GEOLOGY for CIVIL ENGINEERS ENCE 231

Dr. Khalil M. Qatu

Earth Sciences

- **Earth sciences** are all sciences that collectively seek to understand Earth and its neighbors in space. (Geology, Oceanography, Meteorology, astronomy)
- **Geology** literally means "study of the earth"
  - **Physical Geology** examines the materials comprising Earth and seeks to understand the many processes that operate beneath and upon its surface.
  - **Historical Geology** is to understand the origin of Earth and the development of the planet through its 4.5-billion-year history.

Earth Sciences

- **Oceanography** it involves the application of all sciences in a comprehensive and interrelated study of the oceans in all their aspects and relationships.
- **Meteorology** study of the atmosphere and it processes that produce weather and climate.
- **Astronomy** is the study of the universe.

Earth can be thought of as consisting of four major spheres:

hydrosphere, atmosphere, geosphere, and biosphere.

Biosphere

Includes all life on Earth.
Ocean life is concentrated in the sunlit waters of the sea.
Most life on land is concentrated near the surface

Hydrosphere

Dynamic mass of water, evaporating from the oceans to the atmosphere, precipitating to the land, and flowing back to the ocean again. 71% earth surface & 97% earth water. 3800 m depth

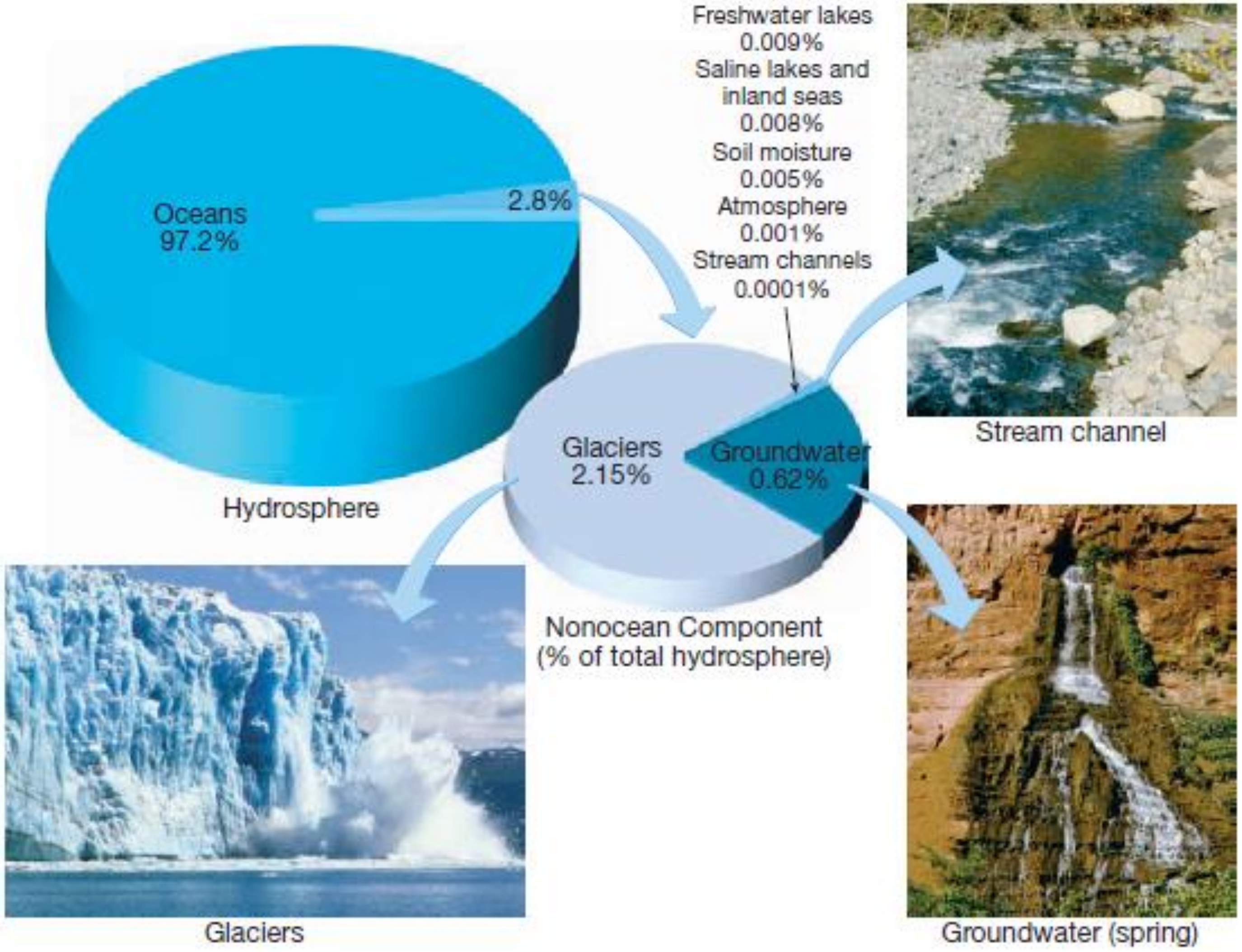
Geosphere

Or **Solid earth**
Extends from the surface to the center of the planet, a depth of nearly 6400 km
the largest of Earth's spheres.
Crust, Mantle, Core

Atmosphere

The envelope surrounding the earth. It provides the air that we breathe, and protects us from the dangerous radiation
50% within 5.6 km
90% within 16 km

