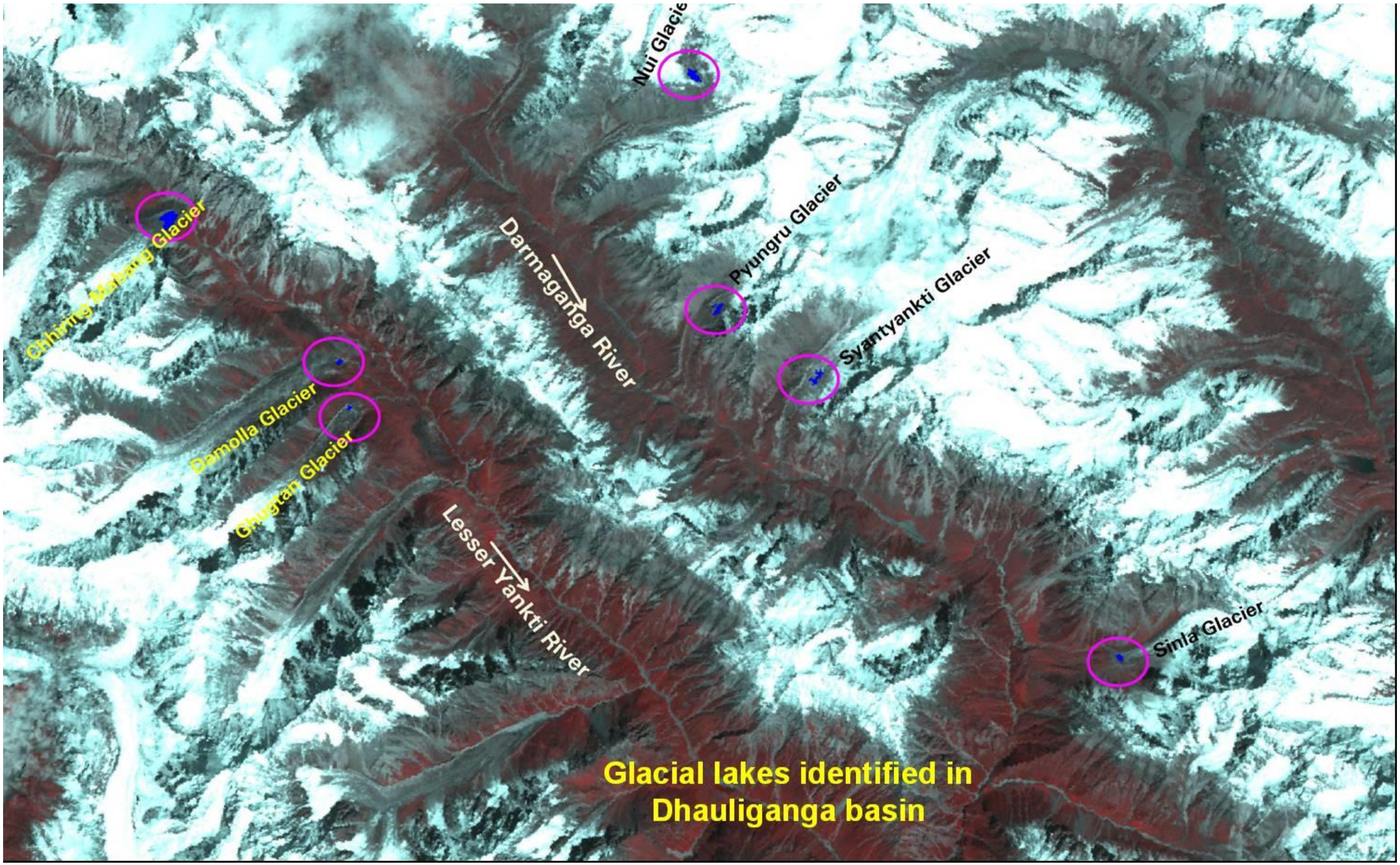
**These floods waves comprise of water mixed with morainic materials and cause devastating consequences for riparian communities, hydropower stations and other infrastructure.**

**The severity of flood wave depends upon the amount of water released, debris load and on basin characteristics of the watershed. Discharge rates of such floods are typically several thousand cubic meters per second.**


Glacier
'1850'
Sediment/Moraine
Bedrock
Lake formation
present
future
GLACIAL
LAKE
OUTBURST
FLOOD



**SATELLITE VIEW OF MORAINE DAMMED LAKE NEAR THE SNOUT OF GEEPANG GATH GLACIER IN THE CHANDRA RIVER BASIN,HIMACHAL PRADESH**


Nui Glacier
Chhiring Mabang Glacier
Darmaganga River
Pyungru Glacier
Syantyankti Glacier
Damolla Glacier
Ghugtan Glacier
Lesser Yankti River
Sinla Glacier
Glacial lakes identified in
Dhauliganga basin

# Ice avalanches

They are flows which move under the influence of gravity

They can be channelized or unconfined

In this sense, they are similar to pyroclastic flows, debris flows, etc

Direct effects:

- impact
- burial

Indirect effects:

- tsunamis generated if an avalanche enters a lake

# Avalanche zones

a) Starting zone: where an avalanche is initiated

b) Avalanche track : where it goes

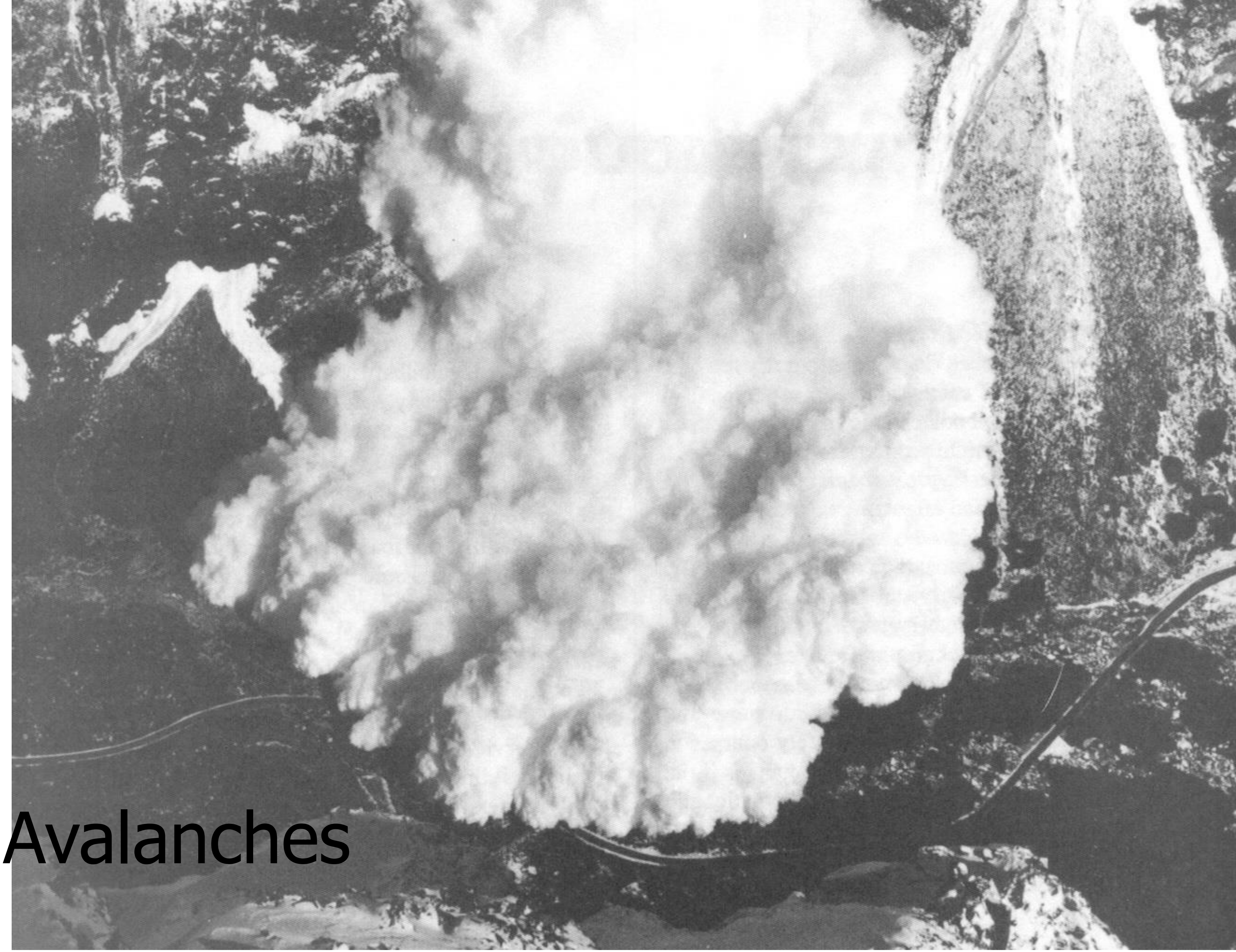
c) Runout area: where it dissipates

Fs = Safety Factor

Fs = (shear strength)/(shear stress)

shear strength: internal resistance to movement
shear stress: force causing movement parallel to slope; increases with slope angle

If Fs is less than 1, then the slope is unstable and prone to failure



# Avalanches

# Glacier retreat and formation of Glacial Lake

**The formation and growth of glacier lakes is a phenomenon closely related to deglaciation.**

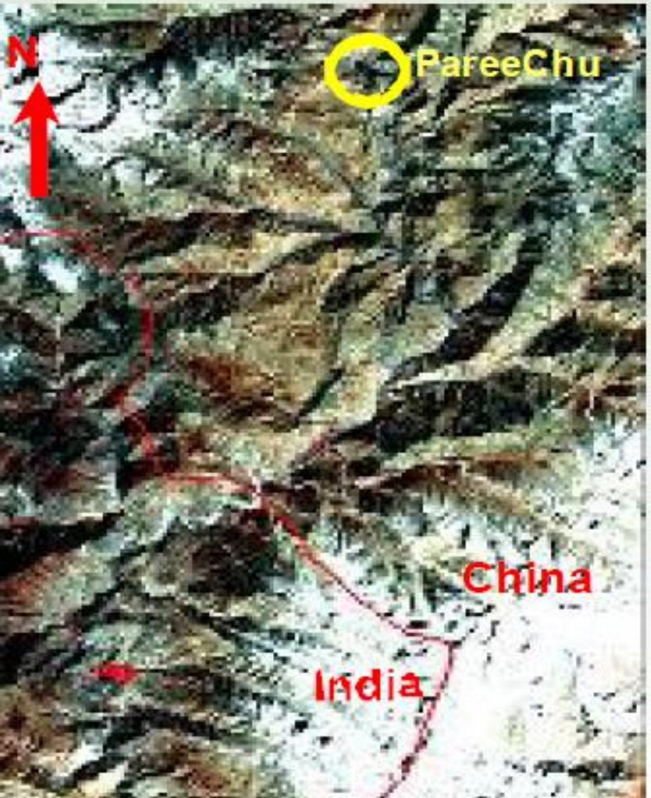
**Valley glaciers generally contain supra-glacial ponds. Due to warming climate, these ponds grow bigger and merge.**

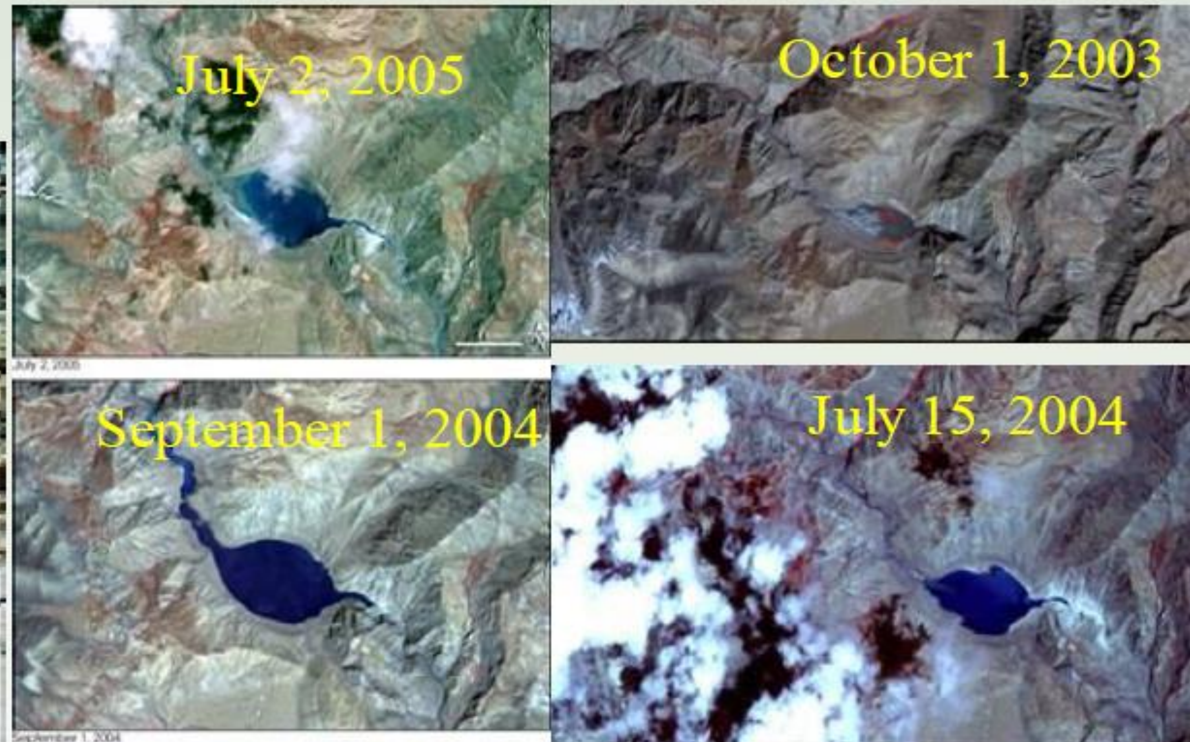
**This process is accelerated by rapid retreat of glaciers. As the glacier retreats it leaves a large void behind.**

**The ponds occupy the depression earlier occupied by glacial ice.**

**The moraine walls that act as dams are structurally weak and unstable and under go constant changes due to slope failures, slumping, etc. and are in danger of catastrophic failure, causing glacier lake outburst floods (GLOFs). Principally, a moraine dam may break by the action of some external trigger or self-destruction.**

# Landslide Damburst




Landslide Dam Lake in Pare Chu Tibet Autonomous Region, China – 35 km upstream of India Sutlej basin

# Periglacial debris flows

Periglacial debris flows in combination with retreating glaciers, large and steep reservoirs of loose sediment (mainly of morainic origin) can become exposed and then represent a potential source of debris flows.

Analysis of the numerous debris-flow events in the Swiss Alps in 1987 has shown that about 50% of all events (with volumes larger than 1000 m3) originated in areas of loose sediment which have been uncovered in connection with the glacier retreat since 1850

Periglacial debris flows are not only released from glacial forefields but also from marginal permafrost sites, from the scree of debris cones and rock-glacier fronts.

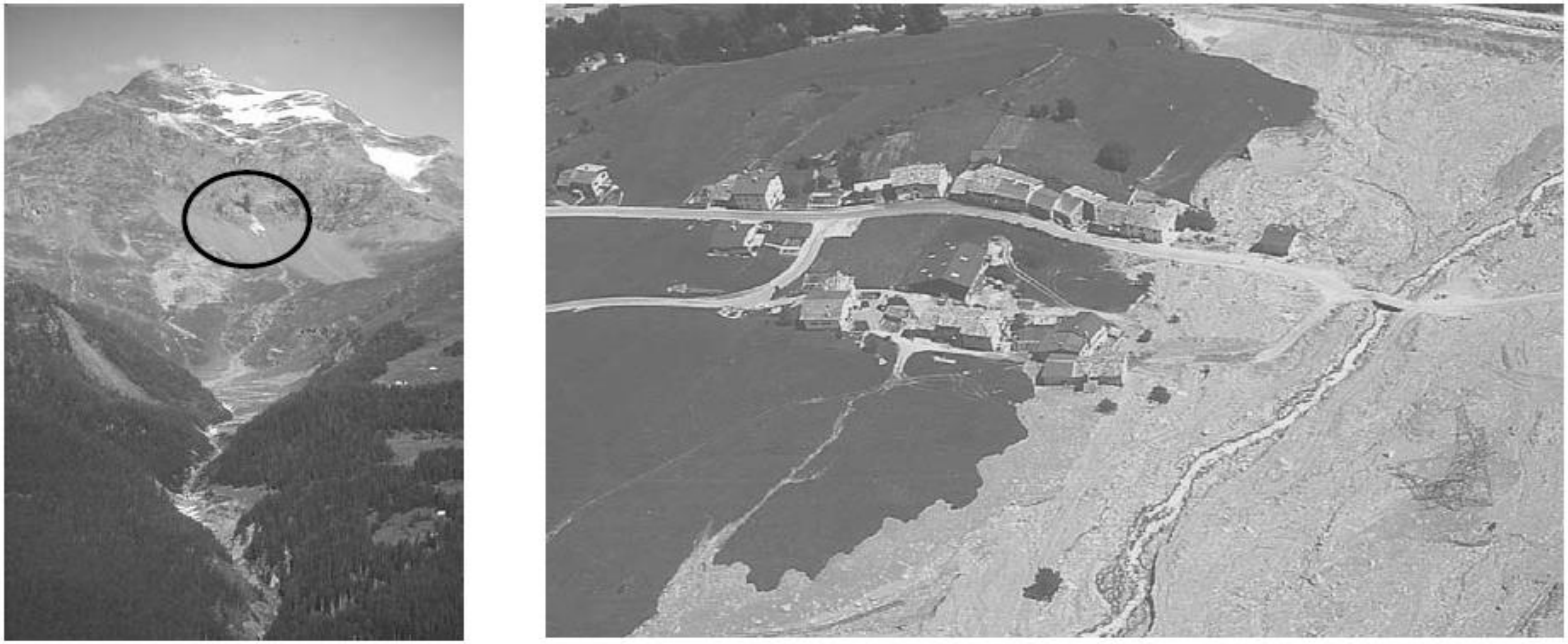


Fig. 4: One of the major flood disasters in the Swiss Alps in 1987 was related to a periglacial debris flow from the Varuna valley (southern Swiss Alps). The debris flow started from a talus slope below Varuna glacier (left image, indicated by circle), damaged the settlement of Privilasco by sediment deposition on the fan (right image), and finally dammed the main river valley. Subsequent flooding caused severe damages of about EUR 30 mill. in the city of Poschiavo (photos: W. Haeberli).

## Rock fall

**In glacial and periglacial environments, the significance of rockfall relates to the interaction with glacier retreat and permafrost changes, combined events with ice avalanches, and enlarged runout on glacier and snow surfaces.**

**Glacier retreat may induce changes in the stress field in rock walls, leading to destabilization processes**

**Shear laboratory tests have shown that a rise in ground temperature may result in a reduction of the shear capacity of ice-bonded discontinuities and eventually in a decrease in slope stability**

Fig. 5: Rockfall at the southwest face of the Matterhorn in August 2003, at about 3800 m a.s.l. near Carrel alpine hut. The event is one out of a rockfall series in the extraordinarily hot summer 2003, originating in permafrost areas (photo: L. Trucco).

## Glacier-clad volcanoes

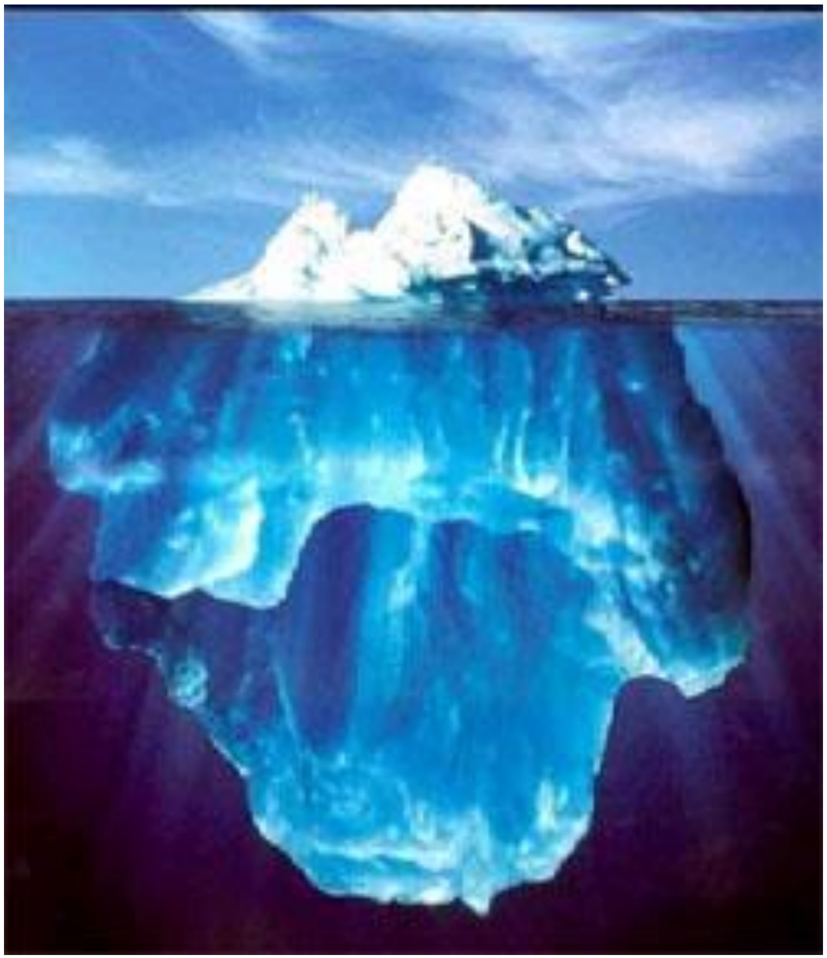
**On a global level, glacier-clad volcanoes represent a further major glacier-related hazard.**

**For instance, lahars (volcanogenic debris flows) can impact downstream areas at a distance of more than 100 km.**

**The investigation of glacier-clad volcanoes was intensified and reinforced following the eruption of Mount St. Helens (Washington, USA) in 1980 and the Nevado del Ruiz catastrophe (Colombia) in 1985**

Fig. 6: Eruption of Popocatépetl volcano, central Mexico, with ash fallout on Ventorillo/Noroccidental glacier (marked by circle, photo: A. Boneta).

# Icebergs

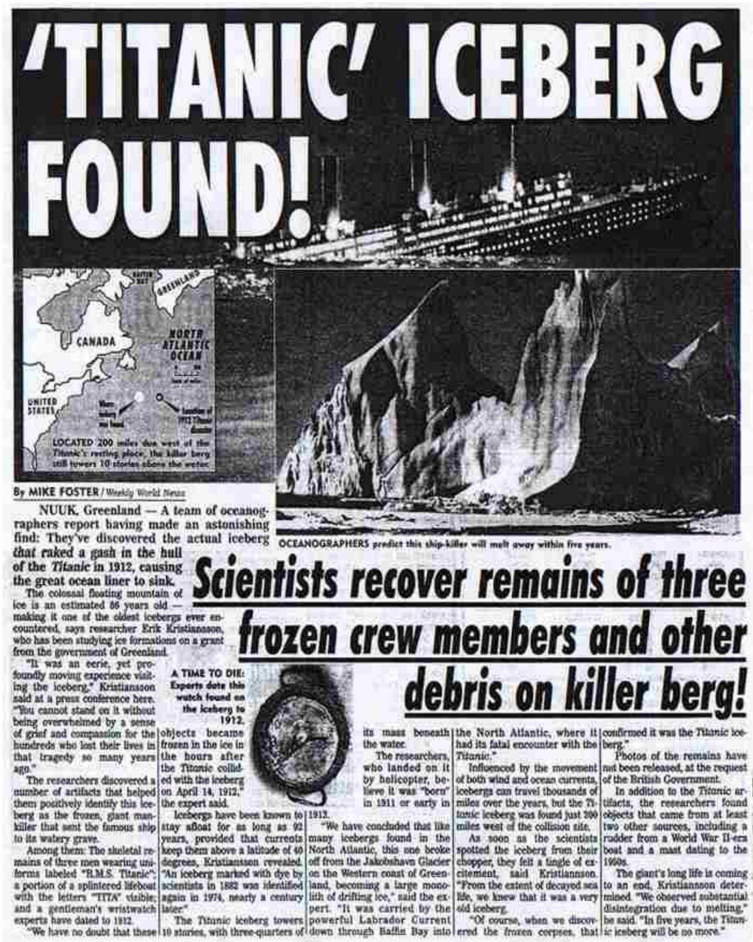


- Glaciers vs. icebergs
- Glaciers move over land and when they hit water they become an iceberg.
- 10,000 icebergs form every year from Greenland.

# Icebergs

- Only about 10 percent of an iceberg is visible.
- 90% of an iceberg lies below the surface.
- The underwater part is a hazard to ships because it is often much wider than the visible part of the iceberg.

# Icebergs



'TITANIC' ICEBERG FOUND!

CANADA

NORTH ATLANTIC OCEAN

UNITED STATES

LOCATED 200 miles due west of the Titanic's resting place, the killer berg still towers 10 stories above the water.

By MIKE FOSTER / Weekly World News

OCEANOGRAPHERS predict this ship-killer will melt away within five years.

## Scientists recover remains of three frozen crew members and other debris on killer berg!

NUUK, Greenland — A team of oceanographers report having made an astonishing find: They've discovered the actual iceberg **that raked a gash in the hull of the *Titanic* in 1912, causing the great ocean liner to sink.**

The colossal floating mountain of ice is an estimated 86 years old — making it one of the oldest icebergs ever encountered, says researcher Erik Kristiansson, who has been studying ice formations on a grant from the government of Greenland.

"It was an eerie, yet profoundly moving experience visiting the iceberg," Kristiansson said at a press conference here. "You cannot stand on it without being overwhelmed by a sense of grief and compassion for the hundreds who lost their lives in that tragedy so many years ago."

The researchers discovered a number of artifacts that helped them positively identify this iceberg as the frozen, giant man-killer that sent the famous ship to its watery grave.

Among them: The skeletal remains of three men wearing uniforms labeled "R.M.S. Titanic"; a portion of a splintered lifeboat with the letters "TITA" visible; and a gentleman's wristwatch experts have dated to 1912.

"We have no doubt that these objects became frozen in the ice in the hours after the Titanic collided with the iceberg on April 14, 1912," the expert said.

**A TIME TO DIE: Experts date this watch found on the iceberg to 1912.**

Icebergs have been known to stay afloat for as long as 92 years, provided that currents keep them above a latitude of 40 degrees, Kristiansson revealed. "An iceberg marked with dye by scientists in 1882 was identified again in 1974, nearly a century later."

The Titanic iceberg towers 10 stories, with three-quarters of its mass beneath the water.

The researchers, who landed on it by helicopter, believe it was "born" in 1911 or early in 1912.

"We have concluded that like many icebergs found in the North Atlantic, this one broke off from the Jakobshavn Glacier on the Western coast of Greenland, becoming a large monolith of drifting ice," said the expert. "It was carried by the powerful Labrador Current down through Baffin Bay into the North Atlantic, where it had its fatal encounter with the Titanic."

Influenced by the movement of both wind and ocean currents, icebergs can travel thousands of miles over the years, but the Titanic iceberg was found just 200 miles west of the collision site.

As soon as the scientists spotted the iceberg from their chopper, they felt a tingle of excitement, said Kristiansson. "From the extent of decayed sea life, we knew that it was a very old iceberg.

"Of course, when we discovered the frozen corpses, that confirmed it was the *Titanic* iceberg."

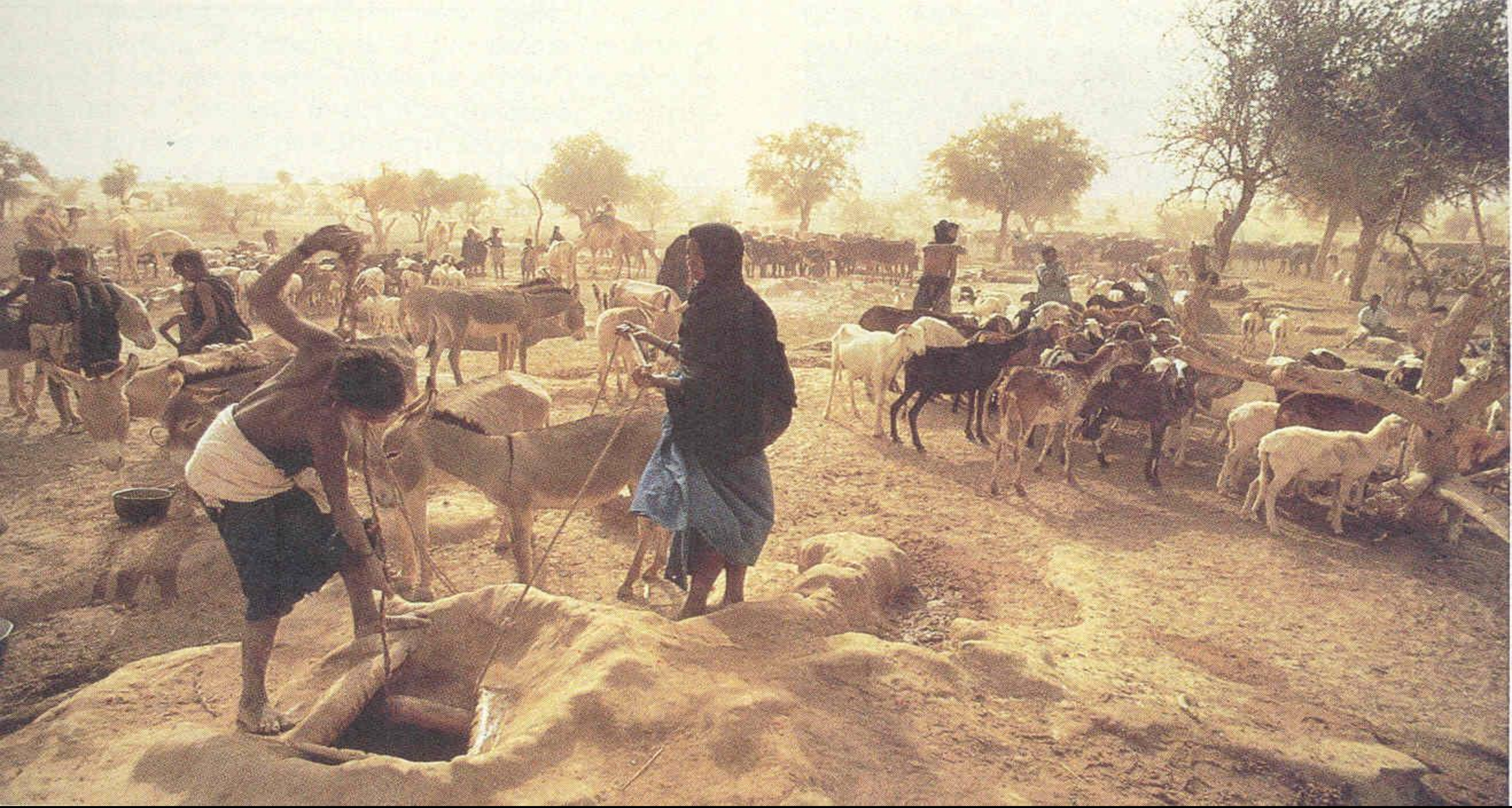
Photos of the remains have not been released, at the request of the British Government.

In addition to the *Titanic* artifacts, the researchers found objects that came from at least two other sources, including a rudder from a World War II-era boat and a mast dating to the 1950s.

The giant's long life is coming to an end, Kristiansson determined. "We observed substantial disintegration due to melting," he said. "In five years, the Titanic iceberg will be no more."

- The International Ice Patrol was set-up to track icebergs alter the Titanic disaster.
- They use ships, planes, and satellites to track icebergs.
- Warnings by the patrol have saved many people from disasters like the Titanic.

At 2:17 A.M., the *Titanic*'s stern rose out of the water, reaching a near vertical position before the great ship disappeared under the sea. From the lifeboats, passengers heard a hideous noise as all the contents of the ship crashed forward. Several survivors reported seeing the ship begin to break apart.



# GROUNDWATER GEOMORPHOLOGY

## *Water beneath the surface (groundwater)*

→ **Largest freshwater reservoir for humans**

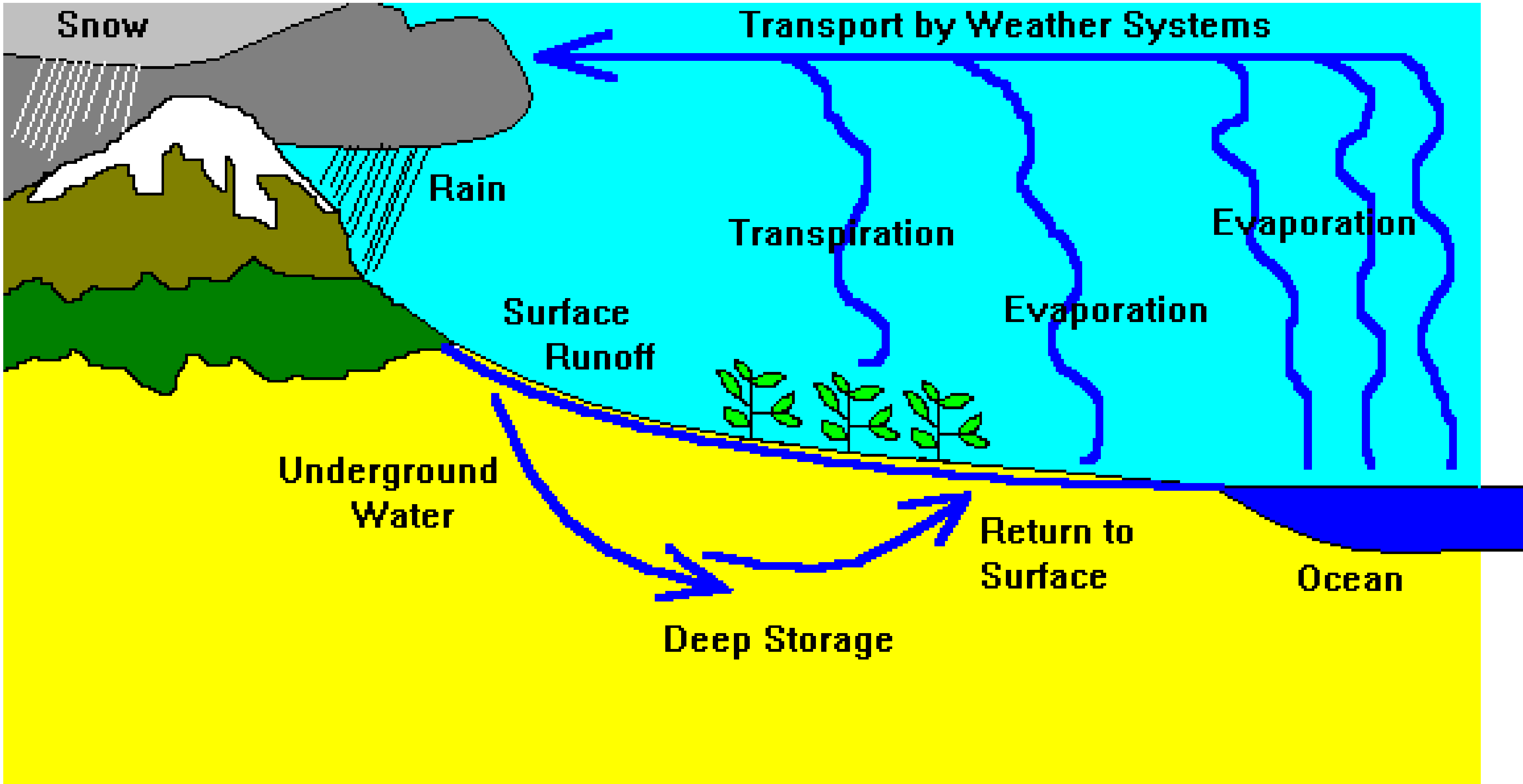
- **Groundwater fills the open spaces in rocks, sediment, and soil beneath the surface**
- **Groundwater is an important source for domestic, industrial, and agricultural use, but is also an important erosional and depositional Agent in subsurface, important energy source in some areas**

**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**

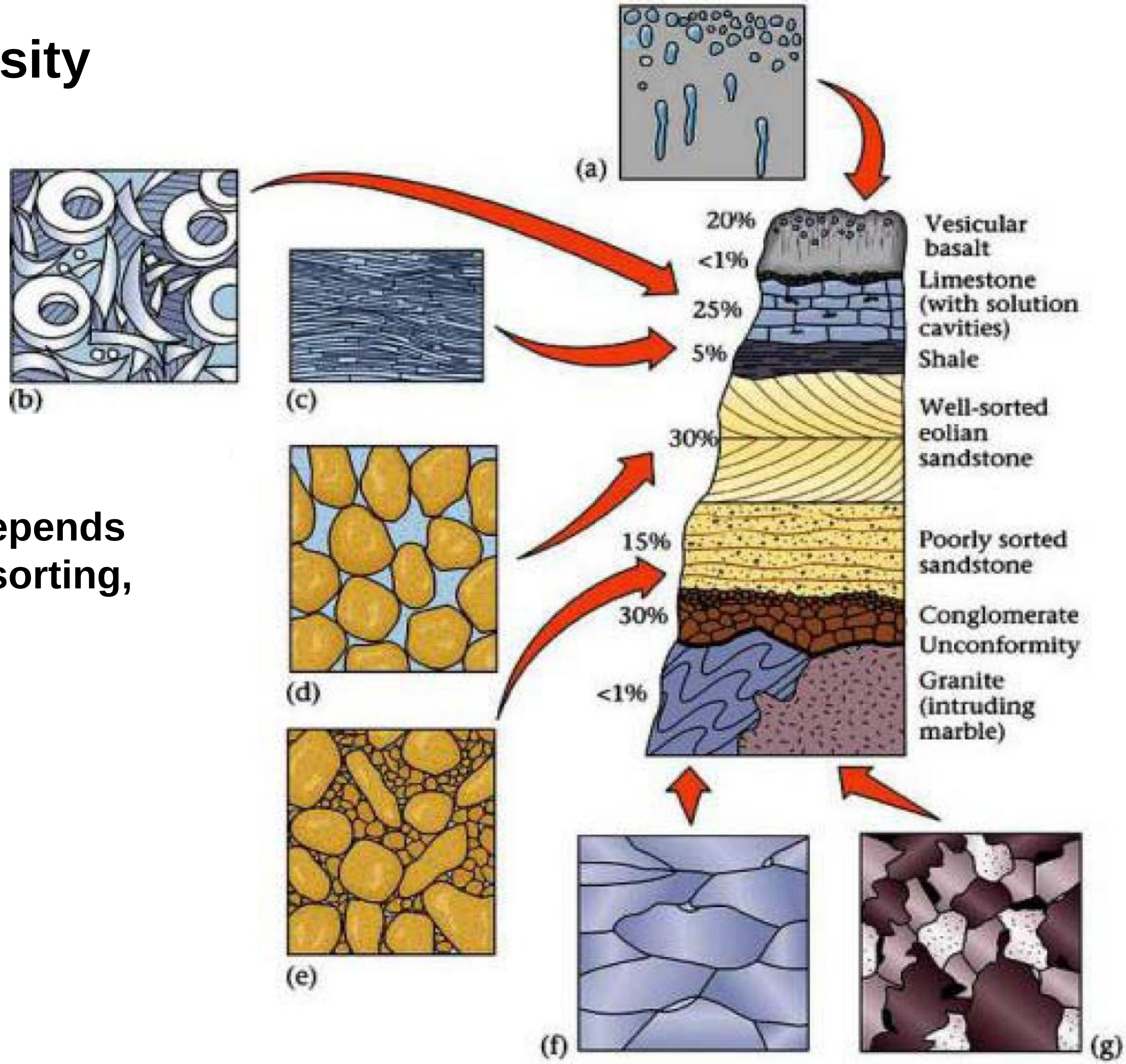
- **Determines how much groundwater can be stored**

### Permeability

- **Ability to transmit water through connected pore spaces**

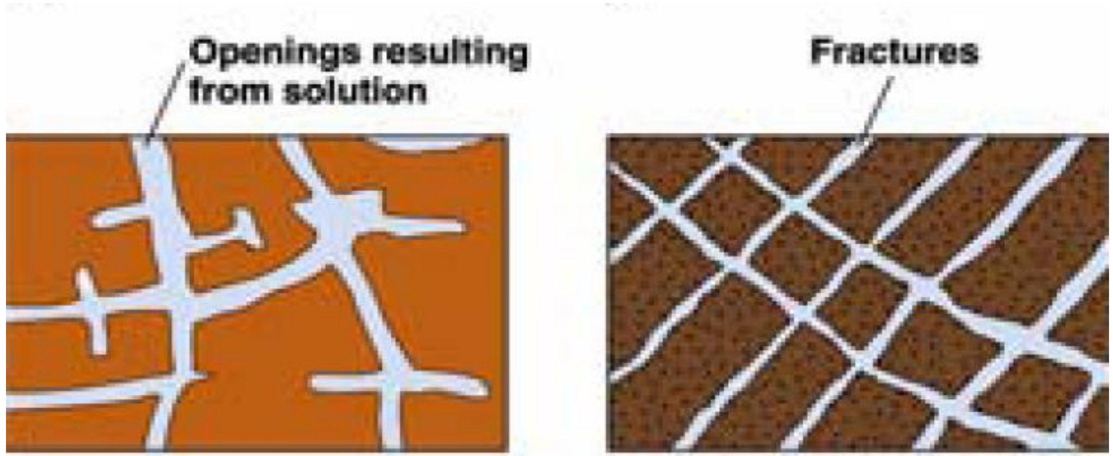
# Porosity

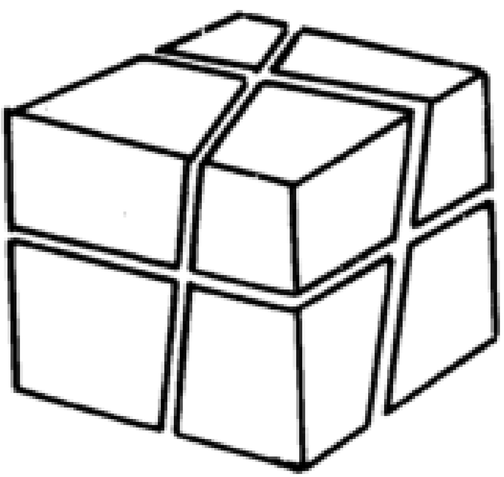
❖**Primary porosity**




**Primary porosity depends on the rock types, sorting,**

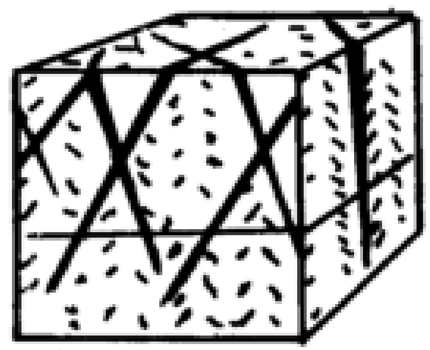
# Secondary porosity



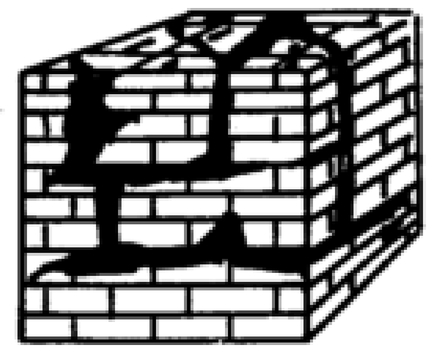



Fractured rock

Secondary Openings



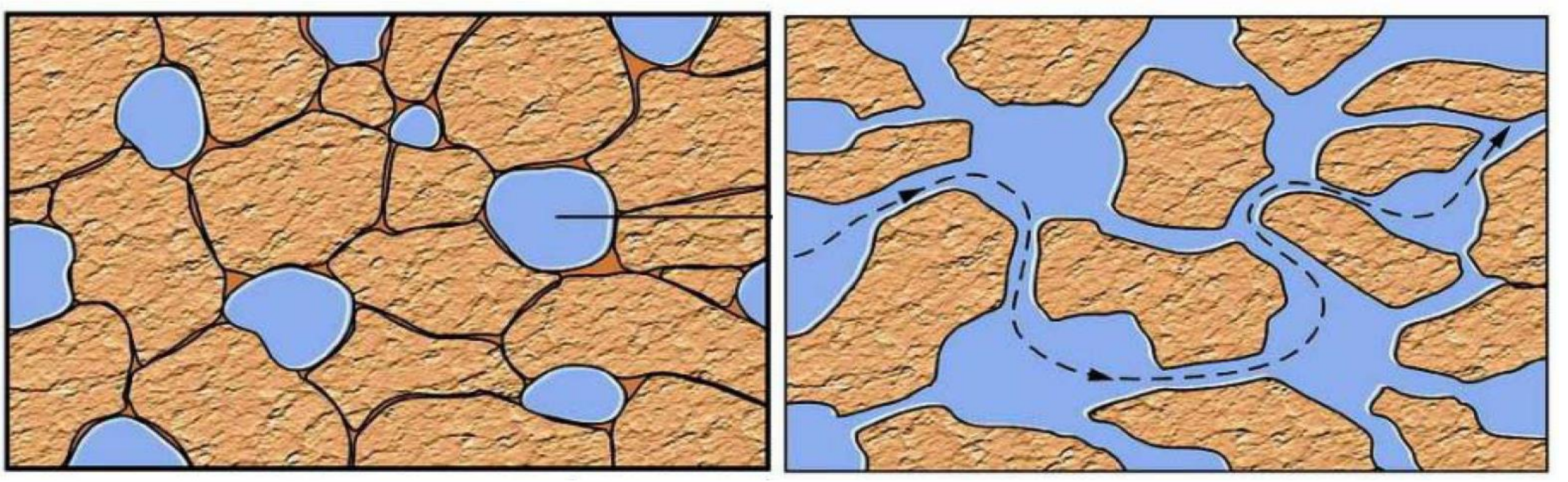
Fractures in granite



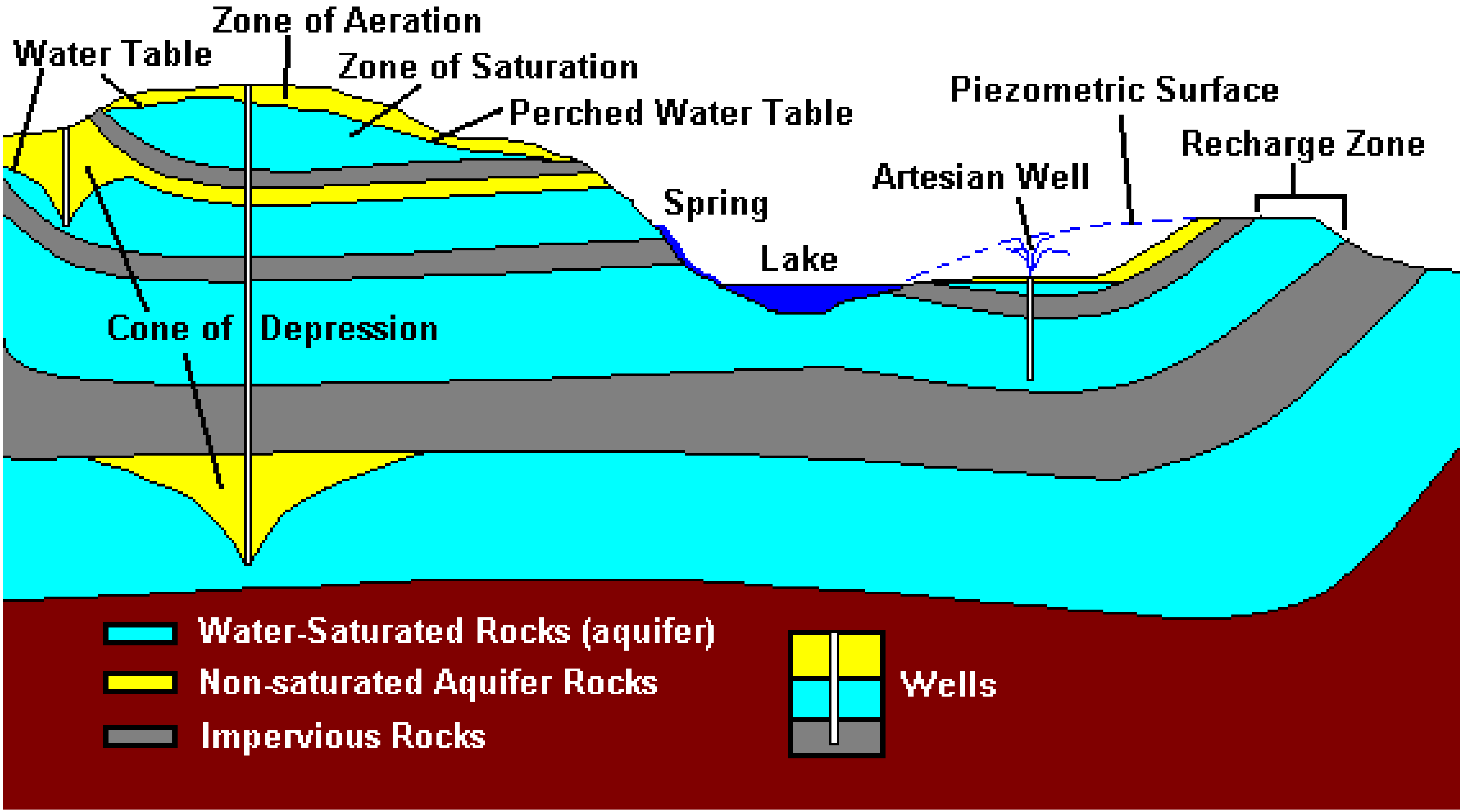
Caverns in limestone

# Permeability

- Ability to transmit water through connected pore spaces

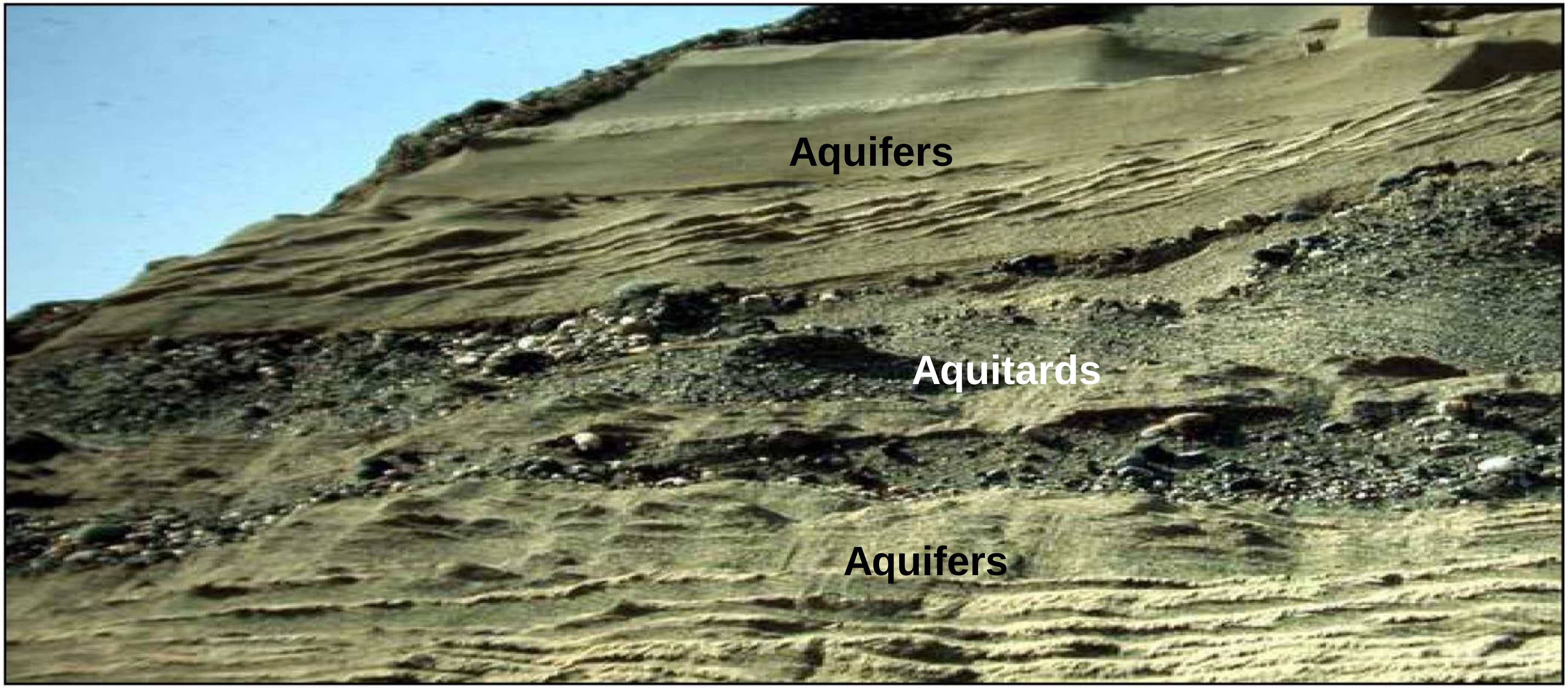


# Aquifers



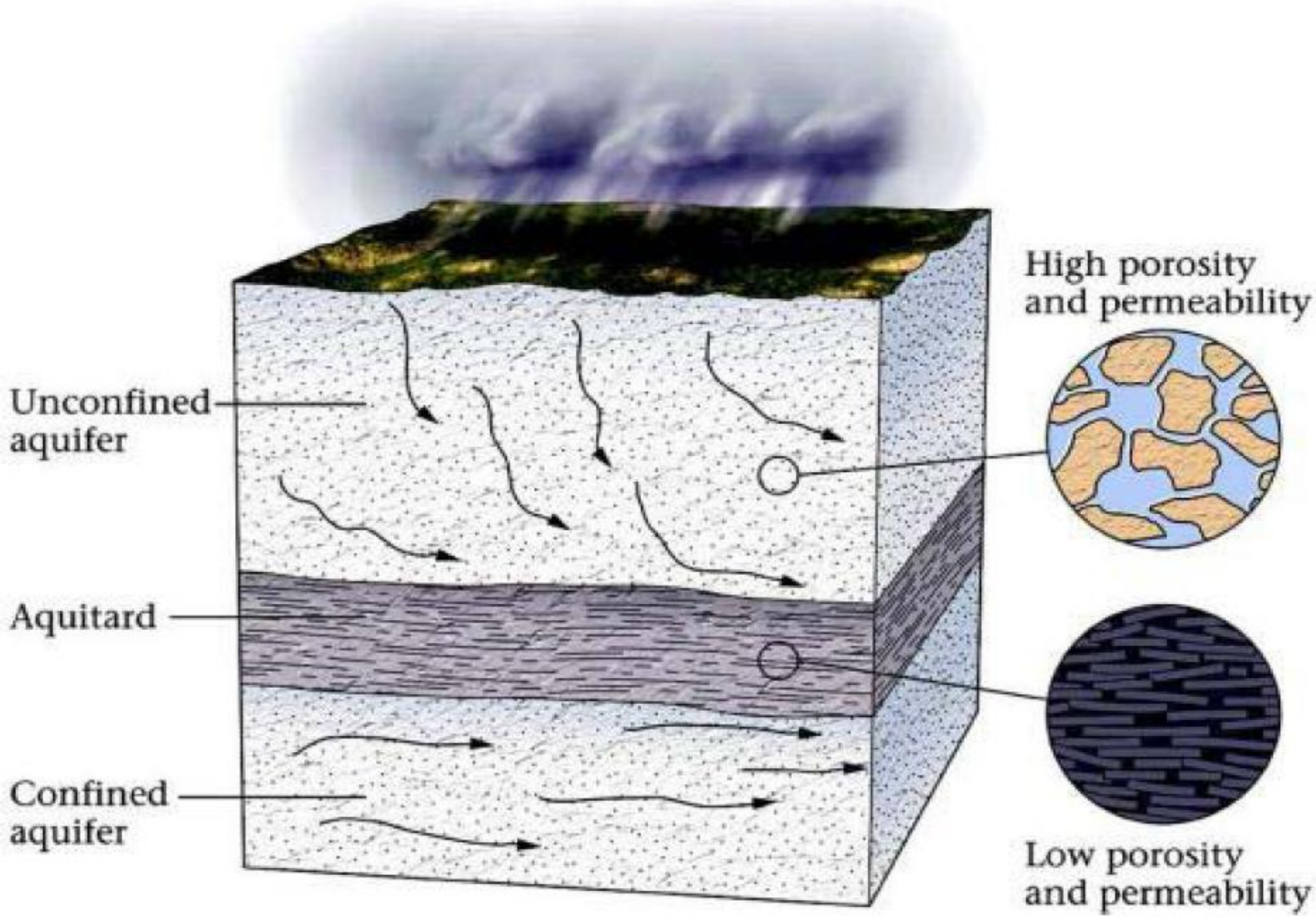
Zone of Aeration
Water Table
Zone of Saturation
Perched Water Table
Piezometric Surface
Recharge Zone
Artesian Well
Spring
Lake
Cone of Depression
Water-Saturated Rocks (aquifer)
Non-saturated Aquifer Rocks
Impervious Rocks
Wells