HYDROSPHERE



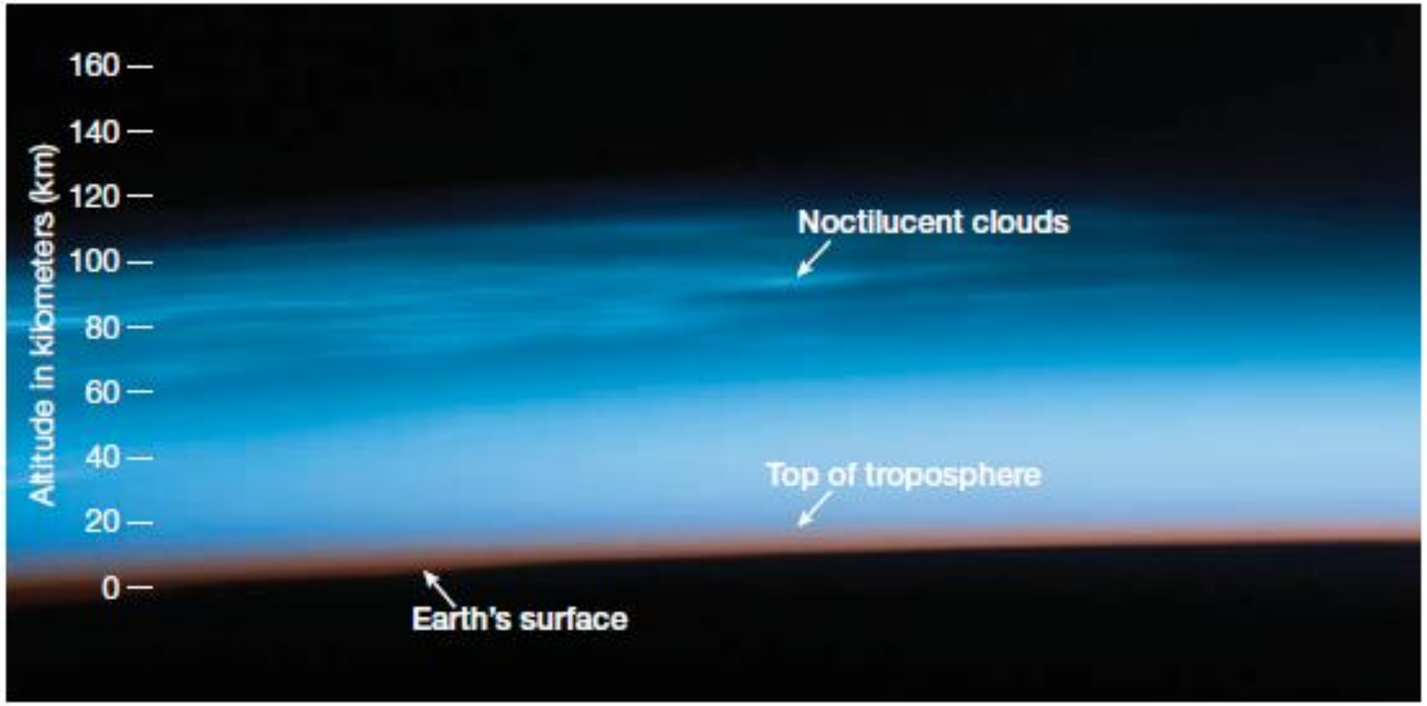