# Aquifers and Aquitards



## Aquifers - types

- Unconfined
- Confined



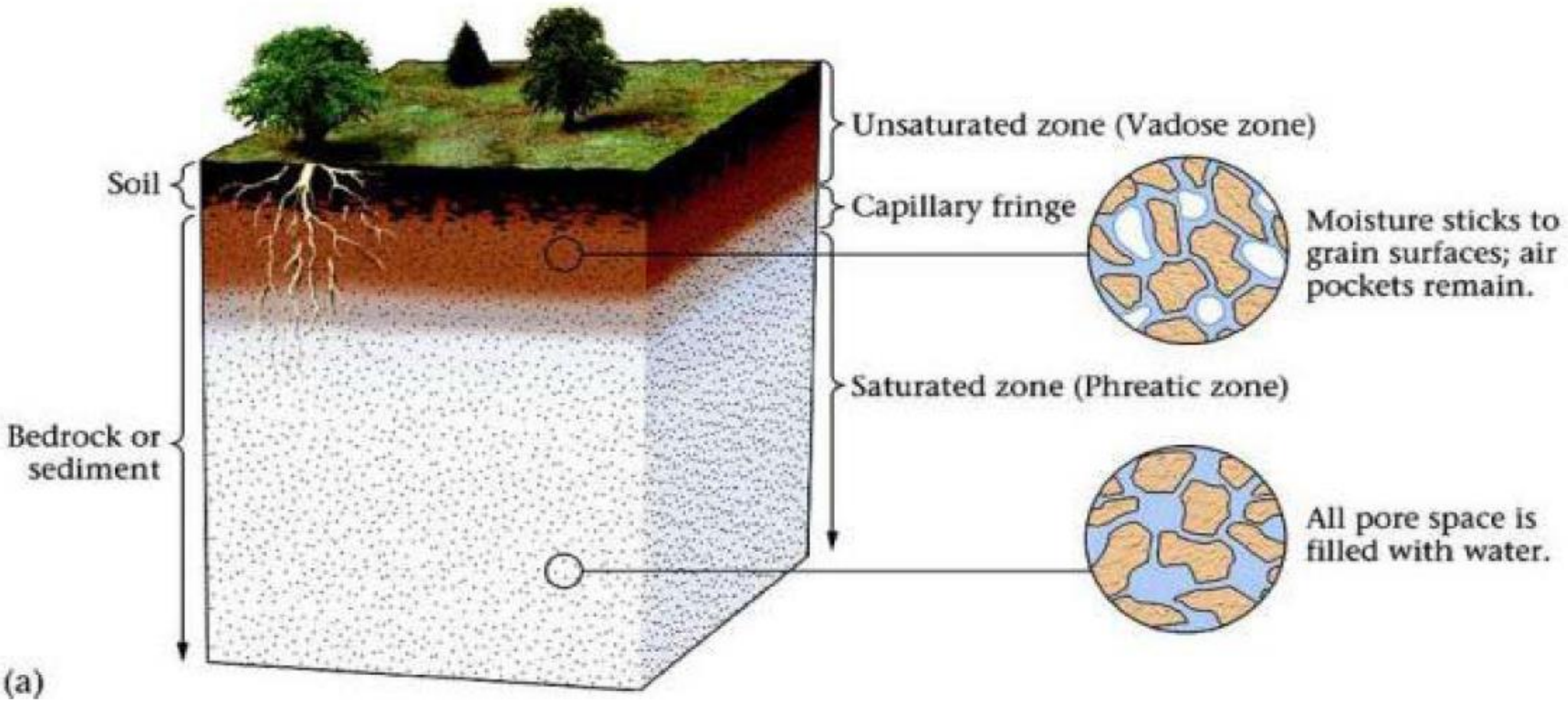
# Water Table

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

→ Vadose zone (Unsaturated zone)

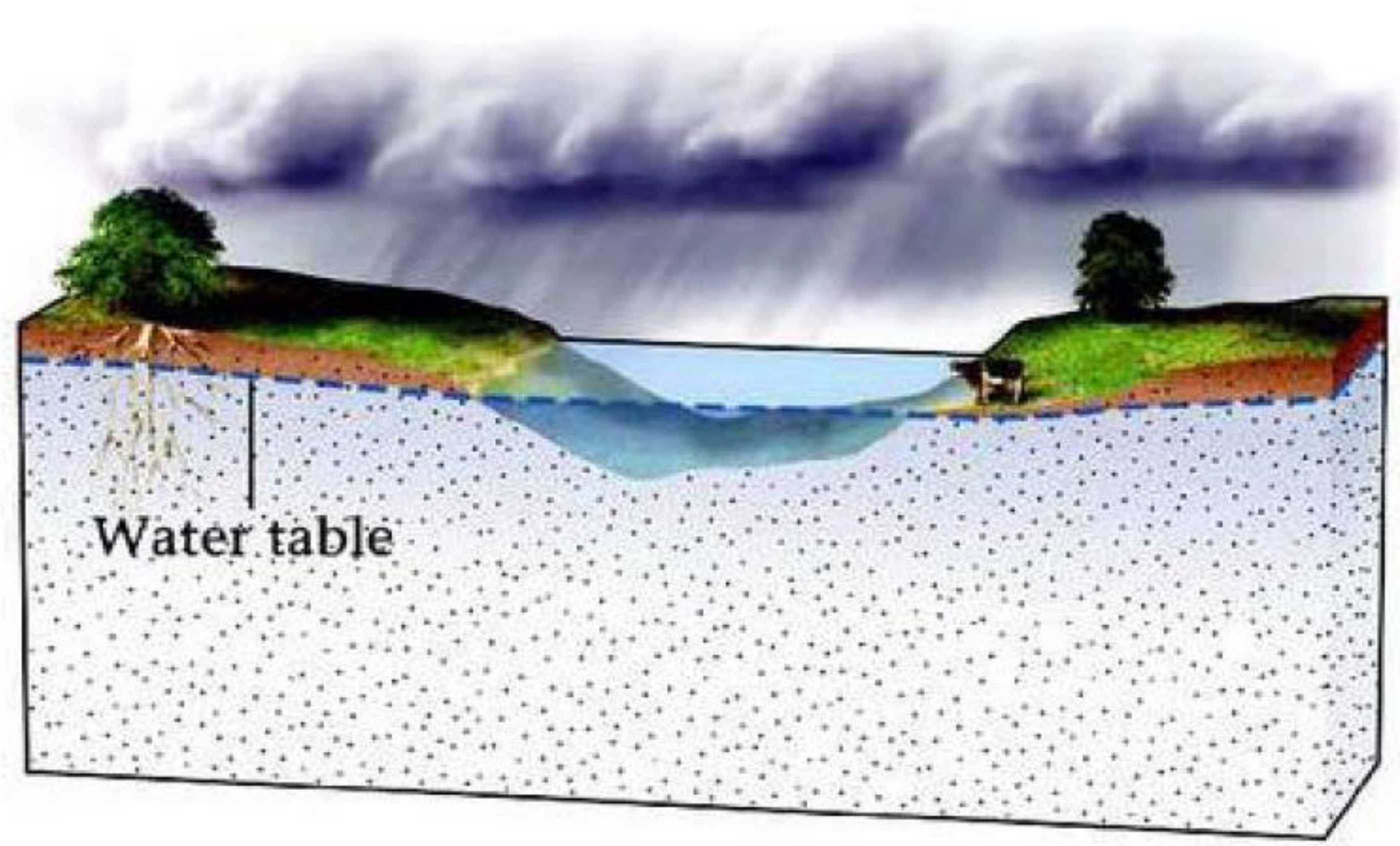
→ The capillary fringe

→ Phreatic zone (Saturated zone)



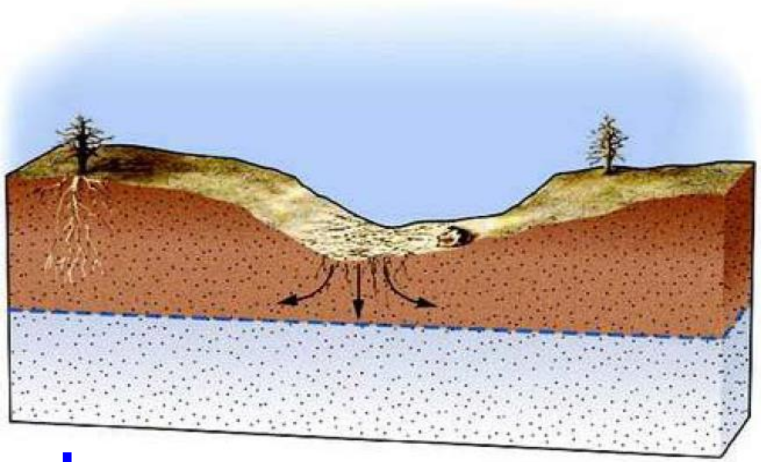
➔The depth to the water table is variable

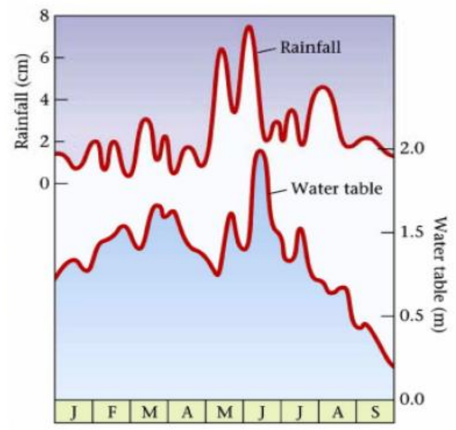
➔Perennial surface water exposes the water table



## Water table position changes with rainfall

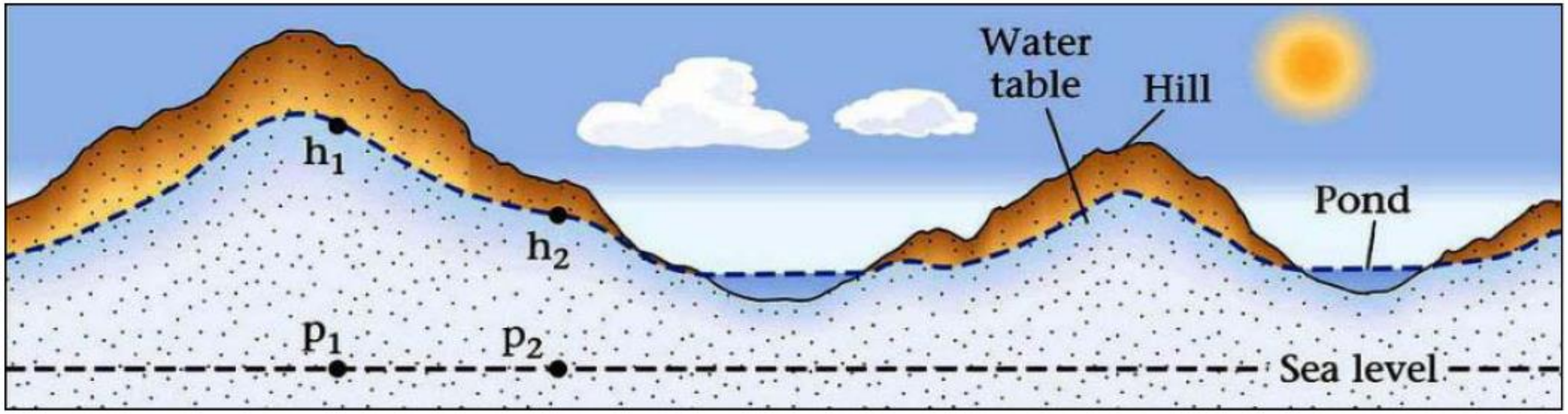
- ❖Ponds go dry if the water table falls below the bottom.



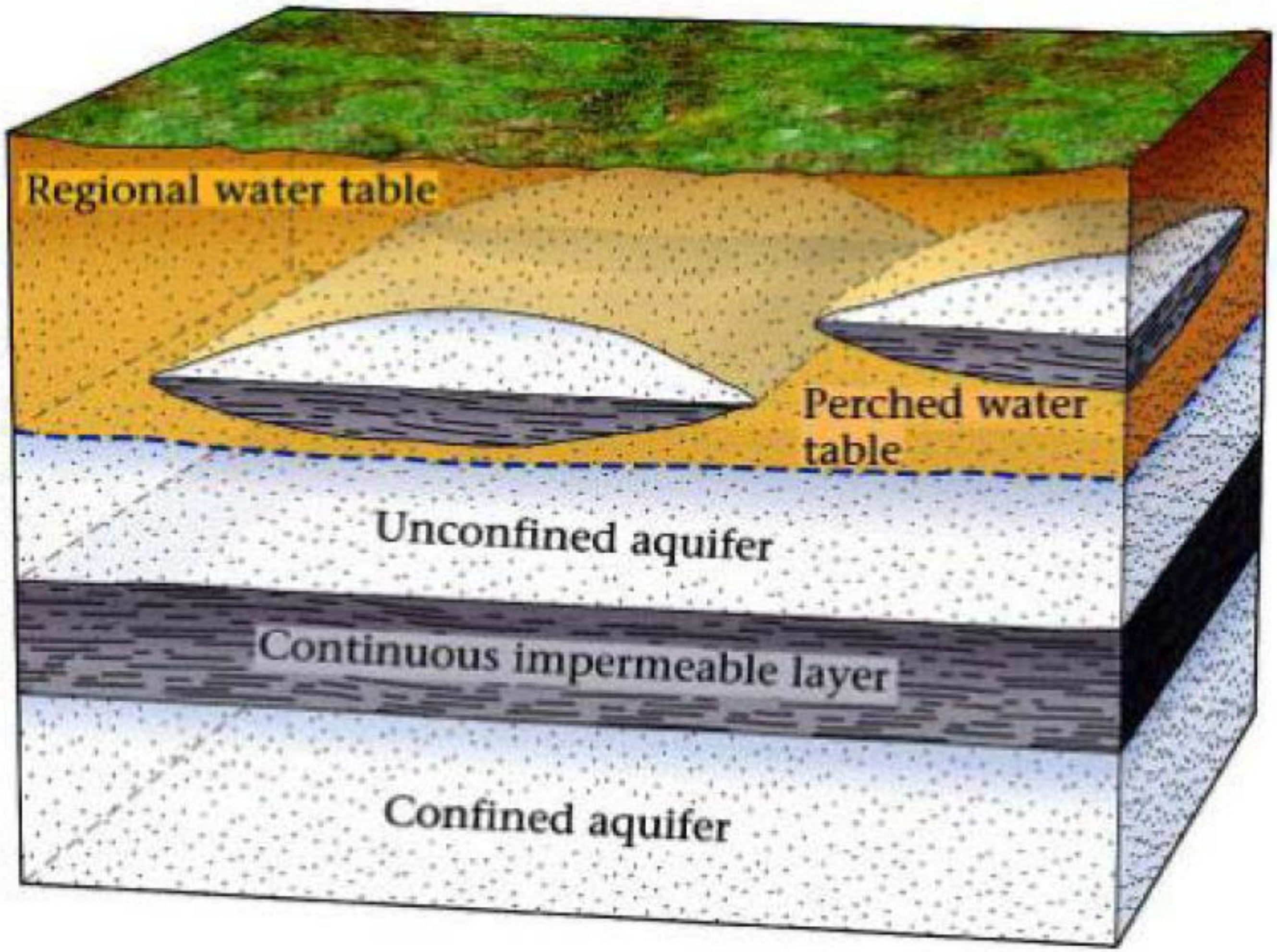



## Water Table Topography

- ❖The water table often follows the land’s topography



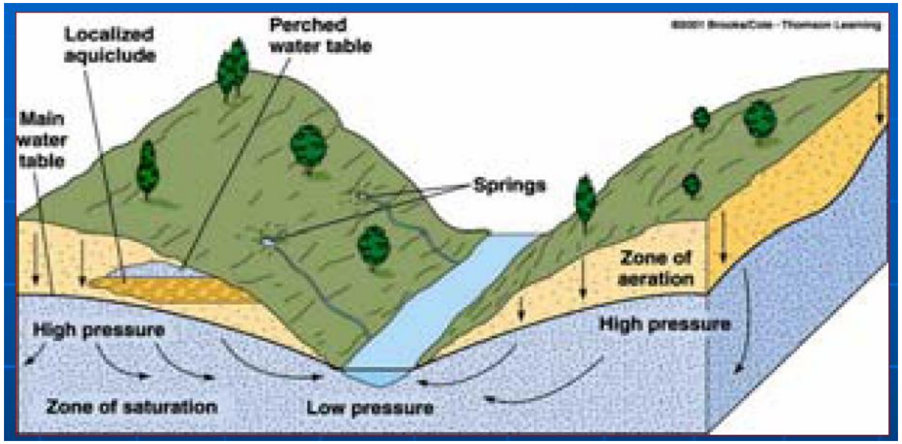
- ❖ **Discontinuous aquitards**
- ❖ **Aquitards can form perched water tables**

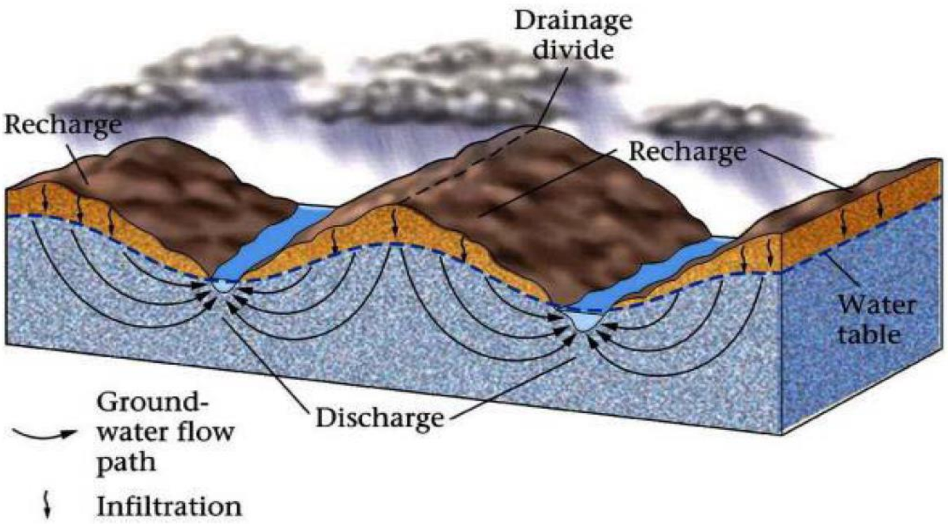


# Groundwater Movement

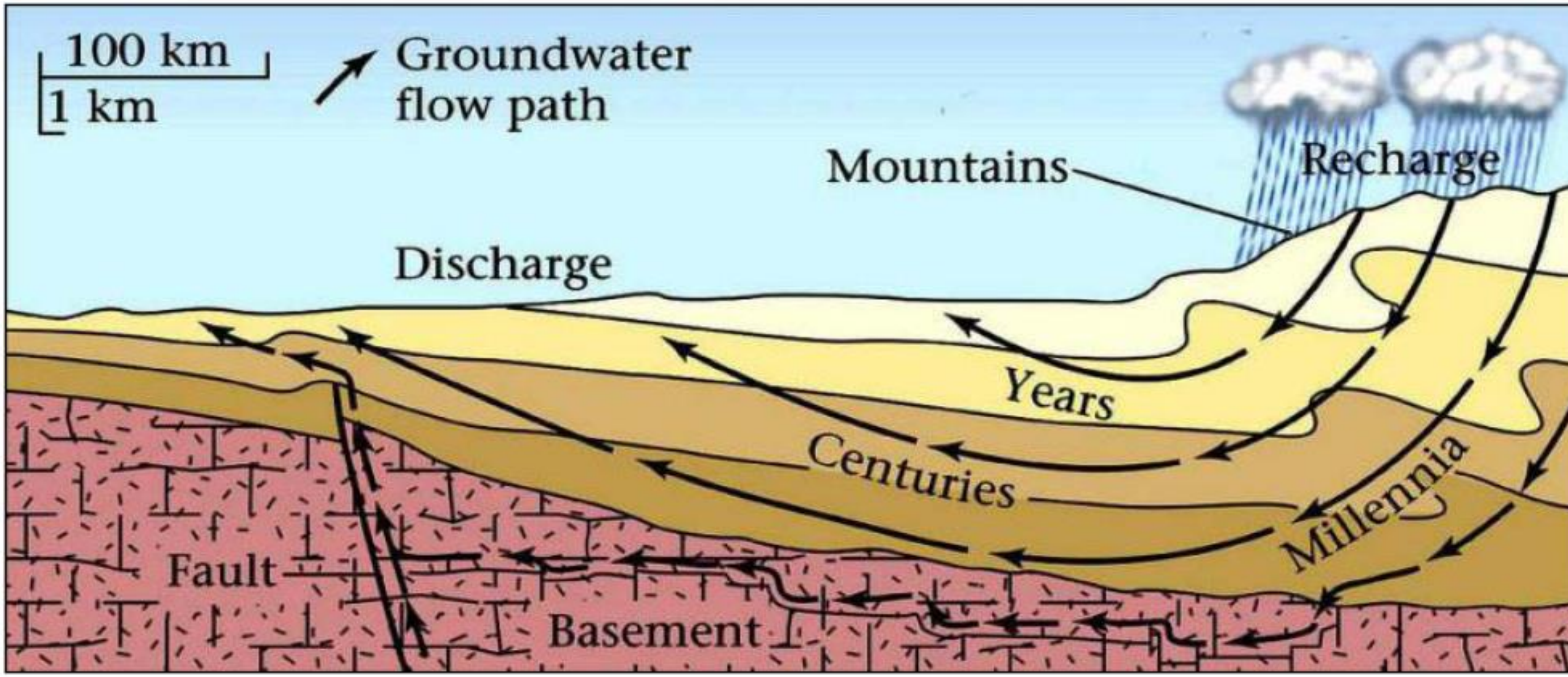
**Gravity moves groundwater, just as it does water in channels**

- 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

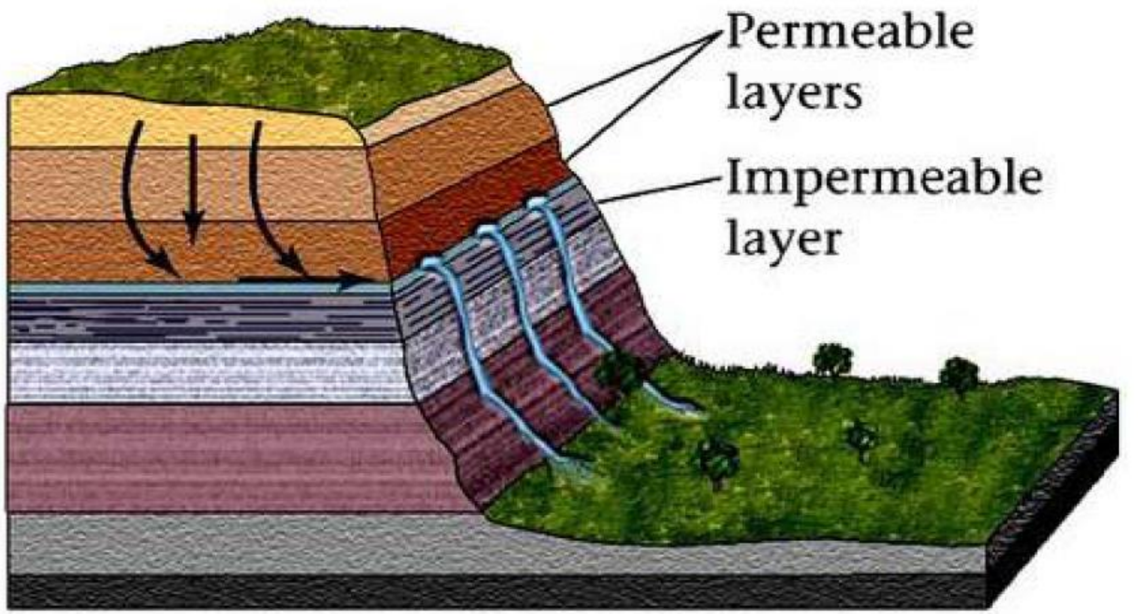


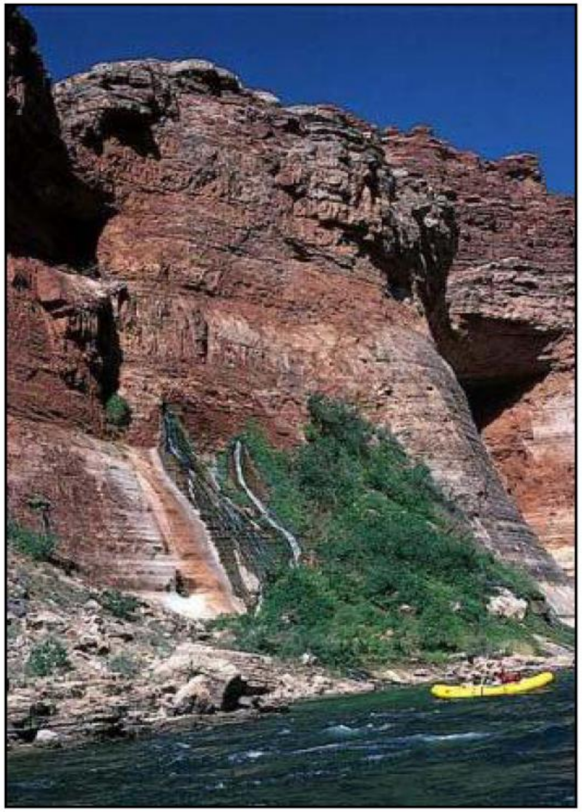
# Springs?

- Springs are locations of natural groundwater discharge.

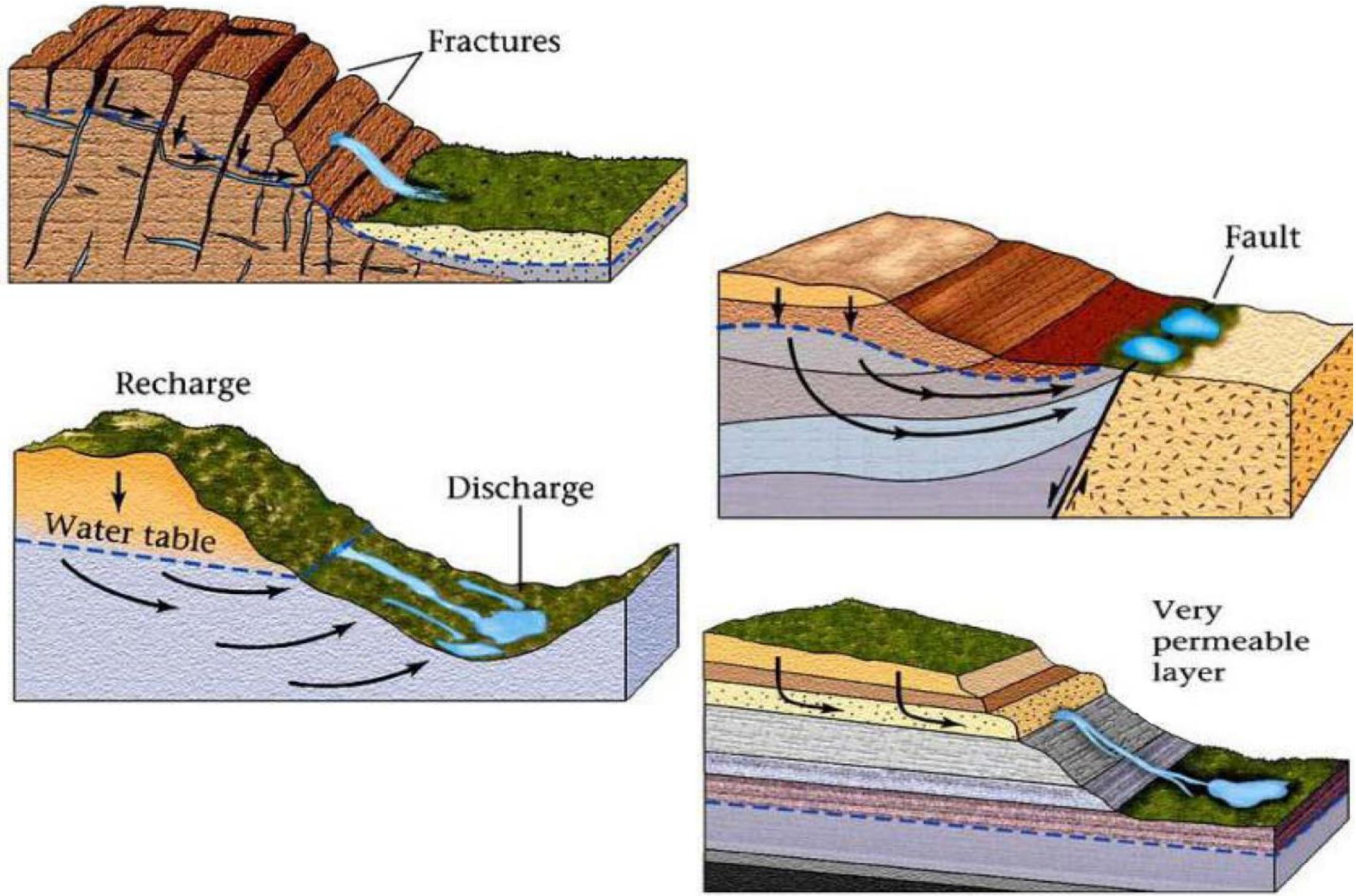
- Places where groundwater flows or seeps out of the ground

- when percolating water reaches the water table or impermeable layer, it flows laterally and may intersect the surface