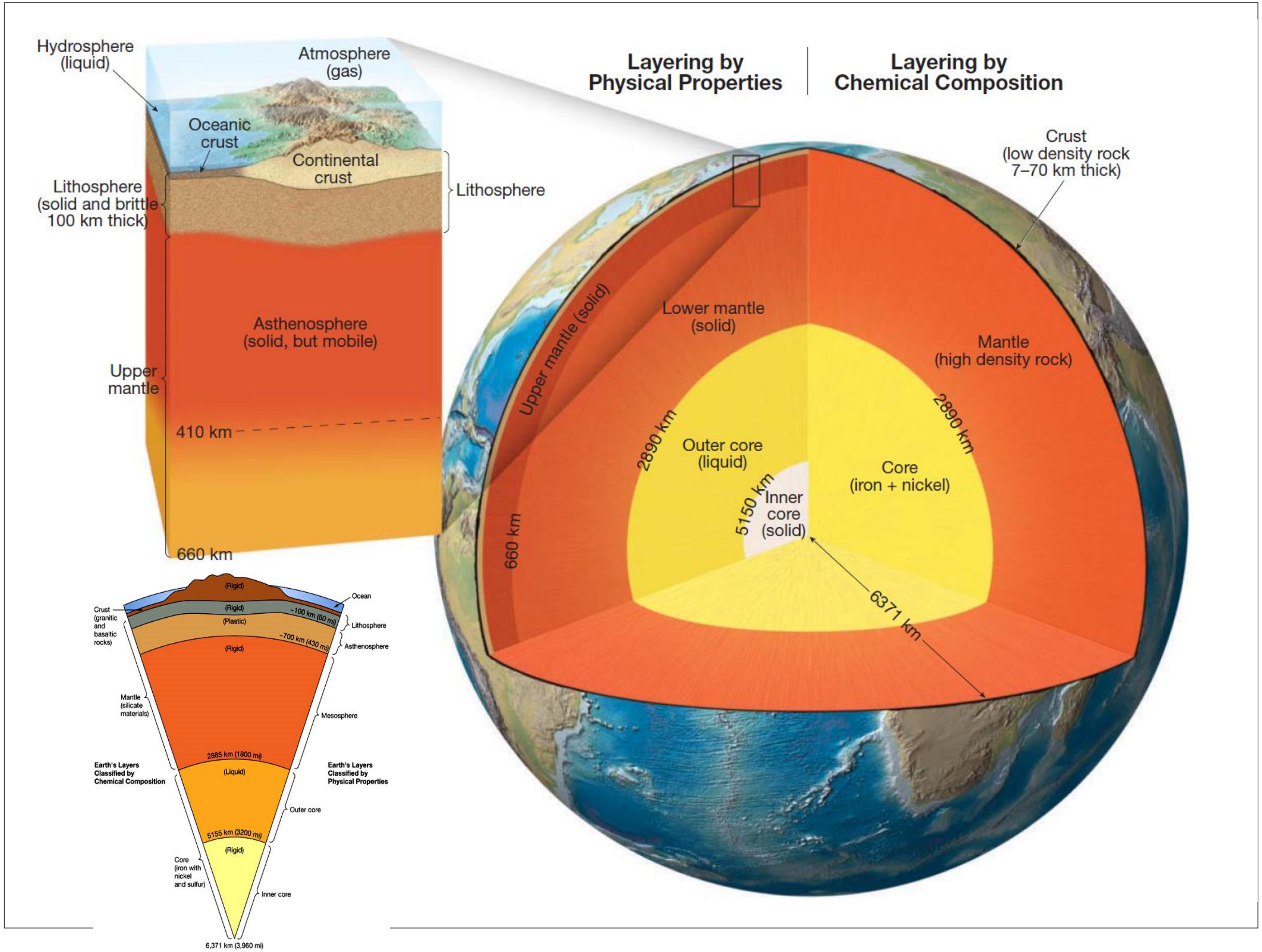