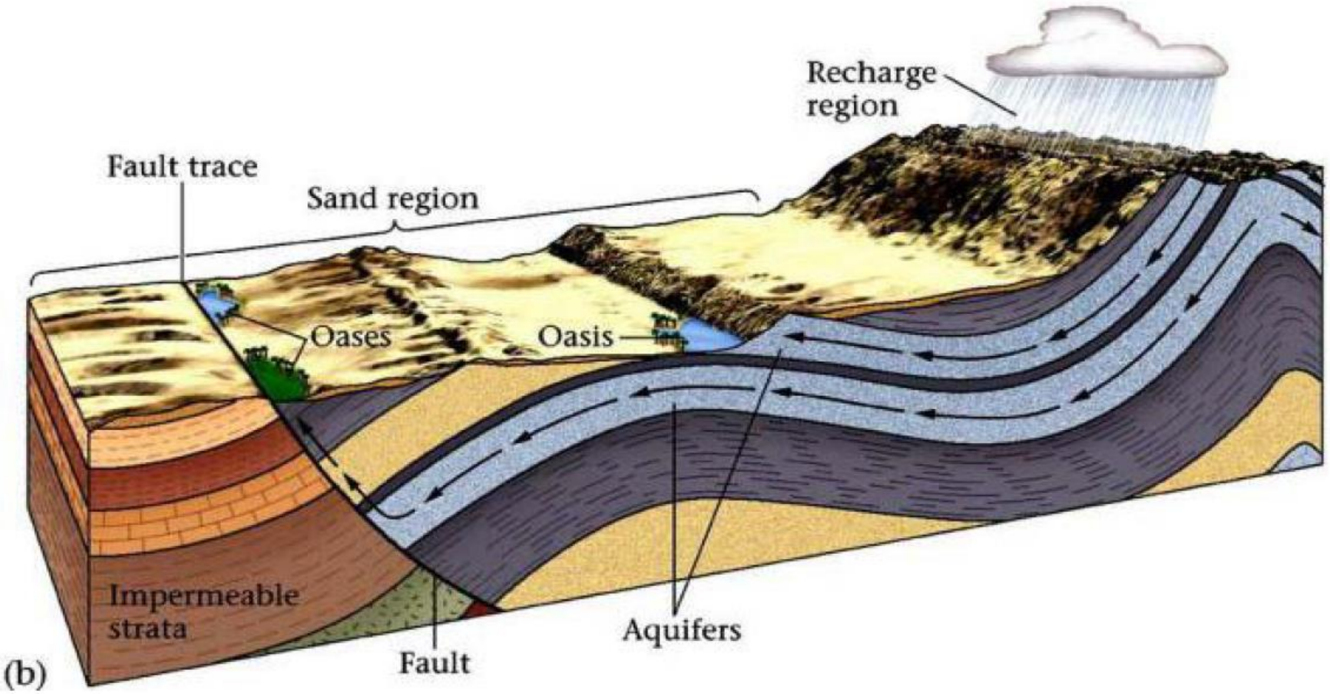


# Springs result from varied geologic features.

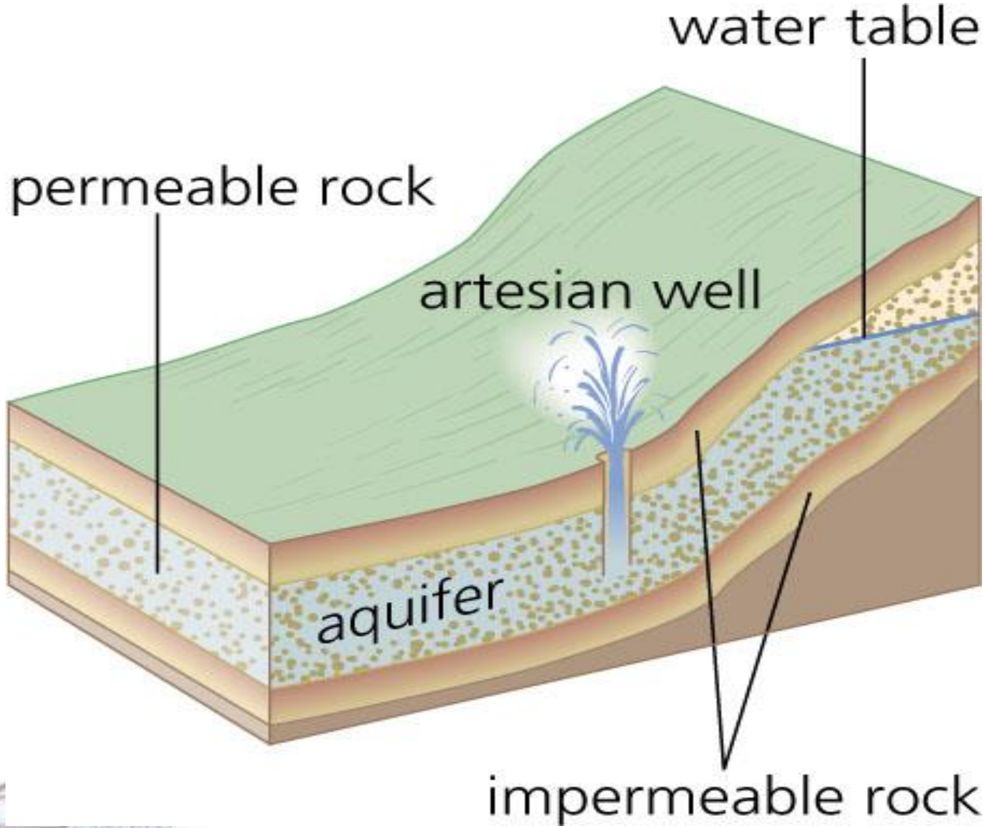


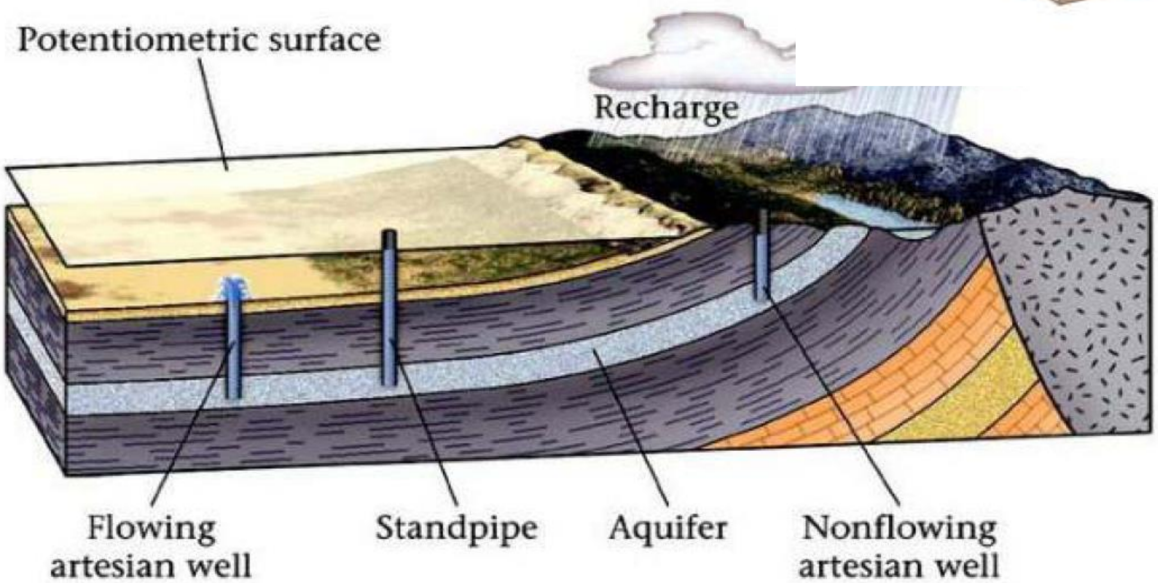
- Oases in the Sahara desert develop from spring flow.
- Water from recharge areas flows to oasis discharge points.



**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**

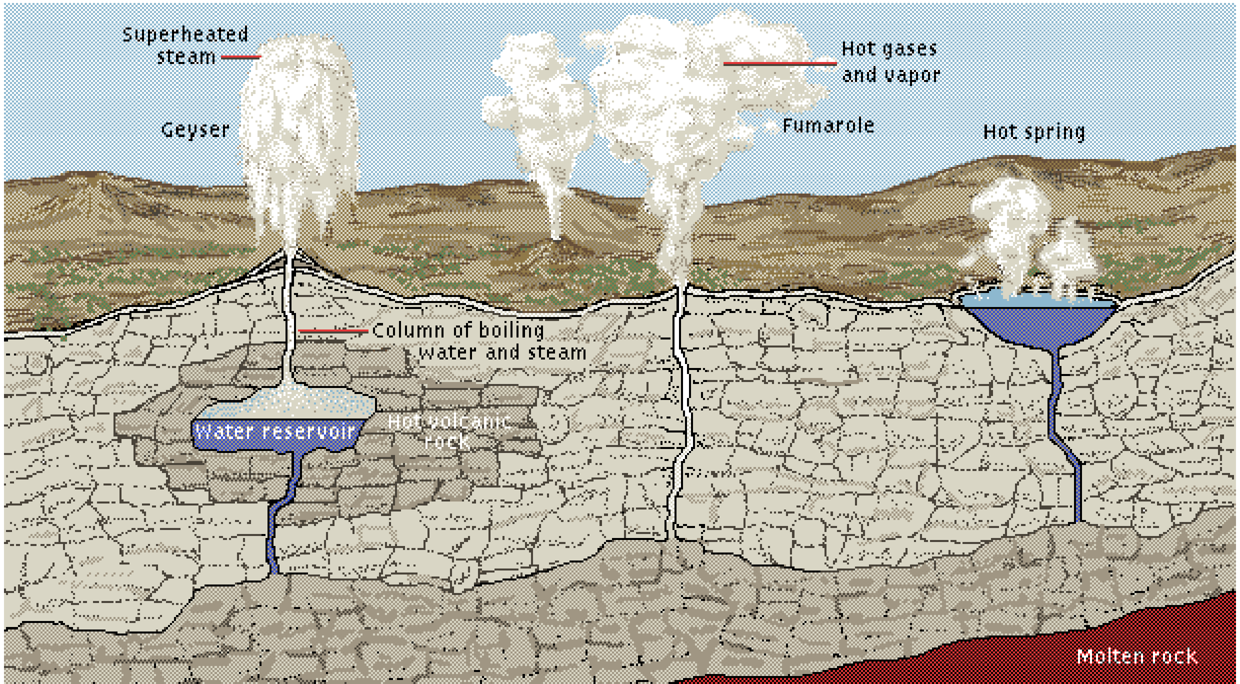
## Hot springs

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

*geyser in Yellowstone National Park*

## Geysers

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



# Old Faithful Geyser

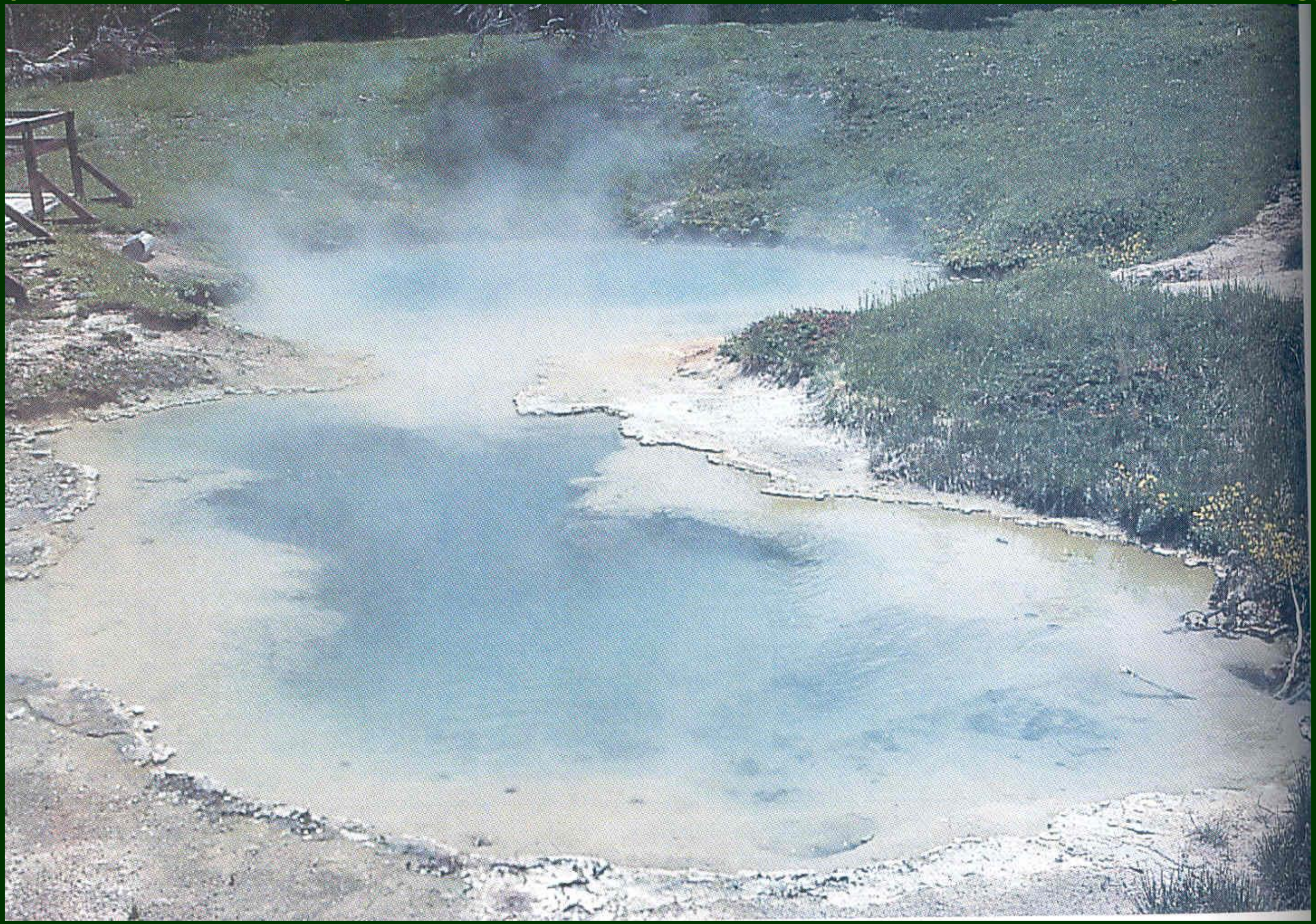
(Yellowstone National Park, Wyoming)

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 ($37^{o}$ 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**

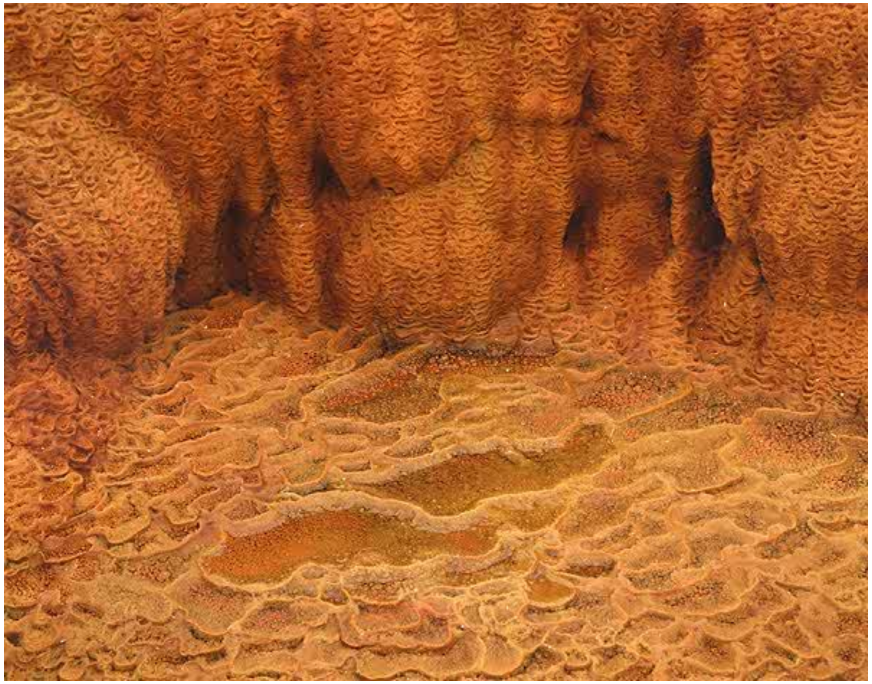
# Geothermal deposits

- **Travertine – a deposit of calcite that forms around hot springs**

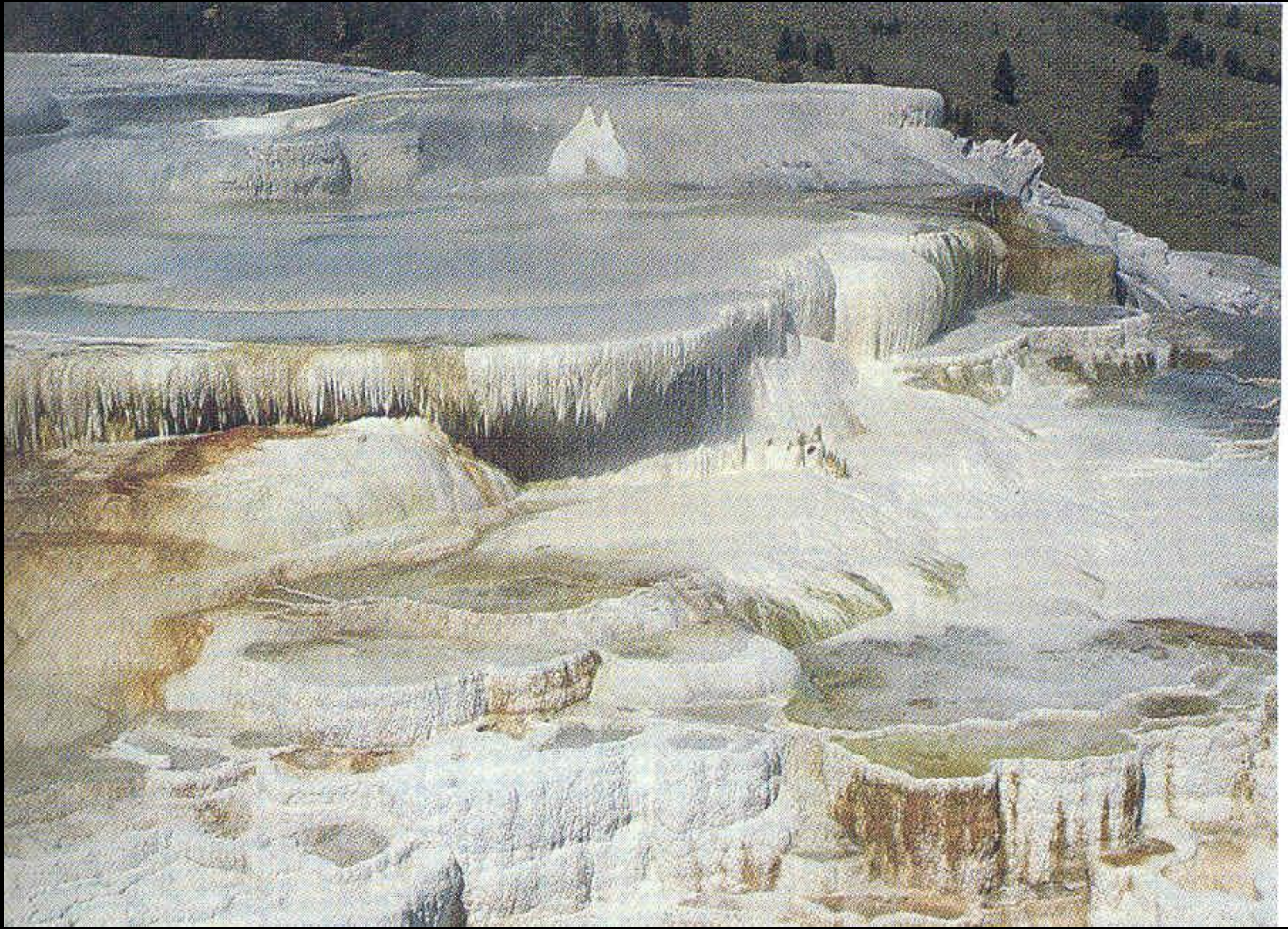
- **Sinter (or geyserite) – a deposit of precipitated silica**

**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**

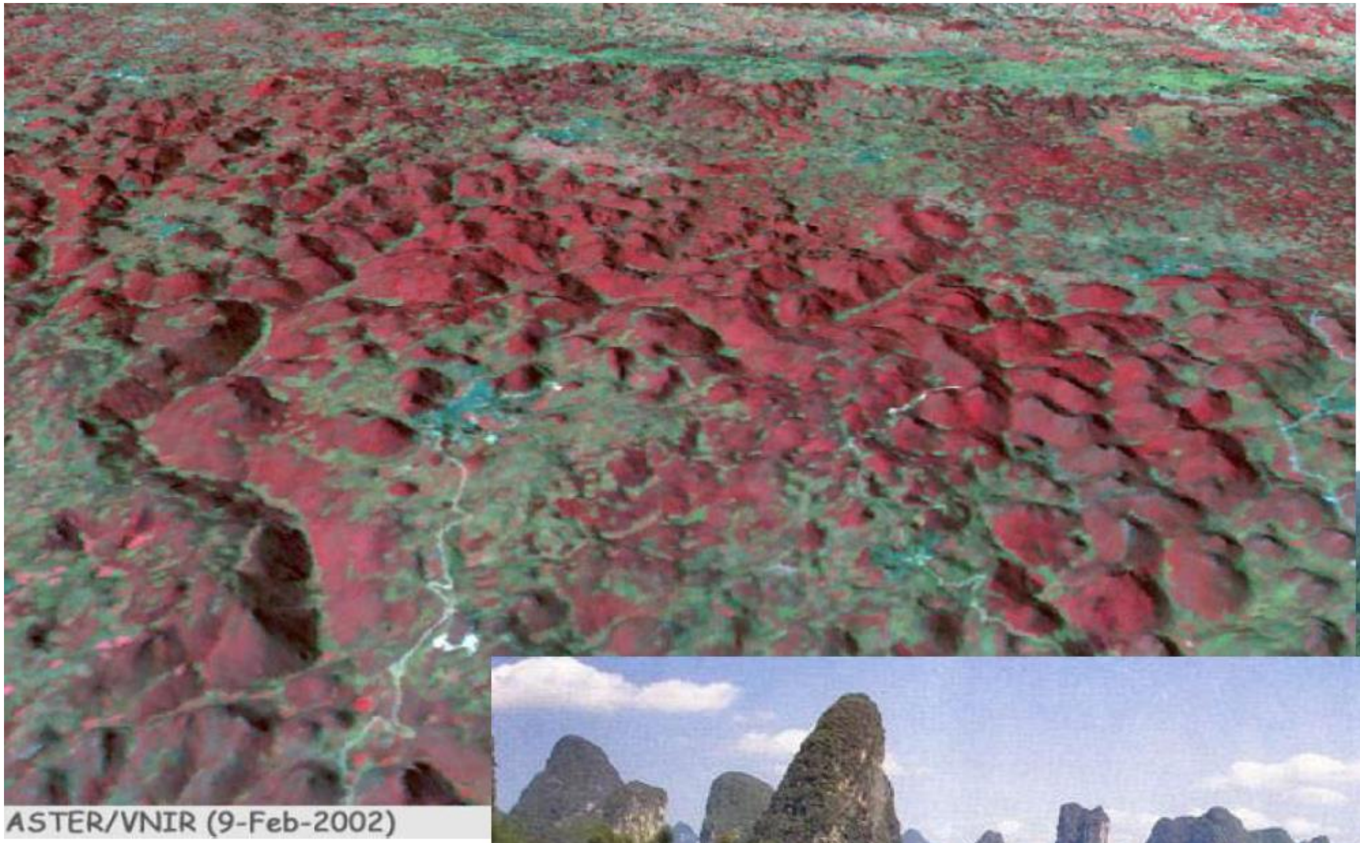
**When soluble rock is exposed at the surface, water can attack minerals chemically and become a significant erosional agent and create the various erosional and depositional landforms**

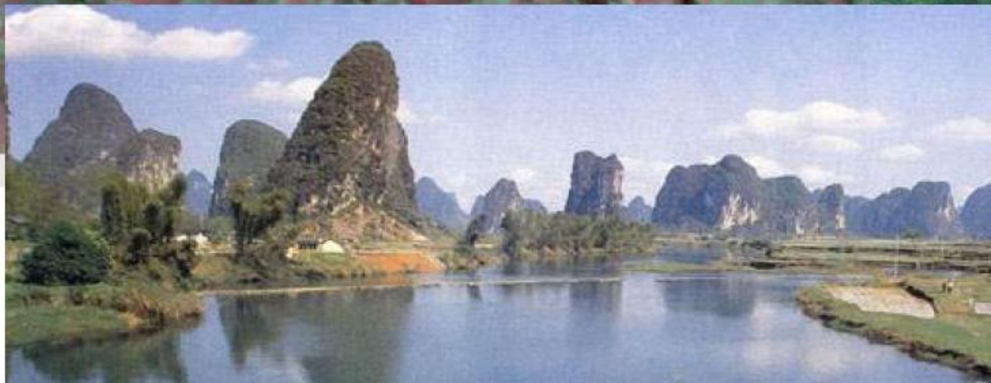
**The resulting topography with shallow depression and small mounts is termed Karst Topography (After the area Karst in Itlay)**

**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."



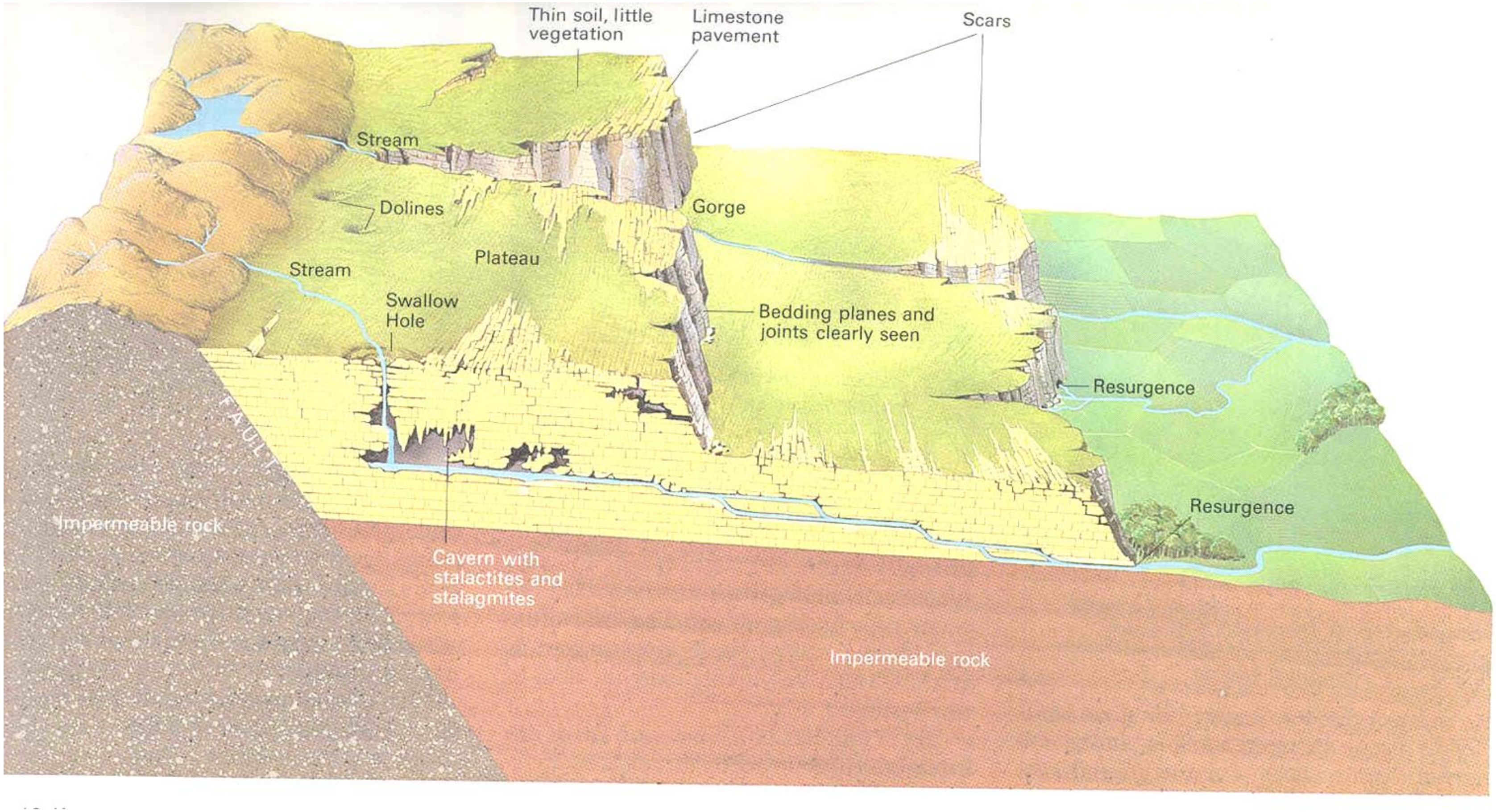
The "type locality" for karst terrain is in the Dinaric Alps of Croatia, where Mesozoic limestones are notably pitted by solution, as seen in this astronaut photo:

perspective view of Jamaican cockpit karst using IKONOS and DEM inputs

# Karst topography

## Generally associated with

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



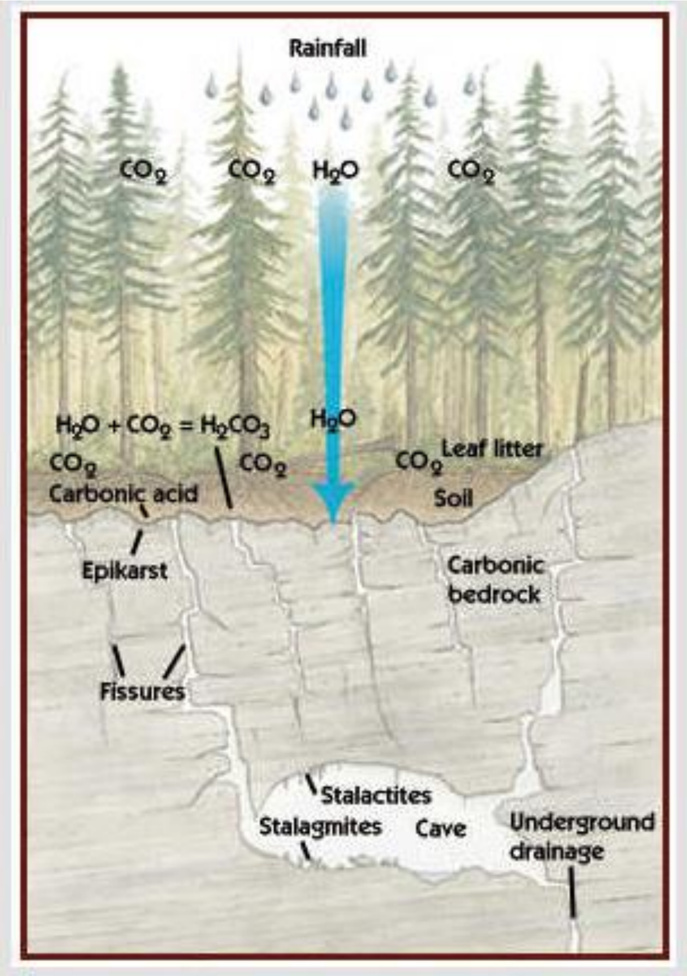
# Dissolution Reactions

- water + carbon dioxide ⇨ carbonic acid

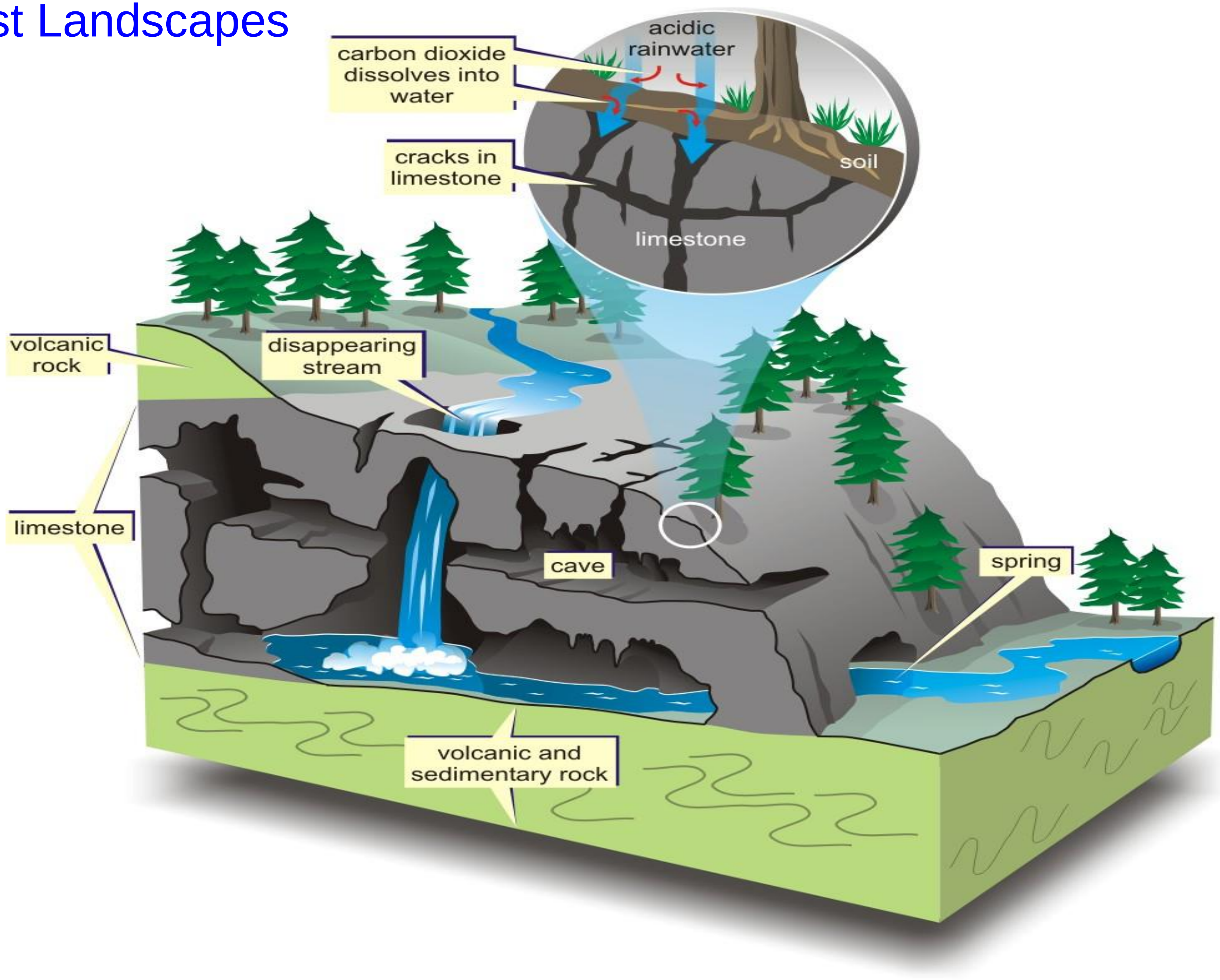
  $H_20$ + $CO_2$ ⇨ $H_2CO_3$

- carbonic acid +limestone ⇨ calcium +bicarbonate

  $H_2C03$ + $Ca\ CO_3$ ⇨ Ca + $HCO_3$



# Karst Landscapes

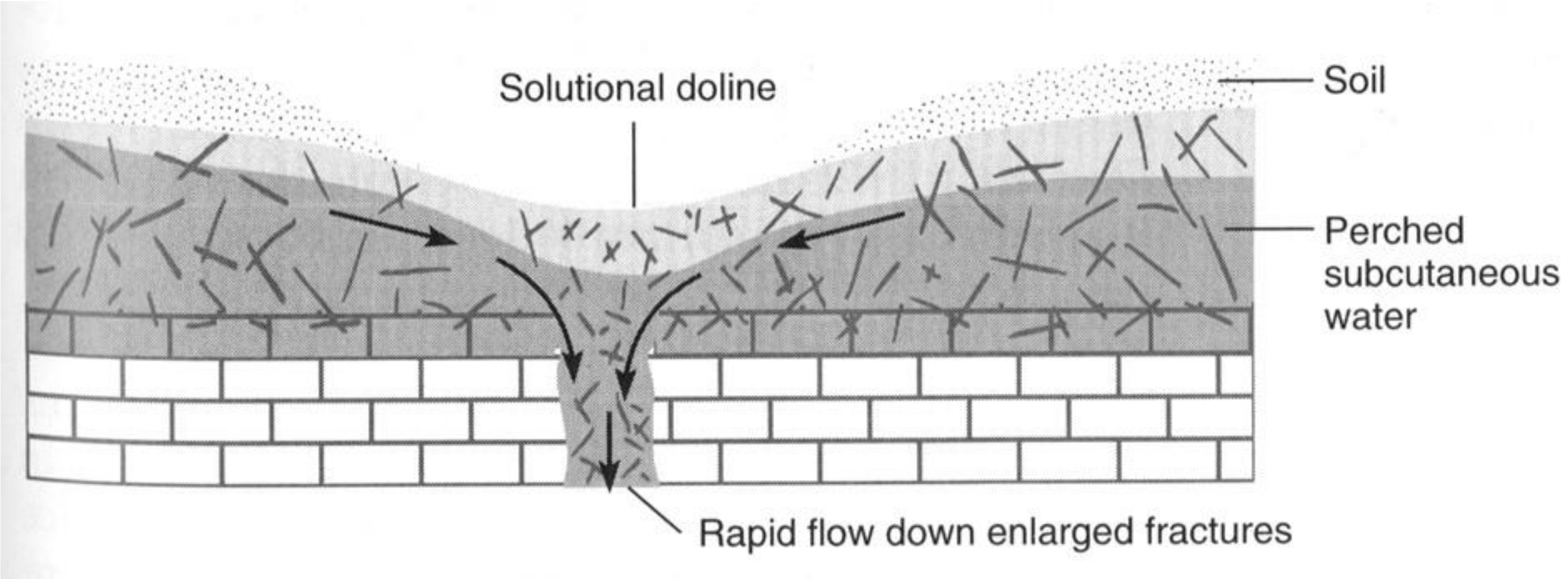


# Karst Landforms

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

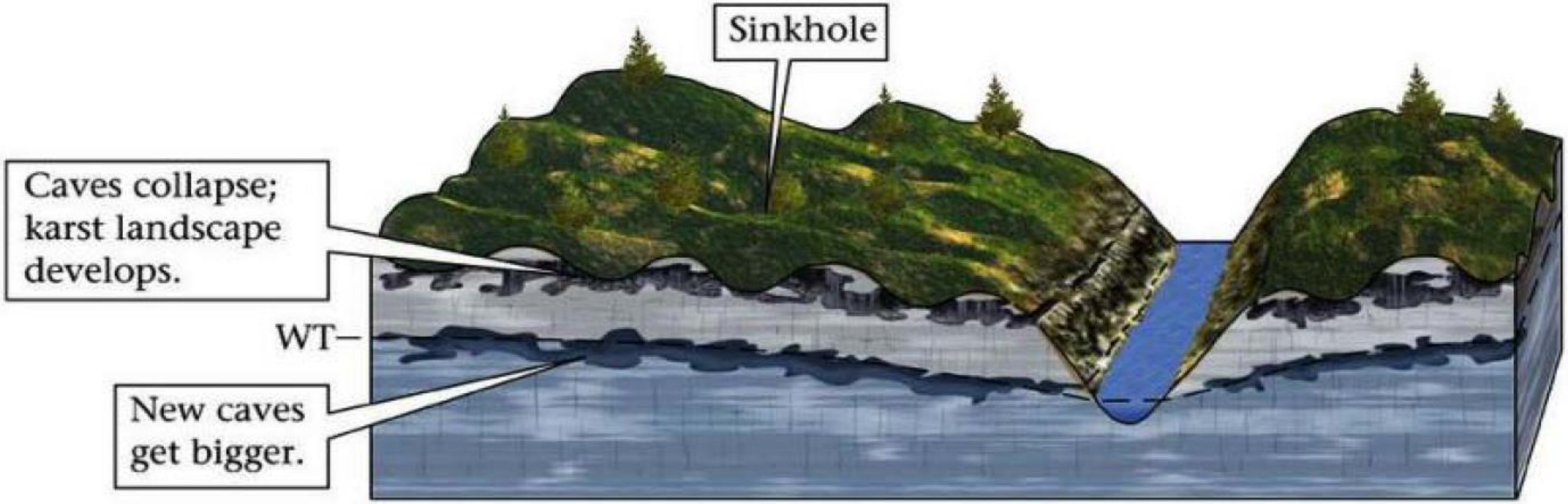
**Dolines or Solution sinkholes: Sink holes developed mainly by solution activity are known as Dolines. These are generally shallow basins to depth of 2-100 m and are 100 – 1000 m across. The sides are rocky or covered with vegetation**

**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

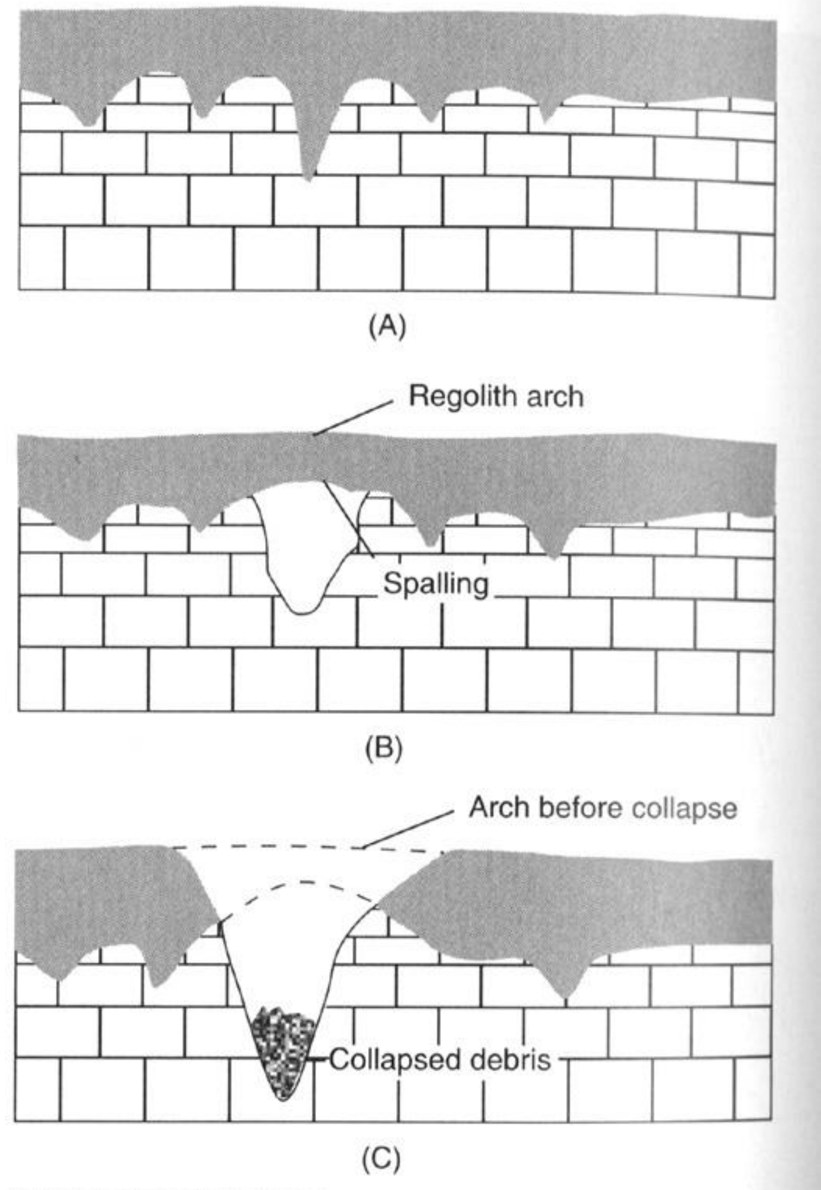
# Collapse Sinkhole

**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**

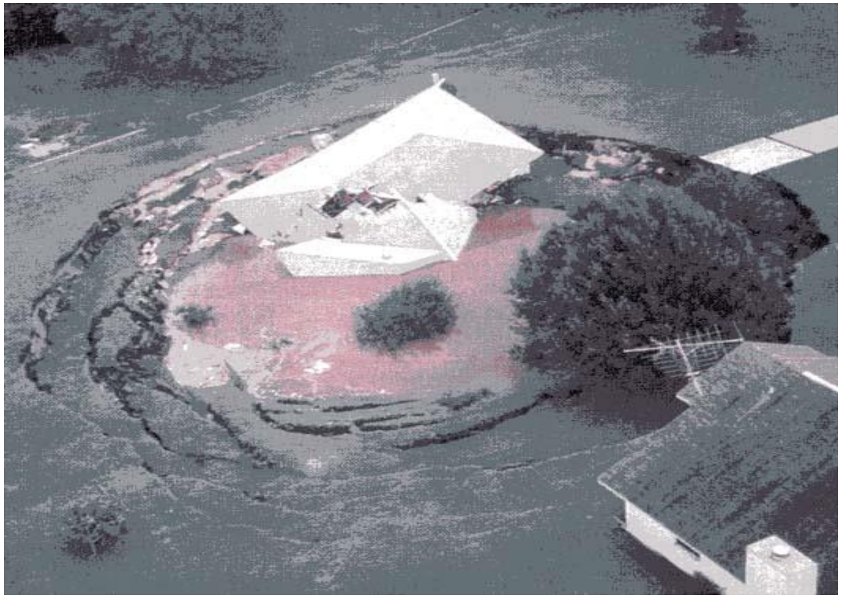
## Collapse Sinkholes

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



# Karst Hazards – Sinkhole Collapse

Winter Park, FL



Crooked Lake, FL

Tucson, AZ ----Karst??

Guatemala City

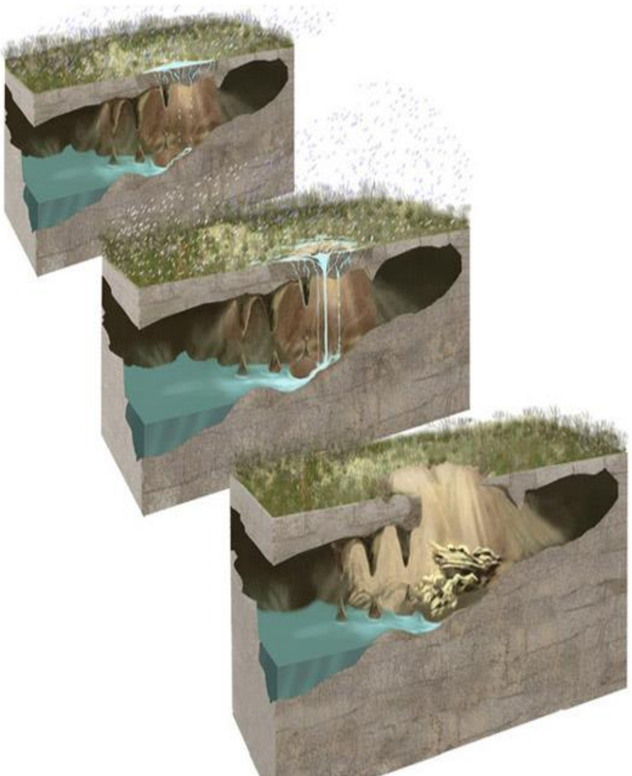
- Sinkholes result from roof collapse.
- Sinkholes decorate large regions of karst landscapes.

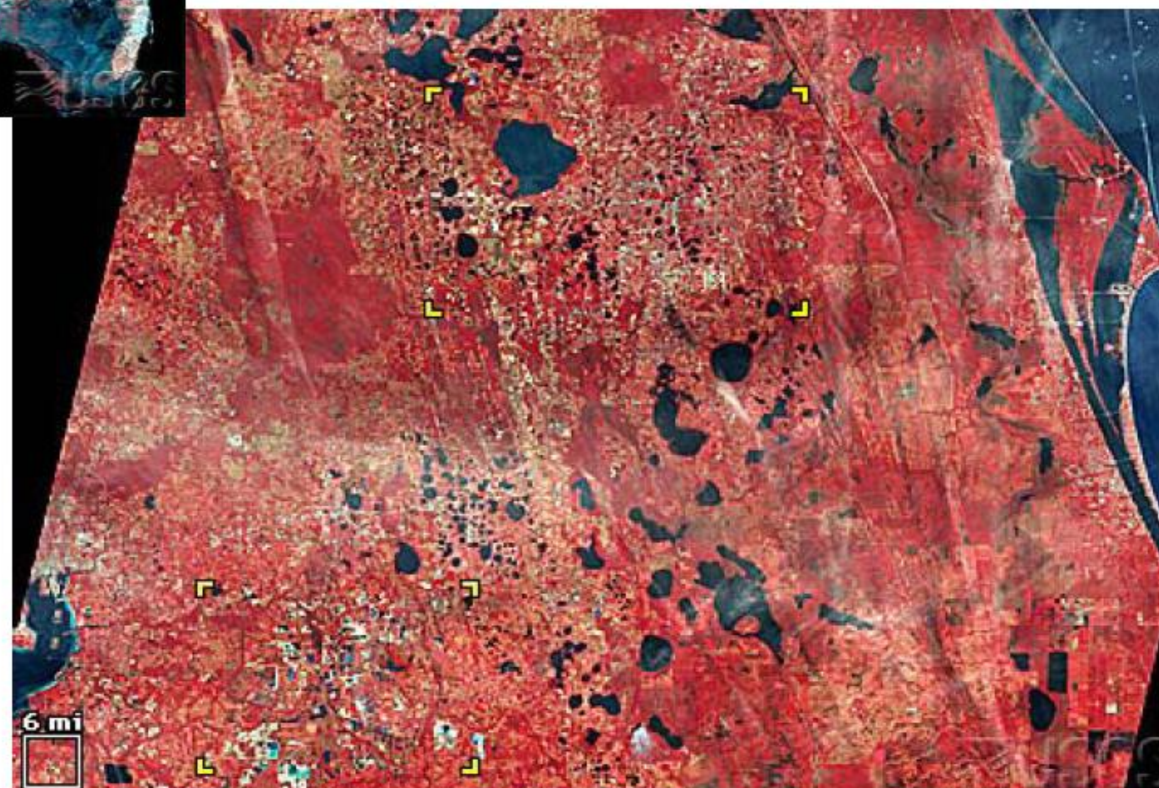



# Winter Park, FL sinkhole

- 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**.**

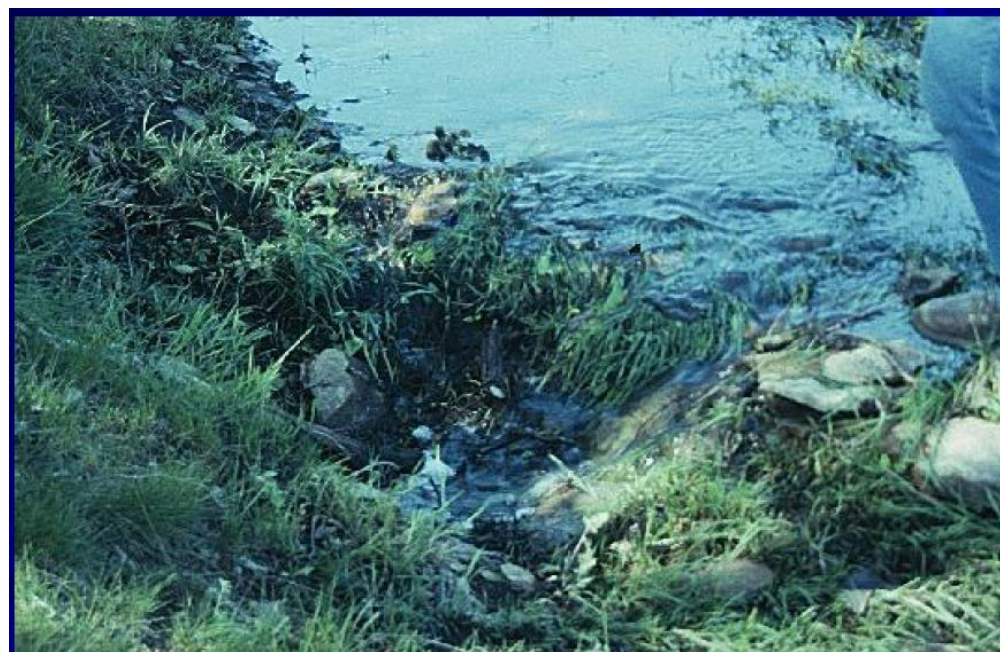
- **Sinking Stream:** stream that vanishes underground, usually at terminus of blind valley.

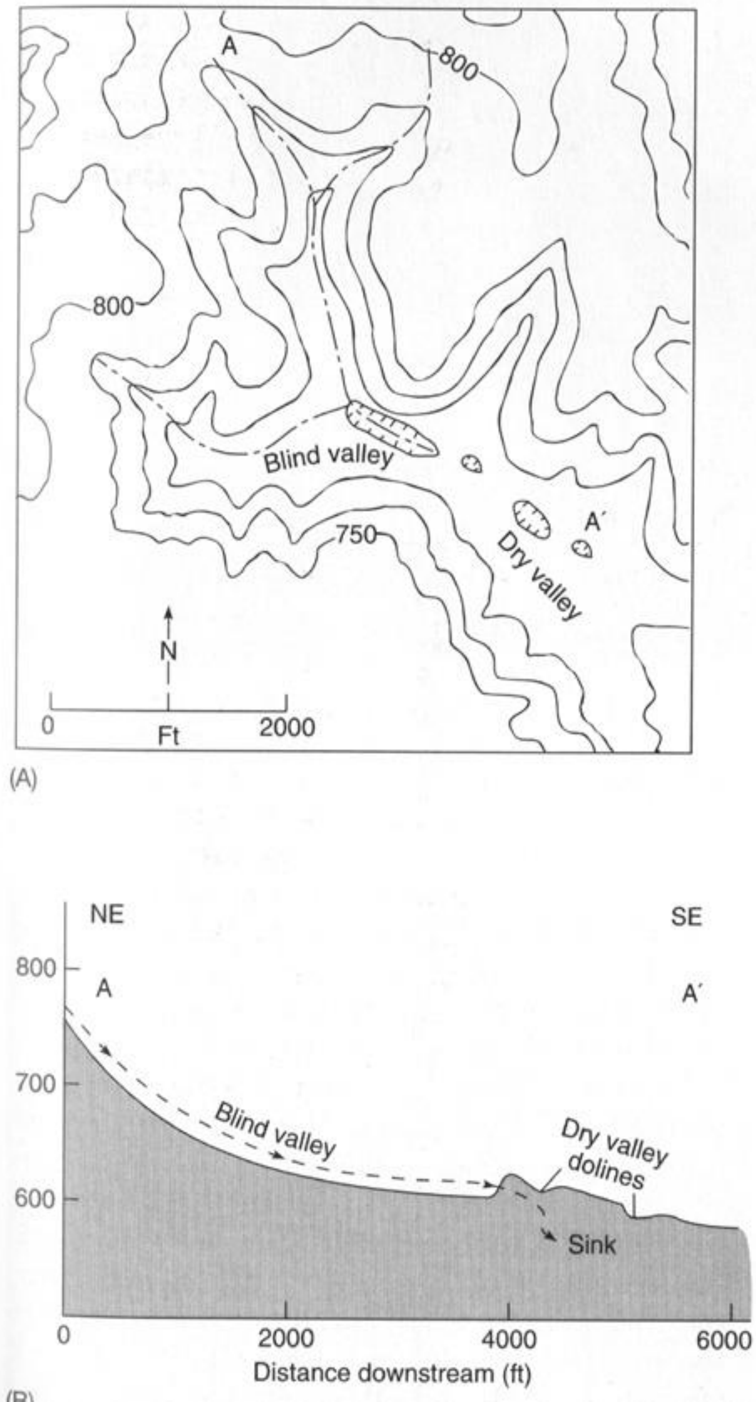
- **Resurgence**: point where waters from sinking stream reemerges from underground.

- **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.