FIGURE 1.15 This unique image of Earth's atmosphere merging with the emptiness of space resembles an abstract painting. It was taken over western China in June 2007 by a Space Shuttle crew member. The thin silvery streaks (called *noctilucent clouds*) high in the blue area are at a height of about 80 kilometers (50 miles). The atmosphere at this altitude is *very* thin. Air pressure here is less than a thousandth of that at sea level. The thin reddish zone in the lower portion of the image is the densest part of the atmosphere. It is here, in a layer called the *troposphere*, that practically all weather and cloud formation occur. Ninety percent of Earth's atmosphere occurs within just 16 kilometers (10 miles) of the surface. *(NASA)*

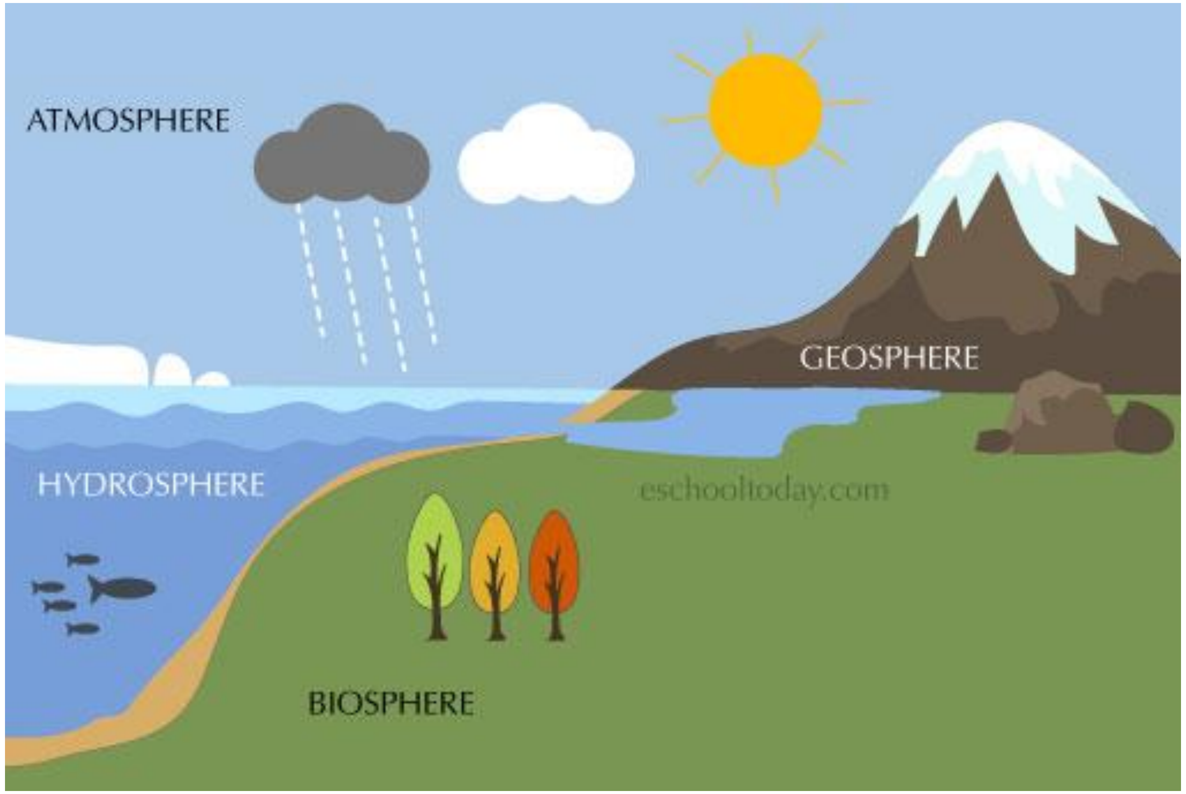
ATMOSPHERE

SOLID EARTH

- Crust
  - Continental
  - Oceanic crust
- Mantle
  - Lithosphere
  - Asthenosphere
- Core
  - Outer core
  - Inner core



EARTH AS A SYSTEM



System: group of interacting parts that form a complex whole.

Closed system : self contained (no matter leaves or enters the system). Energy can move freely in and out of the system (Example ?)

Open system: Both energy and matter flow into the system (Example ?)