• **Swallet (swallow hole): A place where water disappears underground in karst region. Swallet commonly used to describe loss of water in stream bed.**

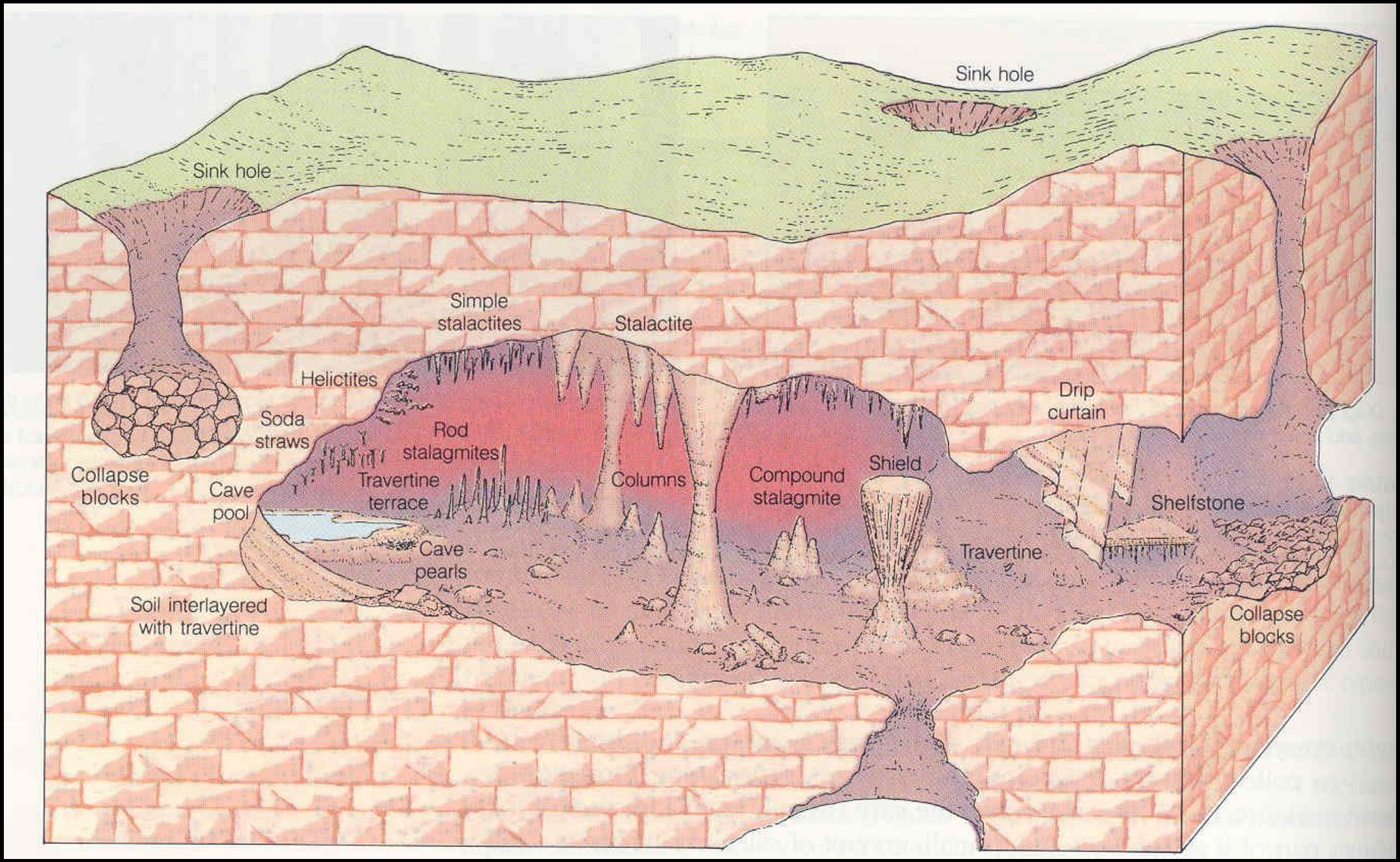




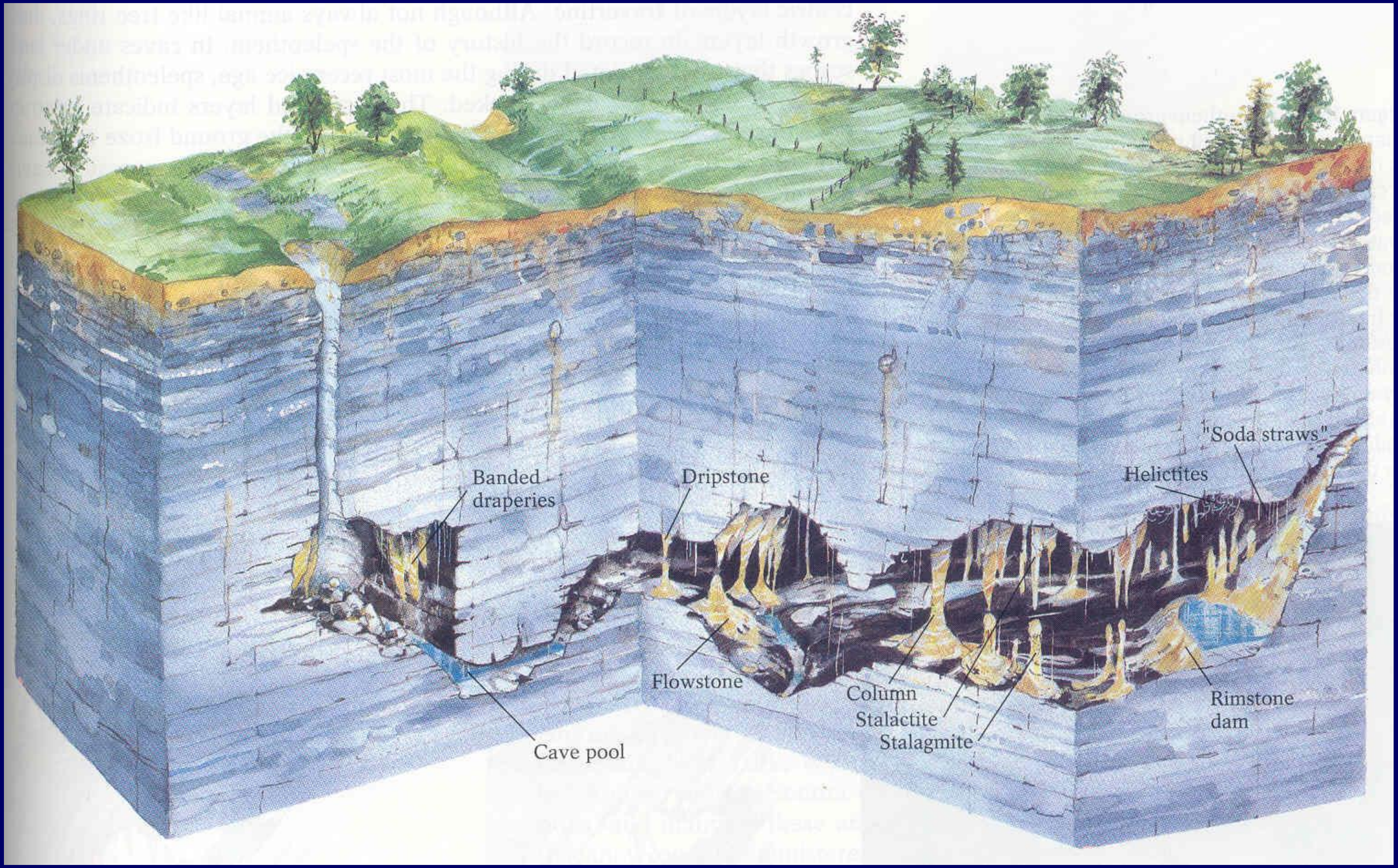

# Blind Valley

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

# DIAGRAM SHOWING LIMESTONE CAVERN ENVIRONMENT

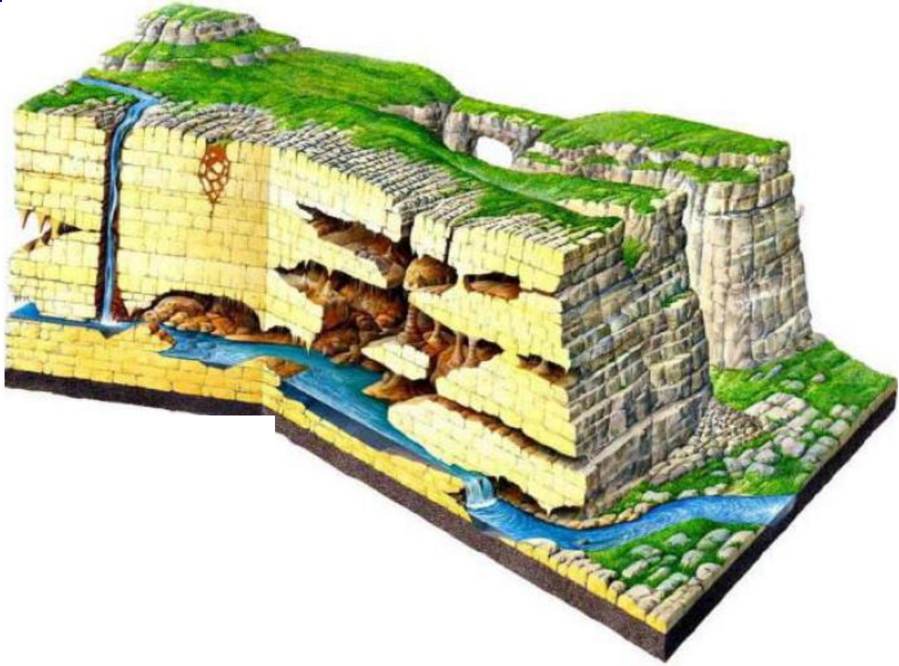


# DIAGRAM SHOWING LIMESTONE CAVERN ENVIRONMENT



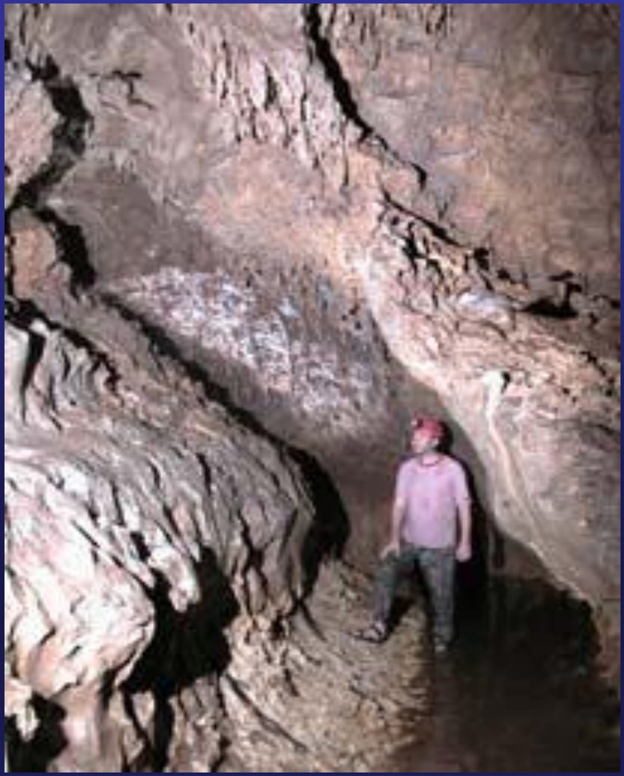
# Epigenic and Hypogenic Caves

- 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

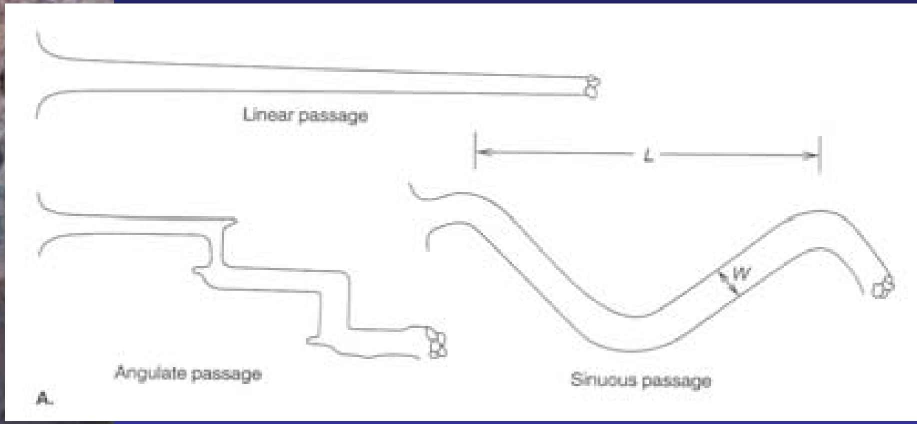


# Cave Formation

- 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

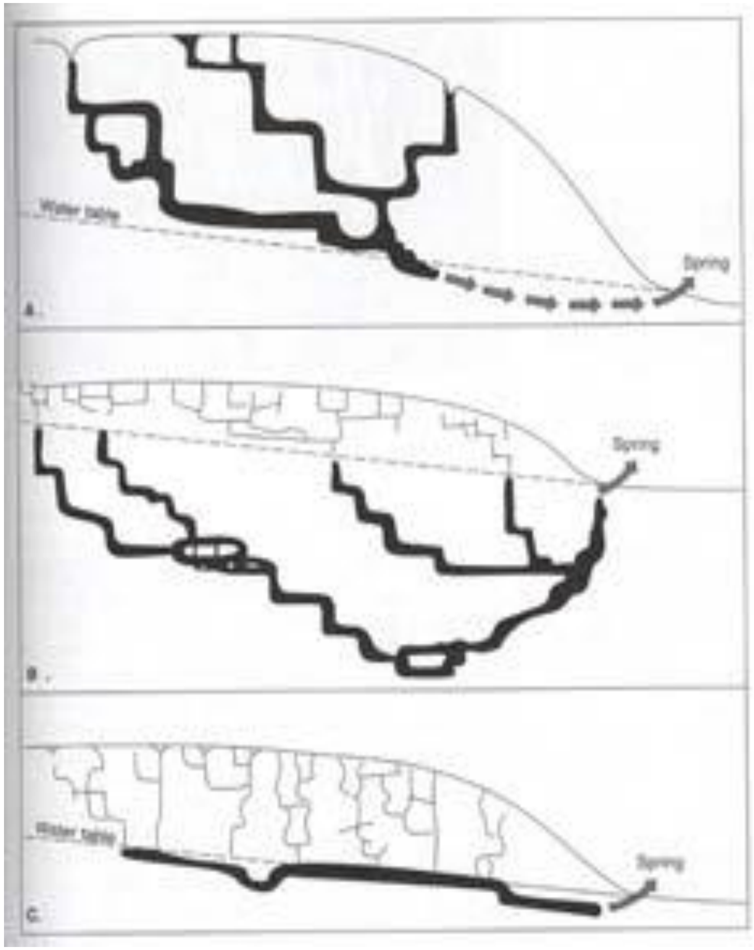


Three principle theories of Cave origins

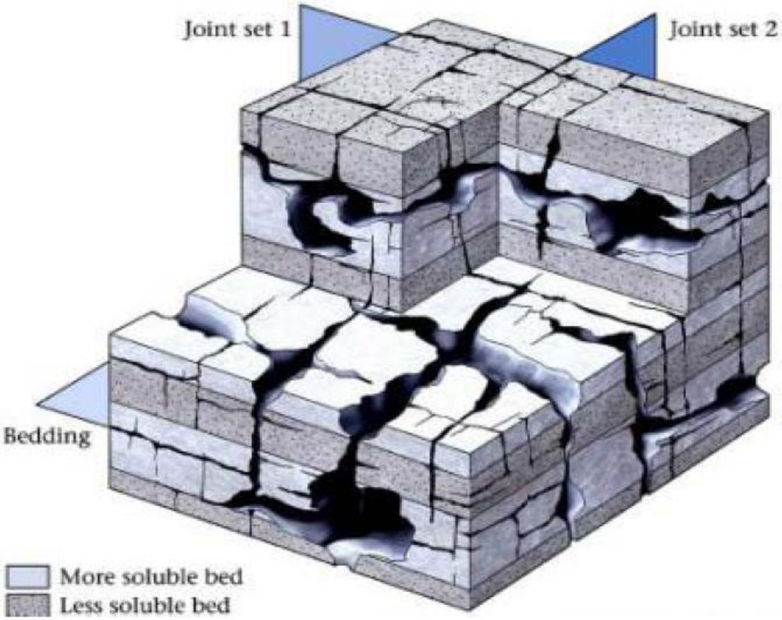
1) Form above water table by *vadose water* (unsaturated zone water)

2) Form beneath water table by circulation of *phreatic water* (=saturated zone water)

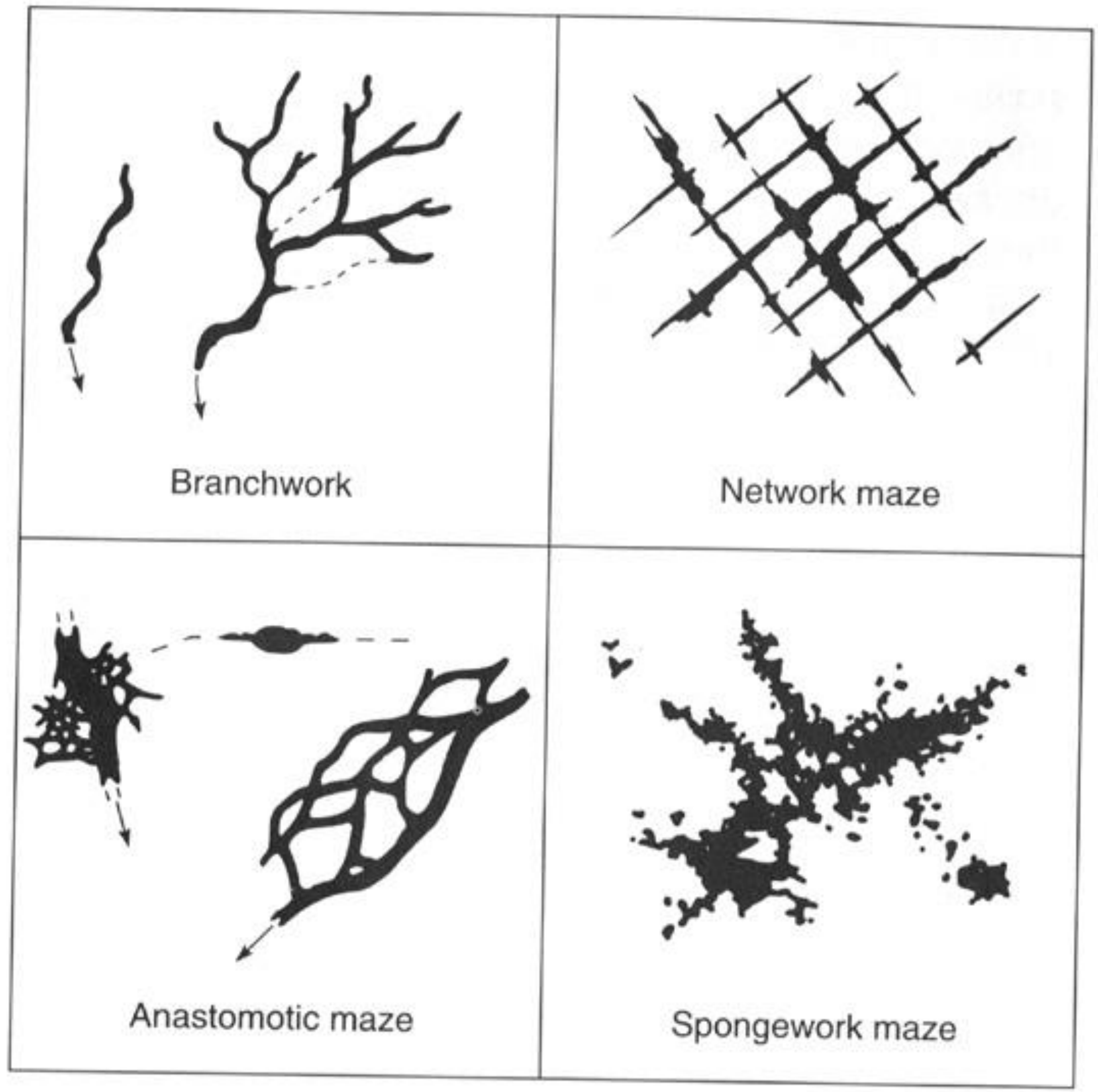
3) Form at water table = *water table caves*



# WATER TABLE CAVE




# Cave Patterns



# 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

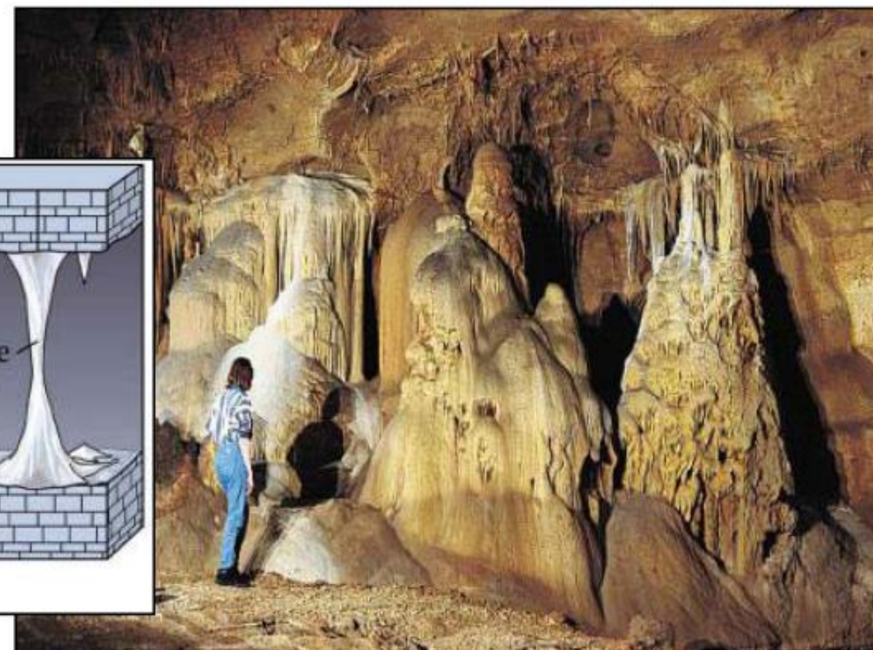
# Speleothems
# deposits in caves

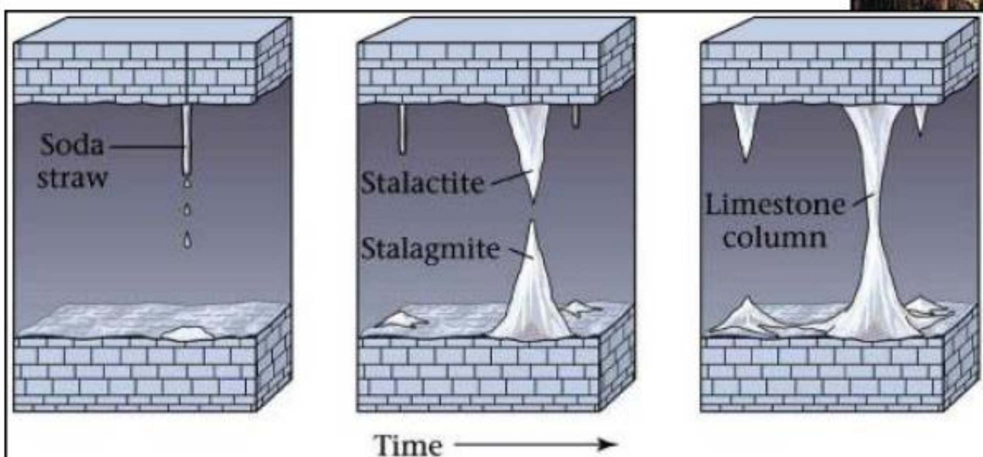
- Stalactite- icicle like deposit from dripping water from cave ceiling
- Stalagmite- same as above but builds from cave floor up
- Flowstone- produced by flowing water over a wall

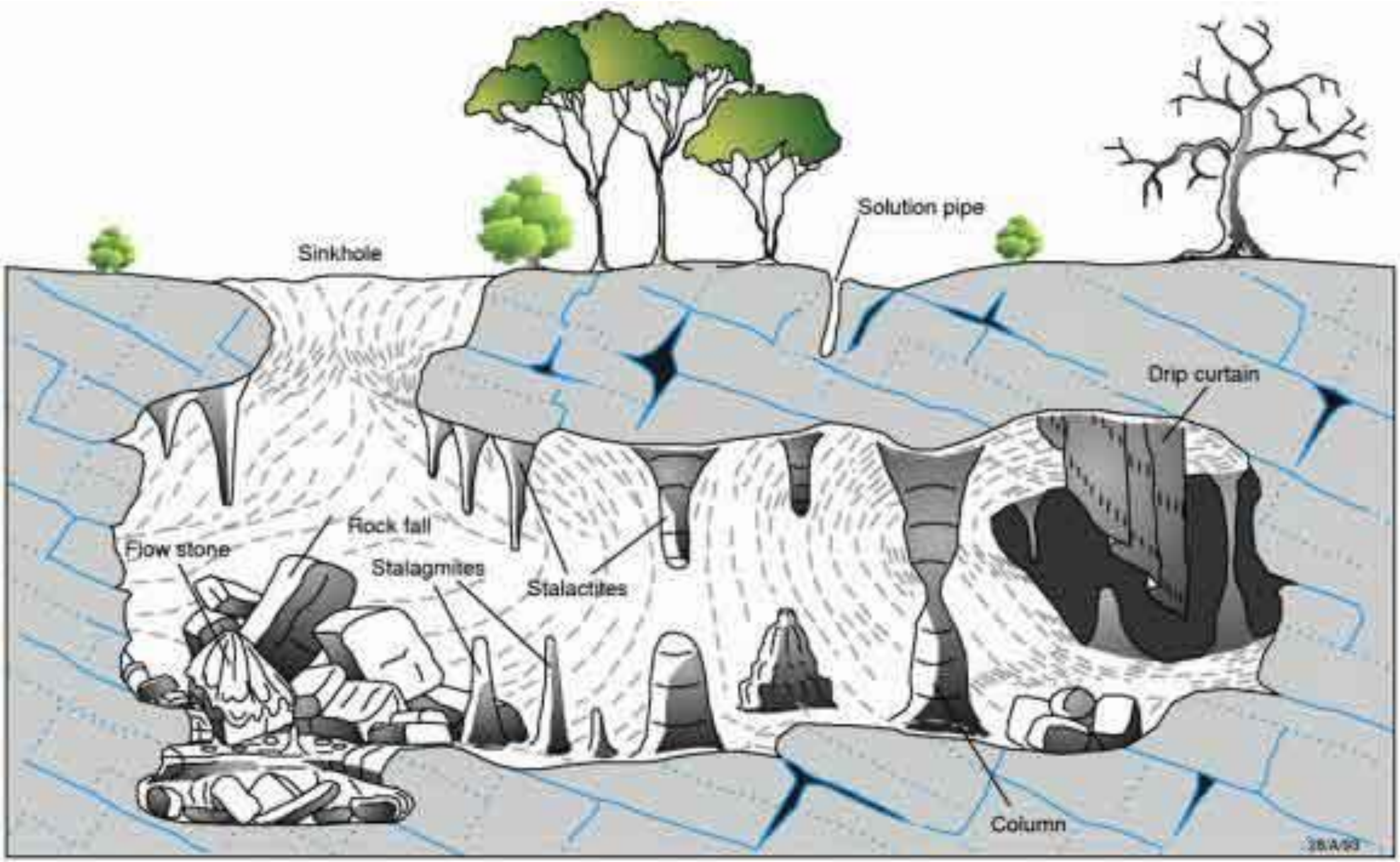
# Caves and Karst

- Speleothems are formed from precipitation of dripstone.
  - Stalactites – Hang down.
  - Stalagmites – Point up.
  - Columns.

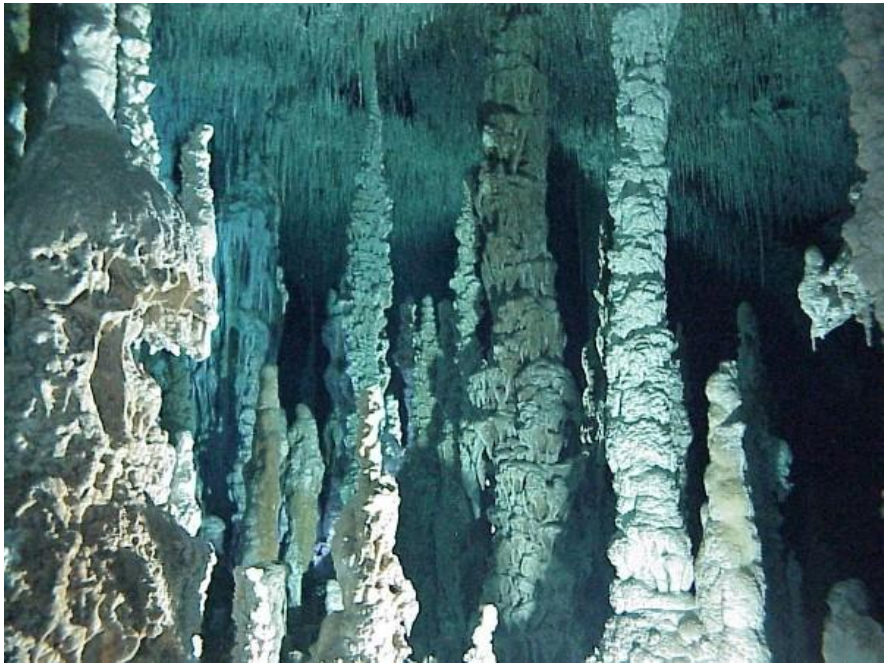
Kartchner Caverns State Park, Arizona





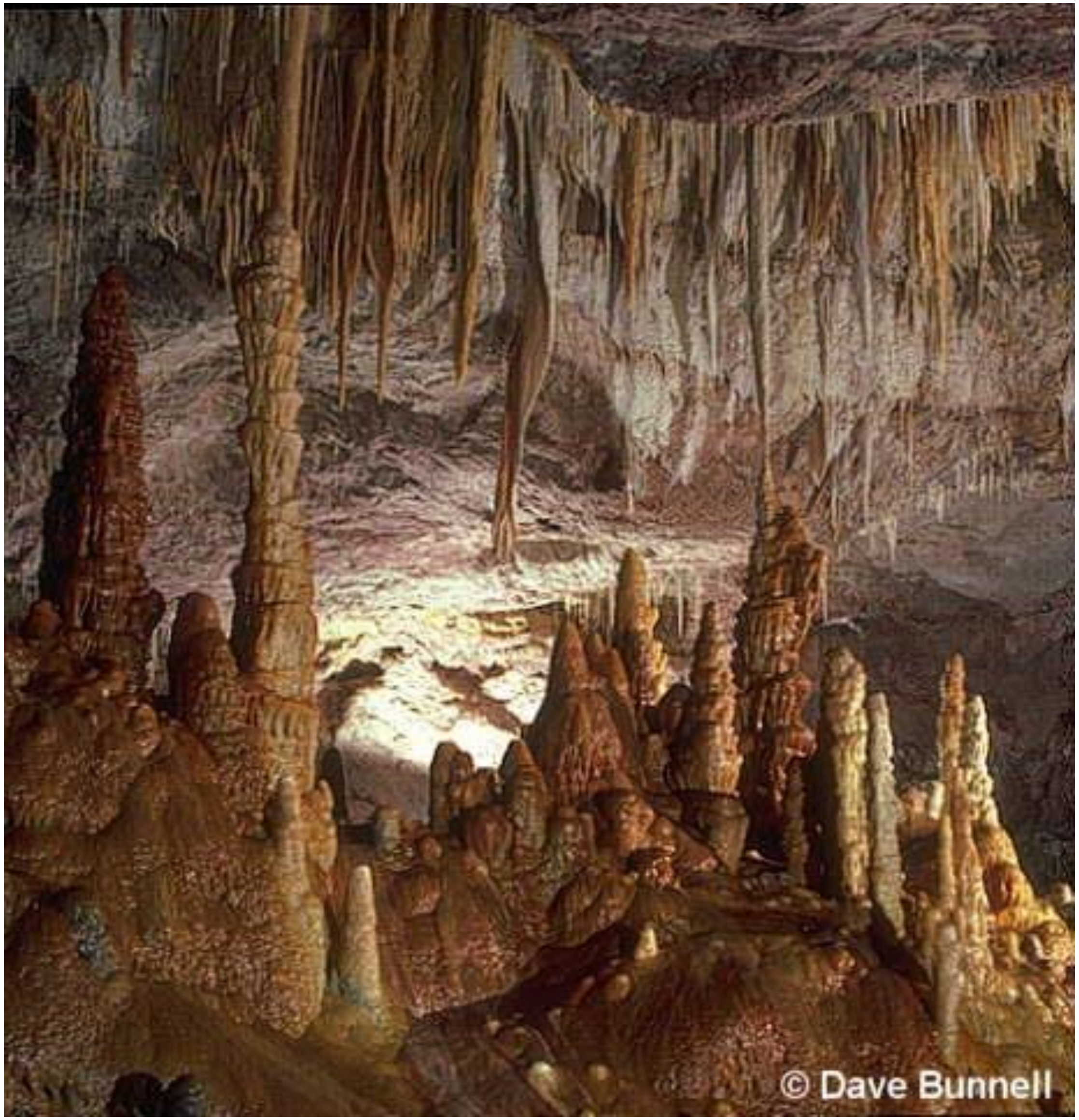

Sinkhole
Solution pipe
Drip curtain
Rock fall
Flow stone
Stalagmites
Stalactites
Column

Stalagmite- same as above but builds from cave floor up

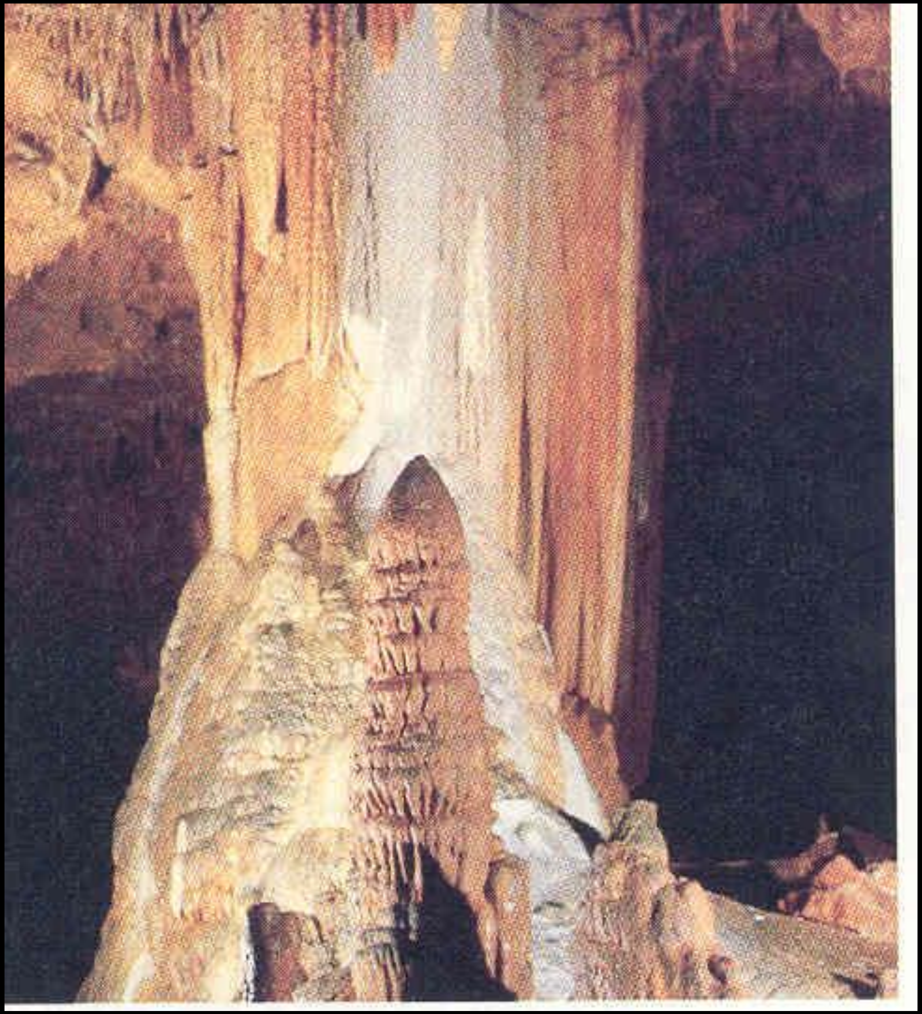


•**Stalagmite- same as above but builds from cave floor up**

**Stalacmite**




Stalactites
and
Stalagmites



# ‘Column’

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

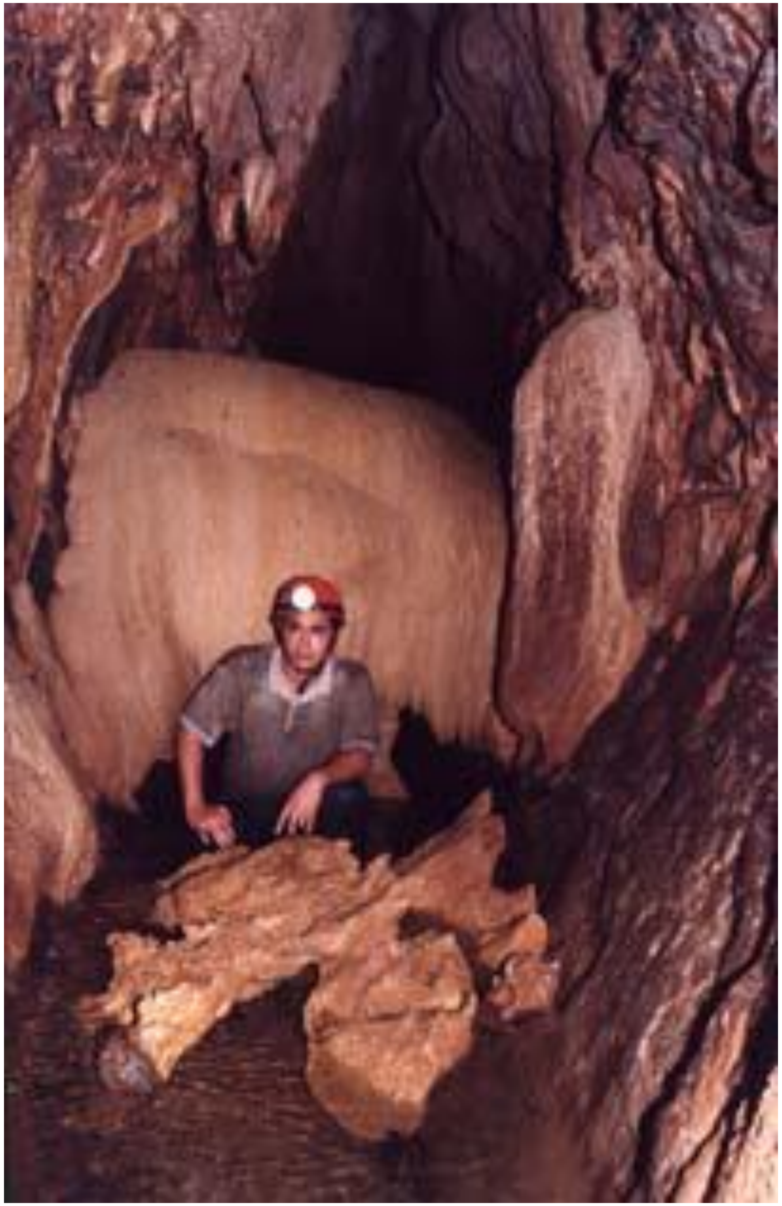
**Column – a joined stalactite and stalagmite**

# 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

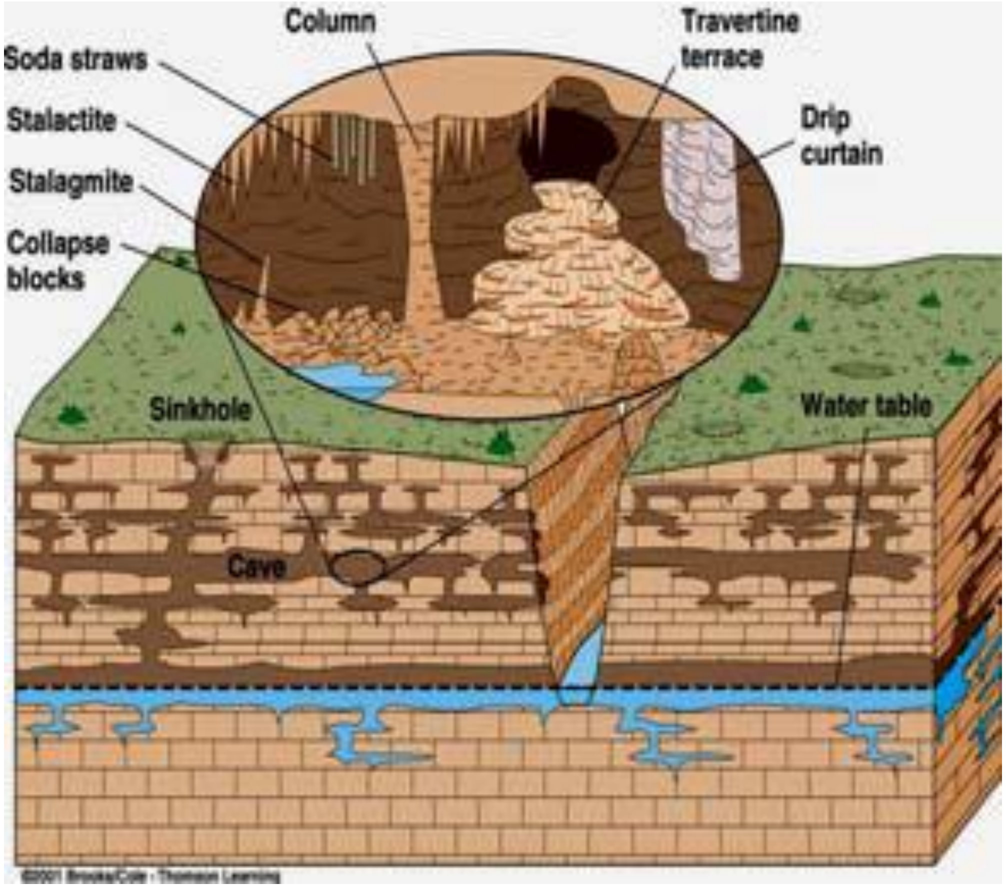
show many of the forms of dripstone. Dripstone originates on the ceilings of caves. Water seeps through a crack and partially evaporates. This causes a small ring of calcite to be deposited around the crack. The ring grows into a tube, which commonly acquires a tapering shape as water seeps from adjacent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



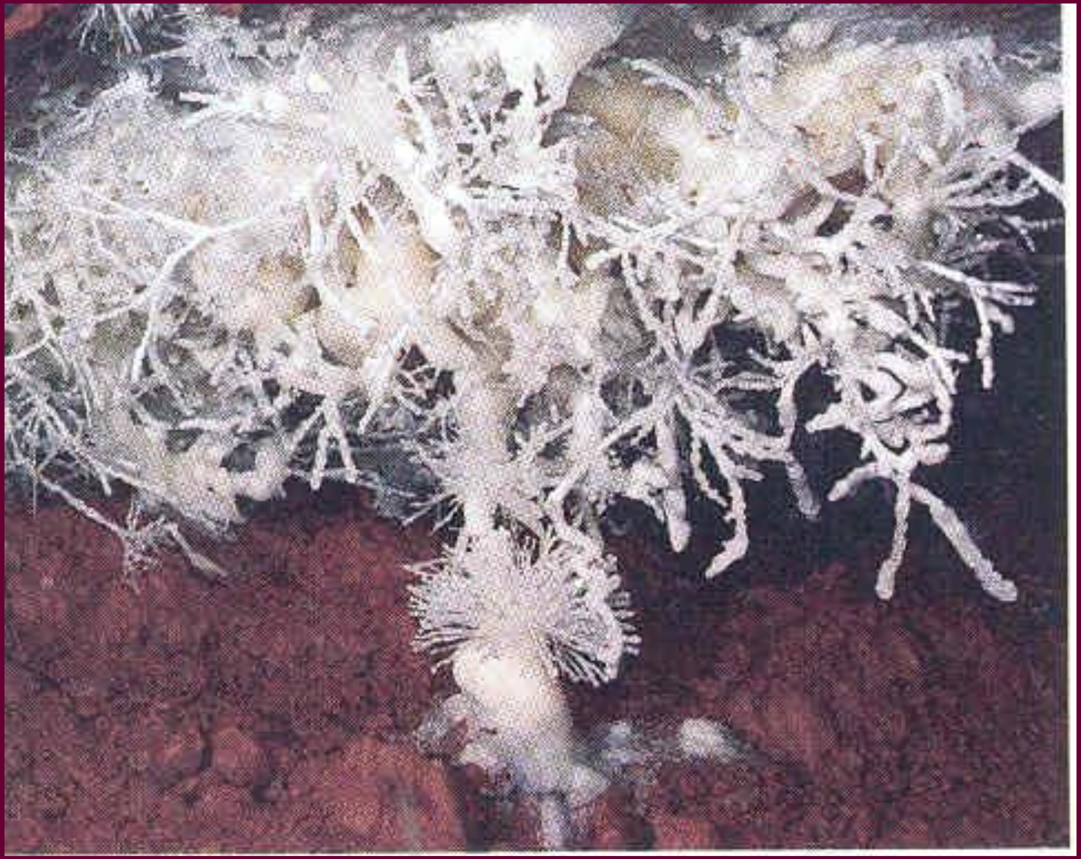
# Flow stone

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’

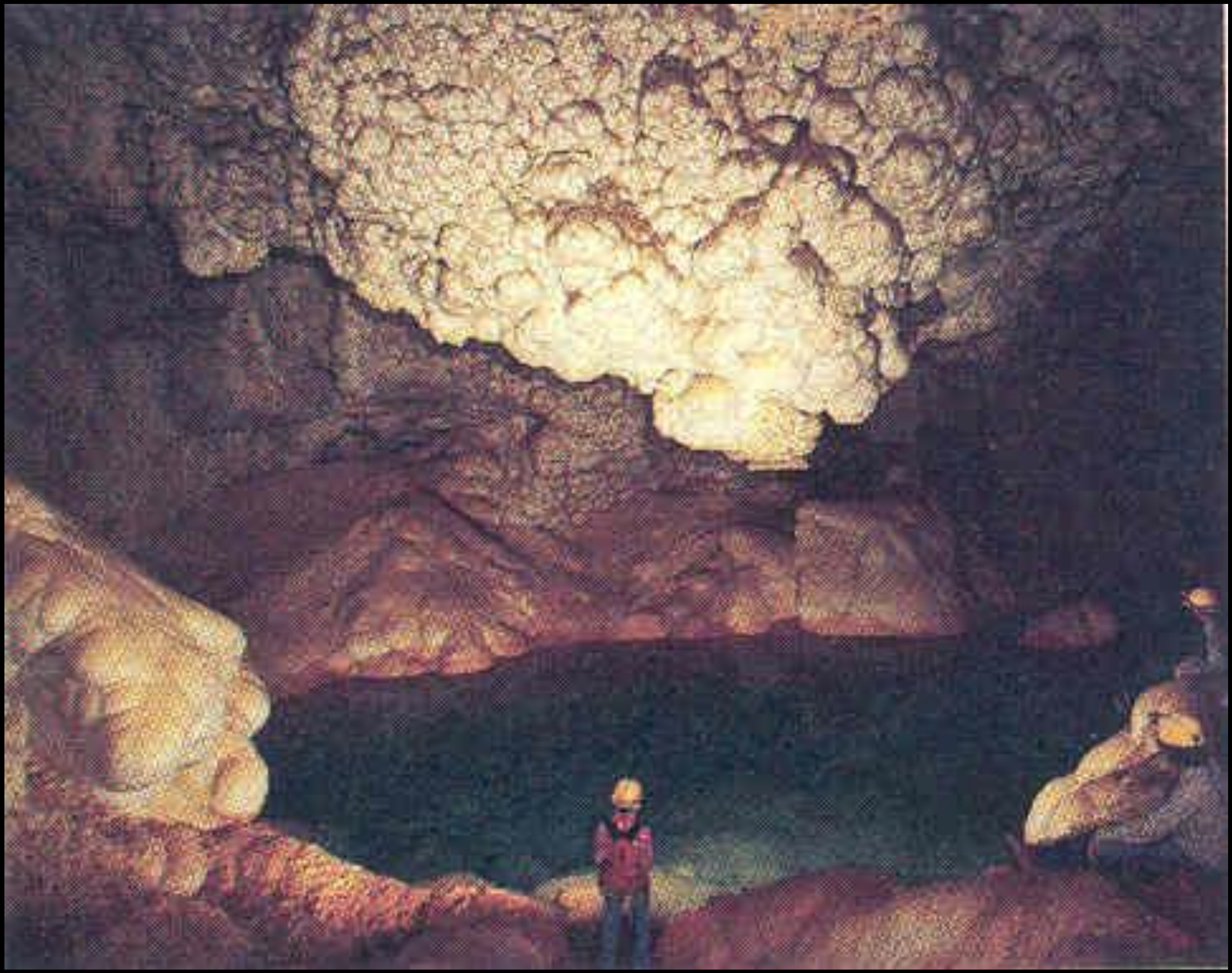


Helictites form by capillary action and can grow in any direction

# Cave 'Pearls'

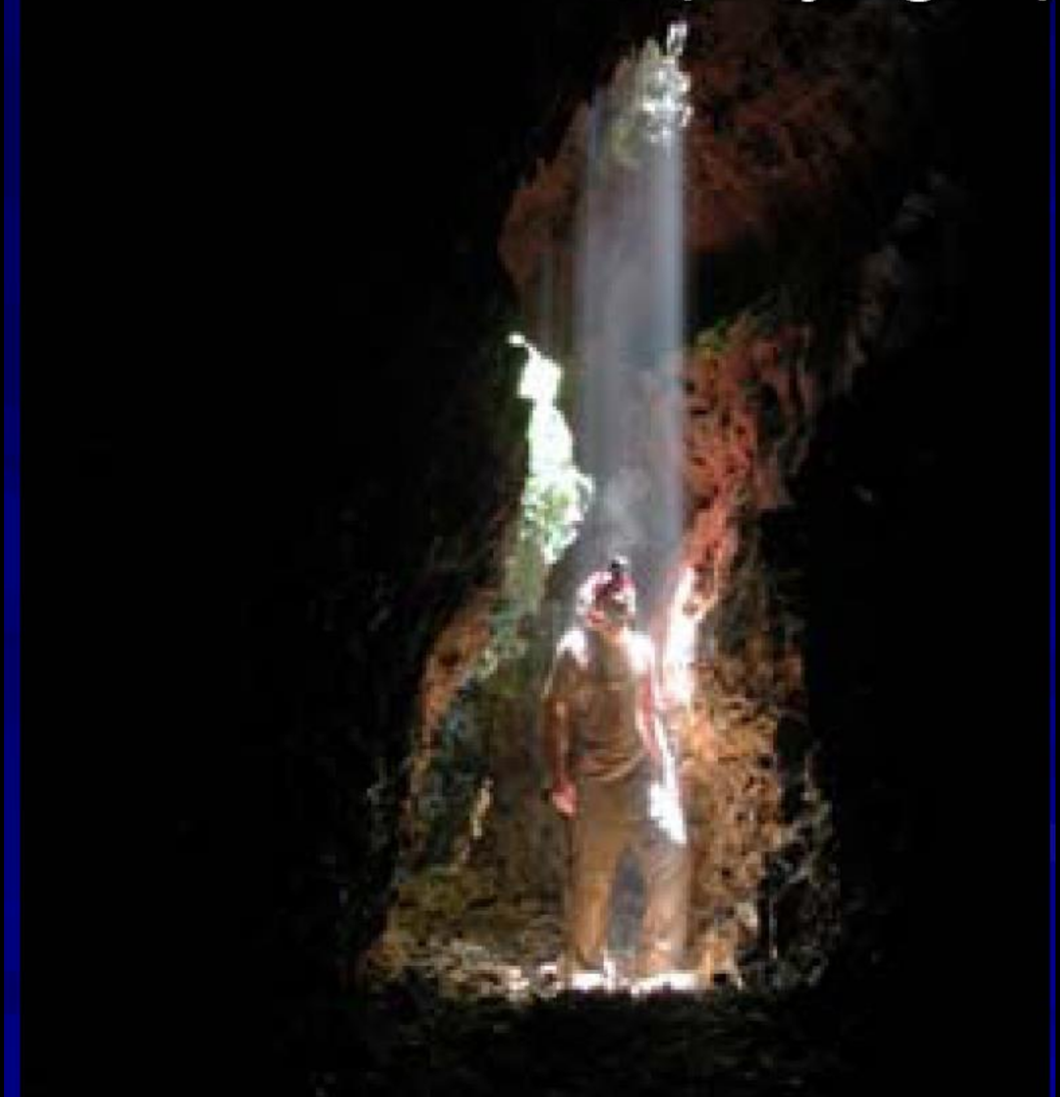
Cave pearls form when layers of travertine precipitate around a sand grain or similar particle

# Cave ‘Popcorn’



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

# Karst Window (skylight)



Form when roof collapses over a cave stream

# Biogenic Activity and Geomorphology

- ❖ Influence of landforms on distribution of organisms

- ❖ Influence of organisms on the development of landforms

**Bidirectional**

- ❖ Effects of geomorphology on organisms

- ❖ Effects of organisms on geomorphology

# Effects of organisms on geomorphology

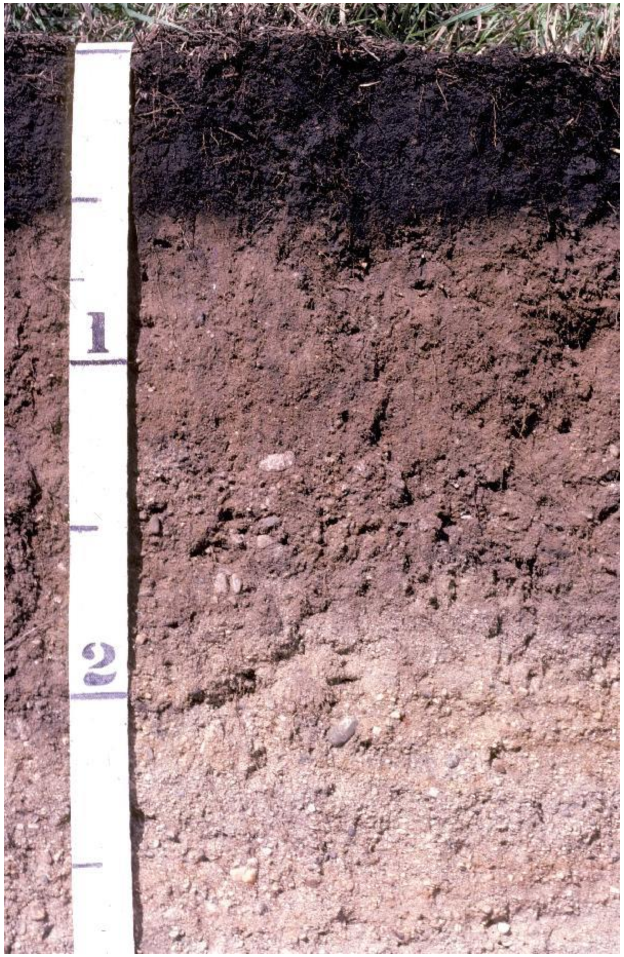
- Animals
  - Modification of landform
  - Direct agents of sediment movement

# Prying action of animals

- Animals and insects like ants make deep holes in the crust and initiate process of denudation.
- Human action- querying and blasting.
- Soil erosion- sheeting

# Effects of organisms on geomorphic processes

- Weathering
  - Provides nutrients to plants, microbes
  - Organisms secrete weathering compounds (acids, enzymes)
  - Roots break up particles
  - Oxidation of the atmosphere
- Organisms influence the development of ‘overburden’



# 10.7 BIOTIC WEATHERING

Biotic weathering is carried out by plants, animals and man.

## (a) Plants

Plants contribute to both mechanical and chemical weathering. The roots of tl plants penetrate into the joints of the rocks. They grow longer and thicker. In th manner they exert pressure on the rocks and the rock joints are thereby enlarg and break into smaller fragments.

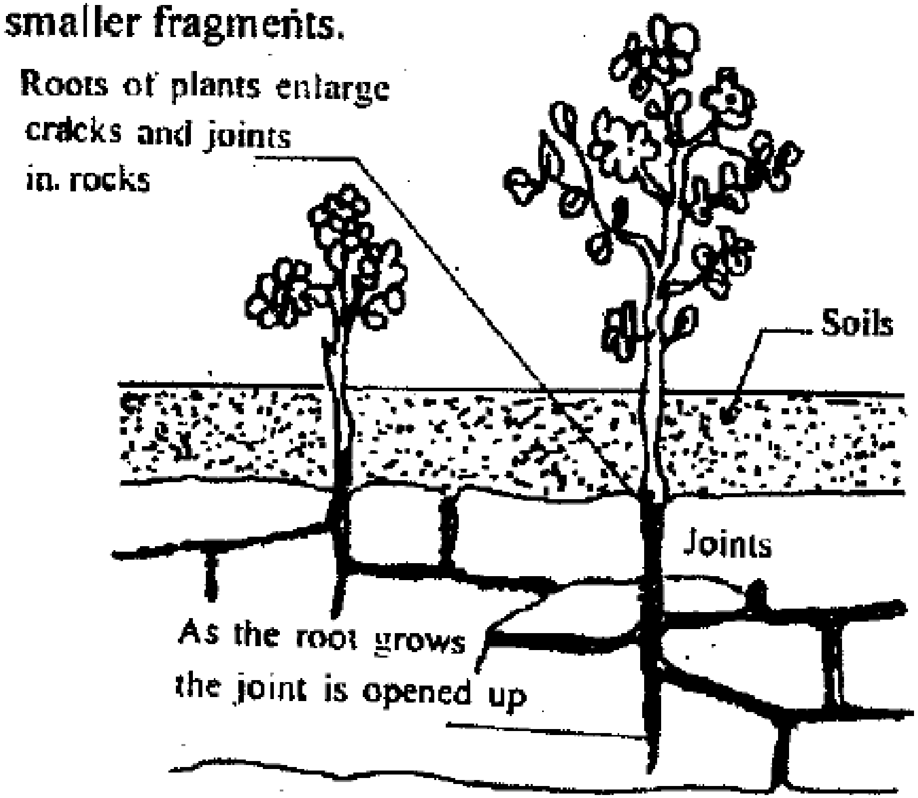



*Fig 10.4 Effect of Vegetation on Rocks*

**(b) Animals**

Burrowing animals like earthworms, rats, rabbits, termites and ants break-down the rocks. These disintegrated rocks can easily be eroded or removed by wind etc. Hooves of animals break the soil and thus assist soil erosion. The role of earthworms and termites is of special significance. According to scientists, there is a possibility of occurrence of about 1,50,000 earthworms in an acre and they can convert 10 to 15 tonnes of rock mass into good soil and bring it to the surface.

**(c) Man**

Human beings play a very important role in weathering of various rocks. Man breaks a large amount of rocks in the course of his activities, like agriculture, construction of houses, roads etc. He quarries for mining minerals, Thus helps in weathering by breaking, weakening and loosening the rocks.

* Biotic agents like plants, animals and man also contribute to physical and chemical weathering.

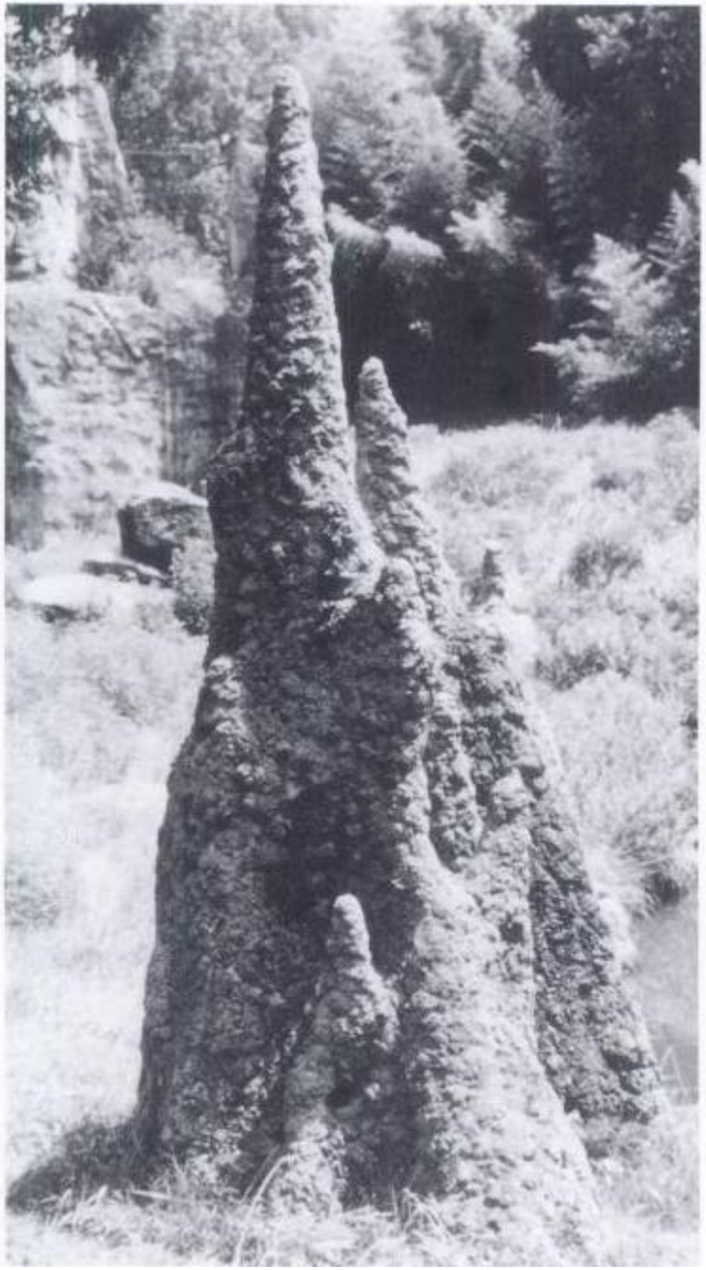
# Prying action of plants

ROOT WEDGING

*Figure 2.3.* The tarantula (*Rhechostica hentzi*), a burrowing arachnid, is common in the southwestern United States and northern Mexico; near Chaco Canyon, northwestern New Mexico.

*Figure 2.4.* A crayfish chimney on the floodplain of the Roanoke River, eastern North Carolina. Lens-cap diameter is 49 mm.

burrowing





*Termites*

As Goudie (1988) pointed out, termite mounds or hills (Fig. 2.2) are the most impressive manifestation of termite activity; indeed, a termite mound graced the cover of Viles's (1988d) book. Termite mounds appear in the fossil record at least as far back as the Miocene (Bown and Laza 1990). Termites are distributed in most climatic zones warmer than those of tundra regions, but they reach their greatest visibility in the tropical environment.

# Effects of organisms on geomorphology

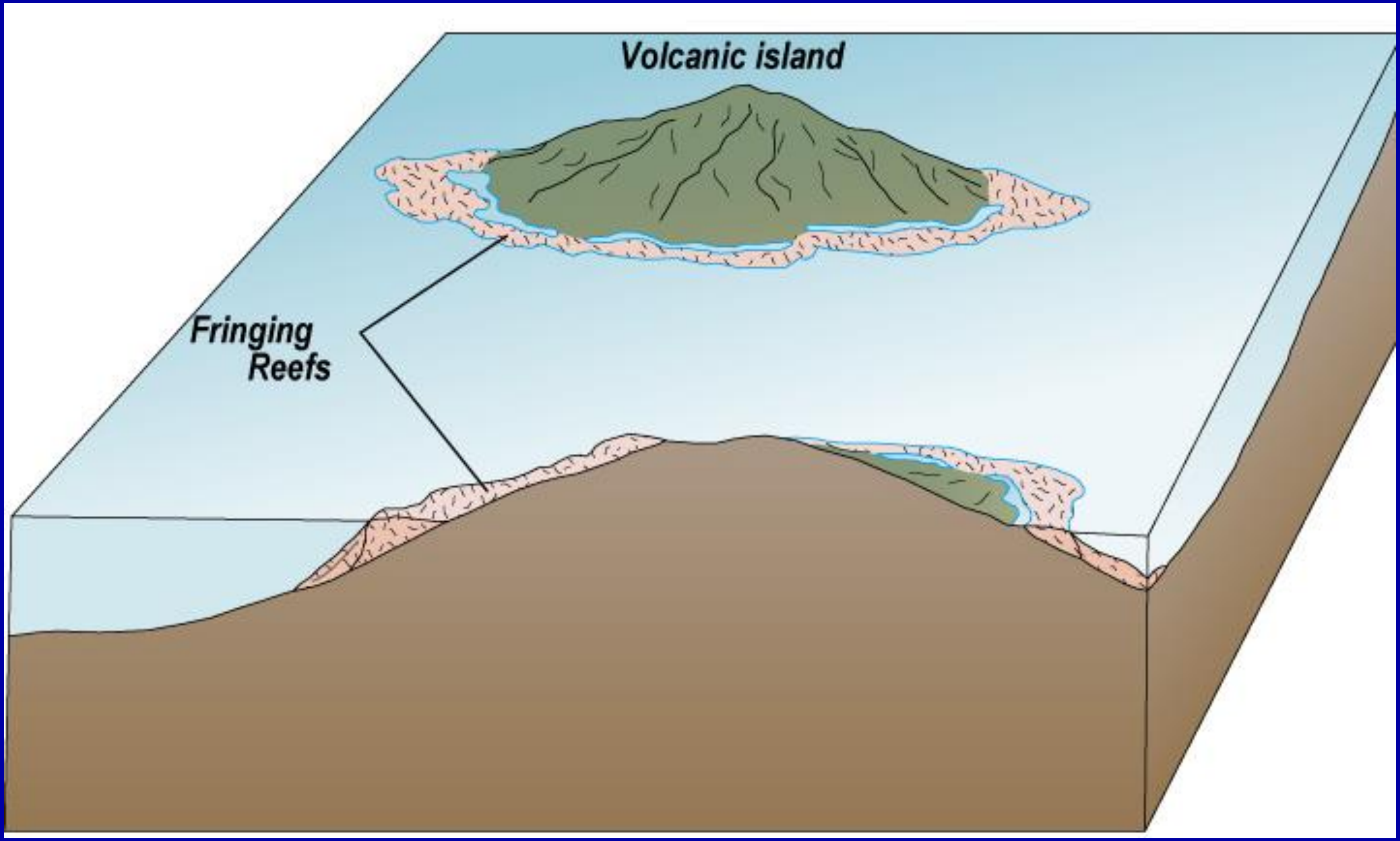
## ORGANISMS AND THEIR ACTION

Polyps live in 150 - 200’ deep water and when water has more $caco_3$ and the temperature is above 68 degree, these organisms segregate and build reefs which finally grow into Islands

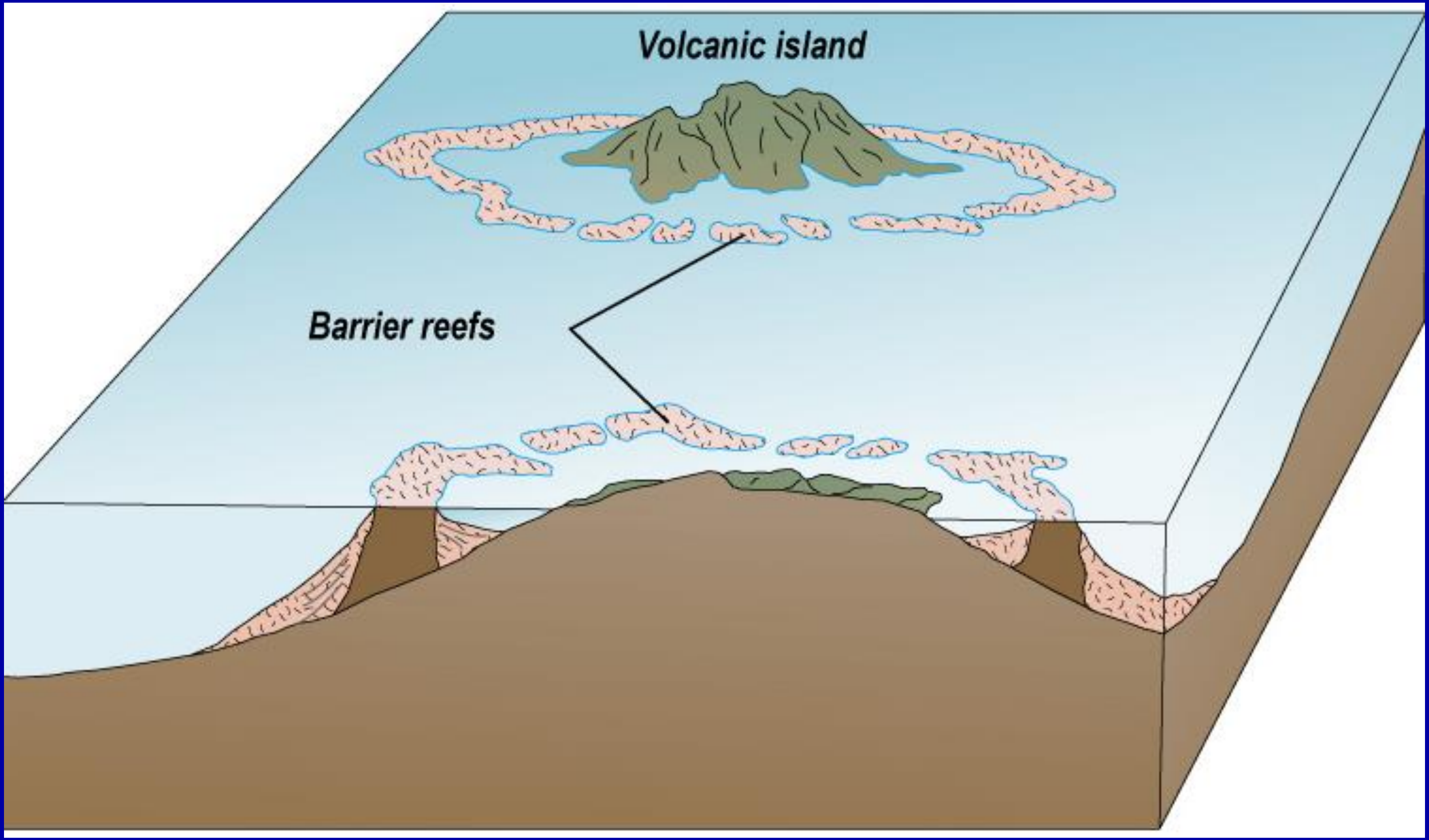
- **Fringing reef**
  - A coral reef built out laterally from the shore, forming a broad bench; slightly below the sea level.
- **Barrier reef**
  - A prominent ridge of coral that roughly parallels the coastline but lies offshore, with the shallow lagoon between the reefs and the coasts.
- **Atoll**
  - Coral reef in the shape of a ring or partial ring that encloses a lagoon that had formally surrounded a volcano, but that volcano has since sunk below surface.

# Coral reef

# Fringing reef



# Barrier reef



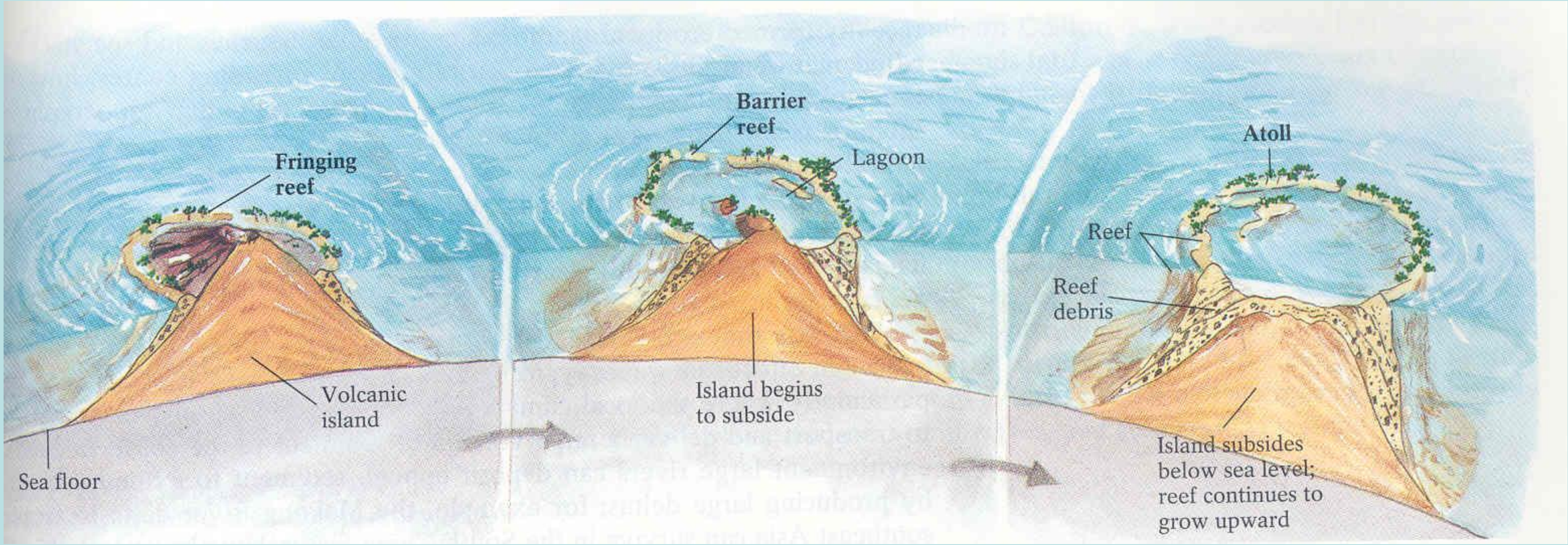
# Atoll

# The Evolution of Carbonate (coral) reefs

**FRINGING REEFS : adjacent to the volcanic Islands**

**BARRIER REEFS: Lagoon between Island and Reef**

**ATOLL: Circular coral reef with central lagoon**

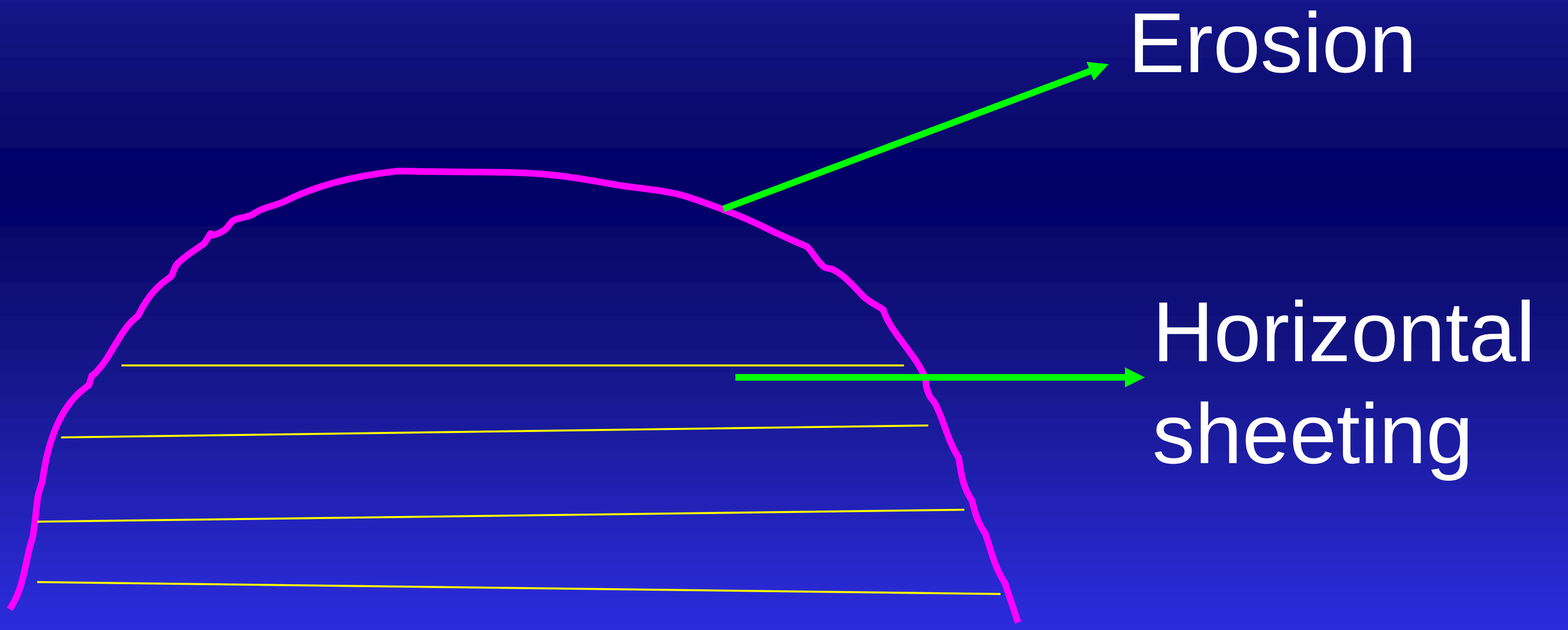


## Channel Modifications

Humans often decide that a stream should flow along a specified path for such reasons as flood control, enhancement of drainage, control of erosion, increasing access to the floodplain for development, or improvement of the appearance of the channel. Such channel modifications involve measures such as the straightening the channel, deepening or widening the channel, clearing vegetation from the banks, or lining the channel with concrete. These modifications are referred to as ***channelization***.


M. COLLINS & SONS
COLLINS

# DEFORESTATION - SOIL EROSION -SHEETING

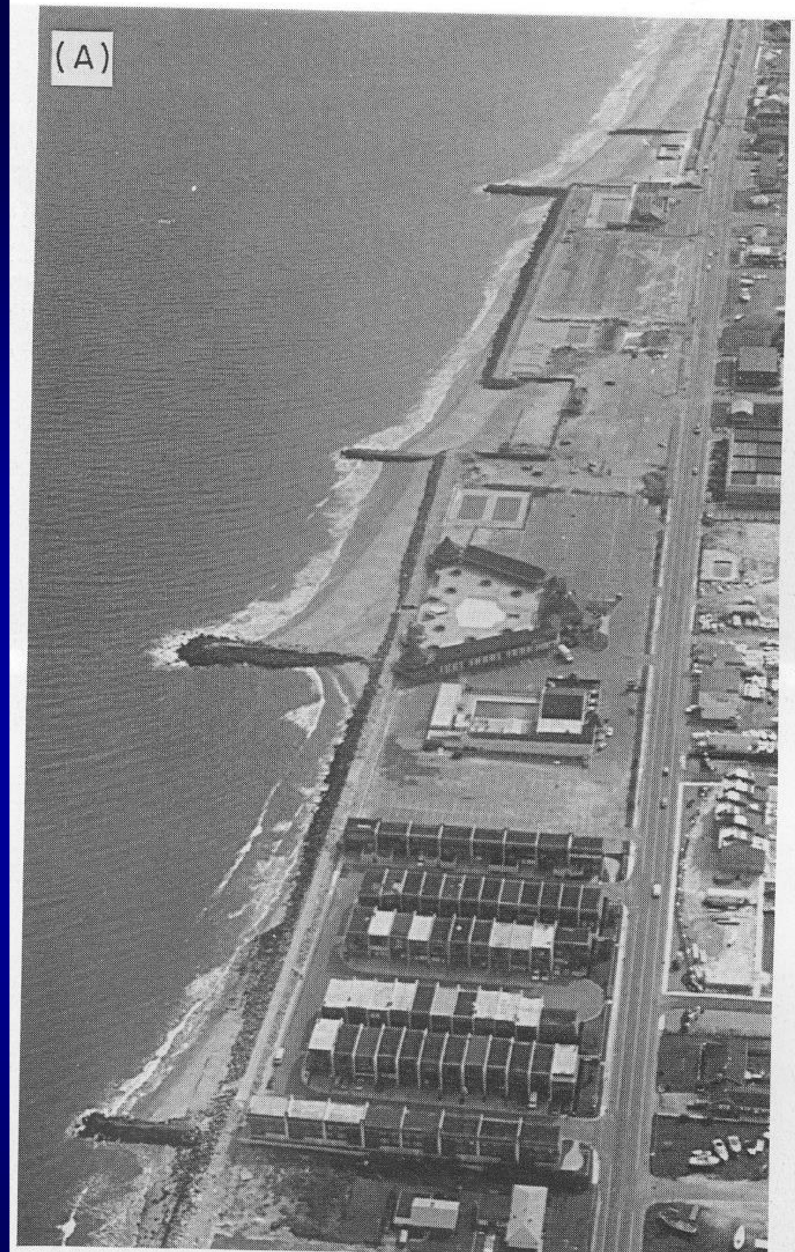


## RESTORATION OF BEACHES

**Groynes:**

**Wooden, concrete and/or rock barriers or walls at right angles to the sea.**

**Groynes arrest littoral drift and make the shore line progress seaward till become parallel to the wave direction**


*(A) Groynes on the sand-starved coast of northern New Jersey have little obvious effect on shoreline stability.*

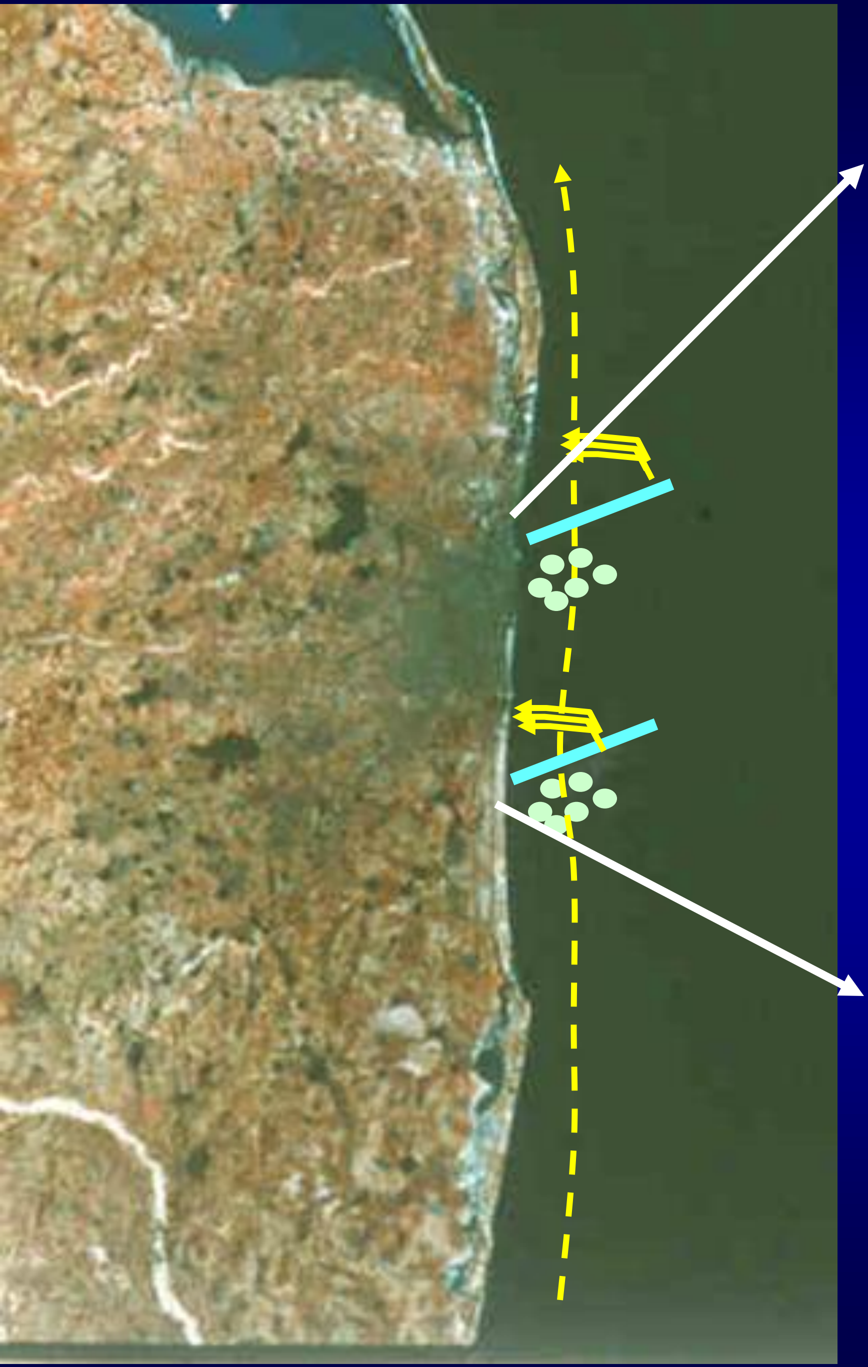
# ROCK REVETMENTS

Rock faced concrete revetment

Sand bags

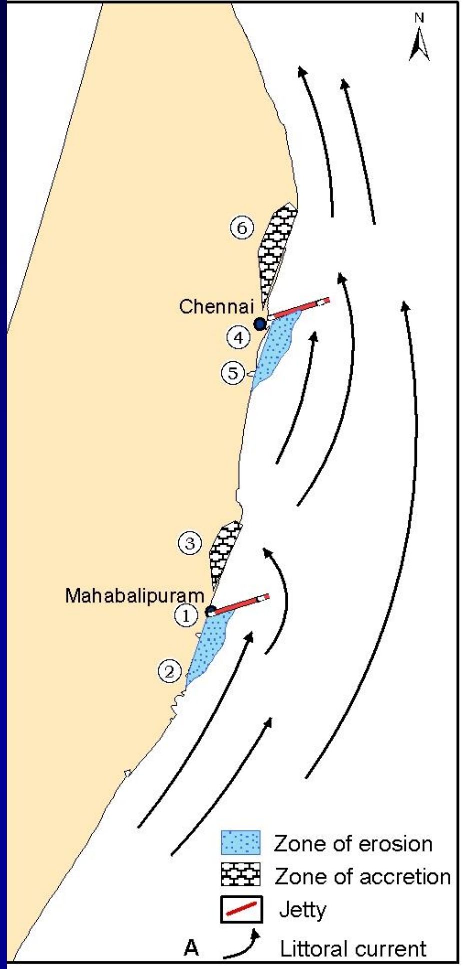
timber and geotextile

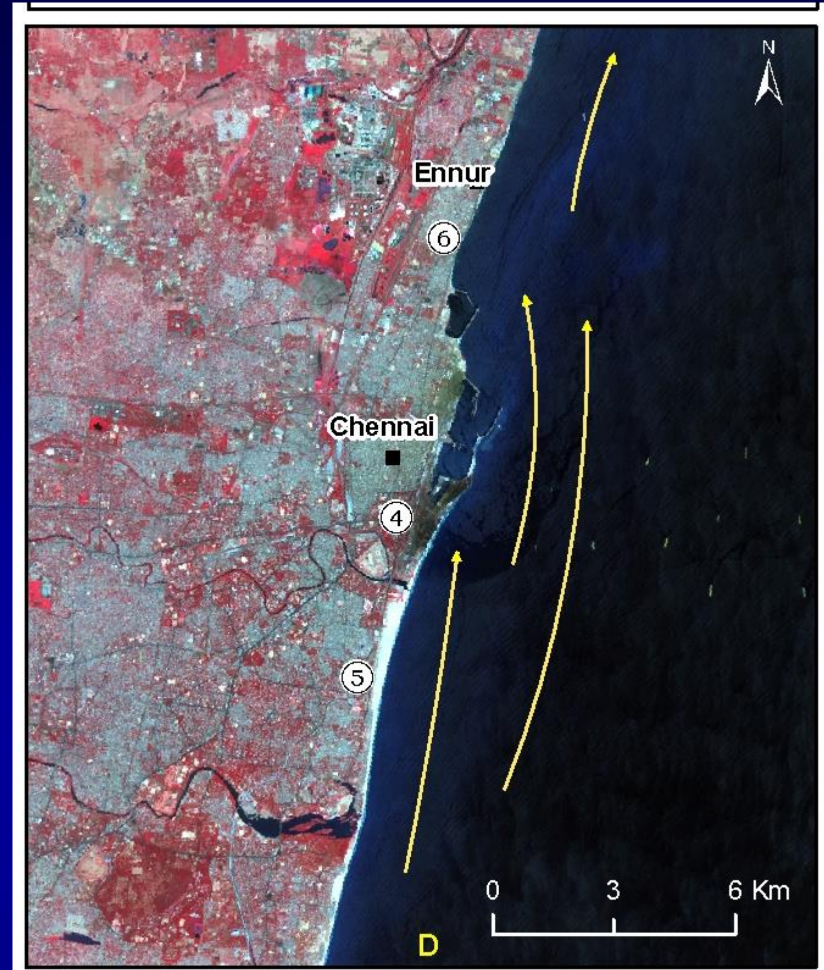
stabilisation using  grass plants.



Madras Harbour

Mahabalipuram


N
6
Chennai
4
5
3
Mahabalipuram
1
2
Zone of erosion
Zone of accretion
Jetty
Littoral current
A


N
Ennur
6
Chennai
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5
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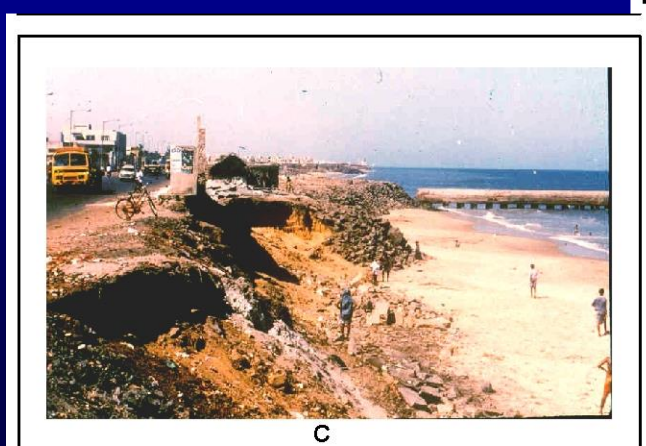
3
6 Km
D


C


B

## OFFSHORE BREAKWATER

**Structures constructed parallel to the coastline in break water zone thereby reducing the magnitude of wave attack**

**Enormous concrete blocks and natural boulders are sunk offshore to alter wave direction and to filter the energy of waves and tides.**

**The waves brake further offshore and therefore reduce their erosive power.**

**This leads to wider beaches**

*Figure 213.* The vertical granite seawall at St. Malo in northern France during an onshore gale. Note the line of wooden posts aimed at reducing the direct wave forces on the wall, and the partial clapotis in the nearshore zone.

**Nearshore breakwaters**