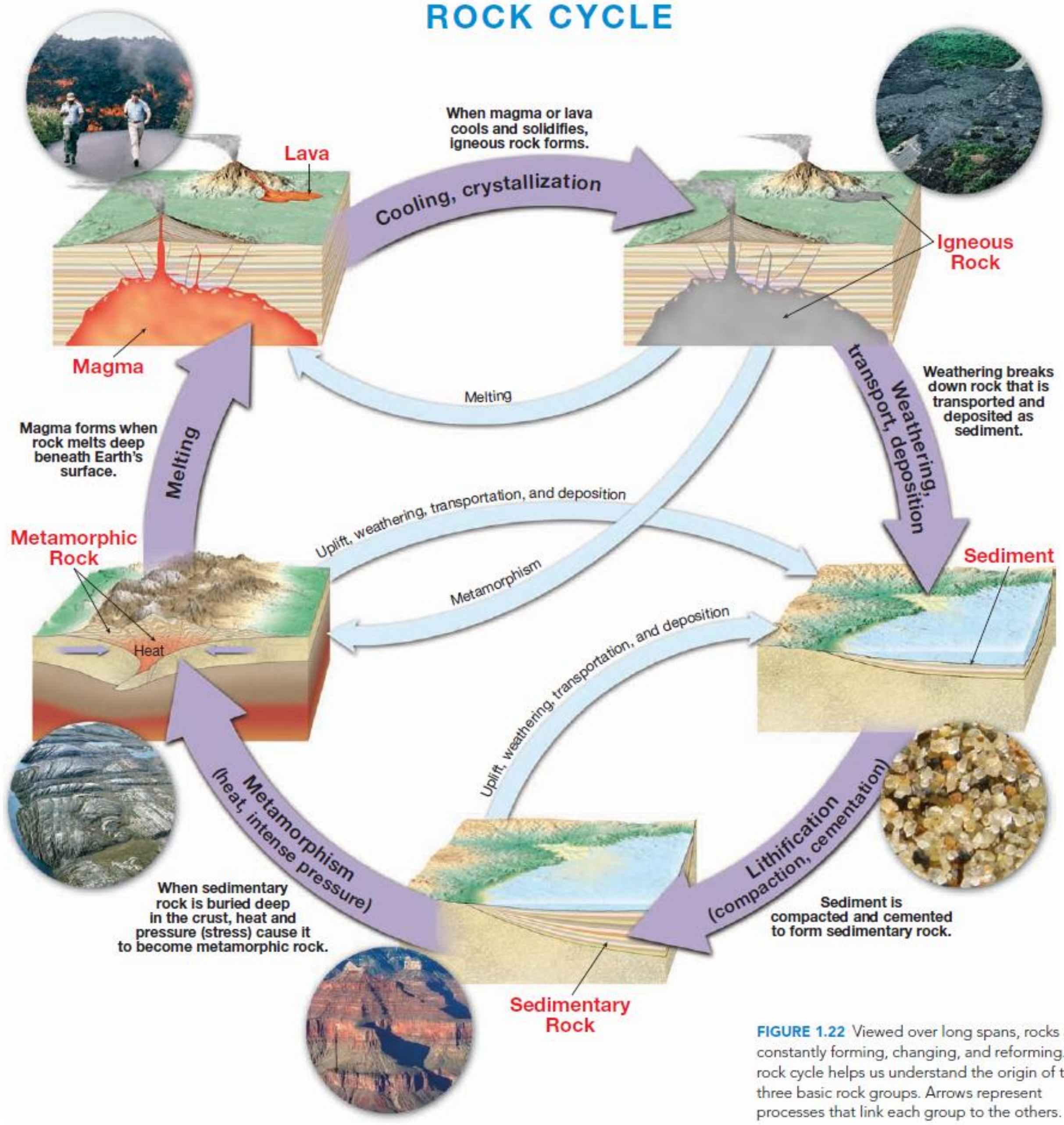


FIGURE 1.22 Viewed over long spans, rocks are constantly forming, changing, and reforming. The rock cycle helps us understand the origin of the three basic rock groups. Arrows represent processes that link each group to the others.

ROCK CYCLE

INTERACTION HYDROLOGIC AND ROCK CYCLES

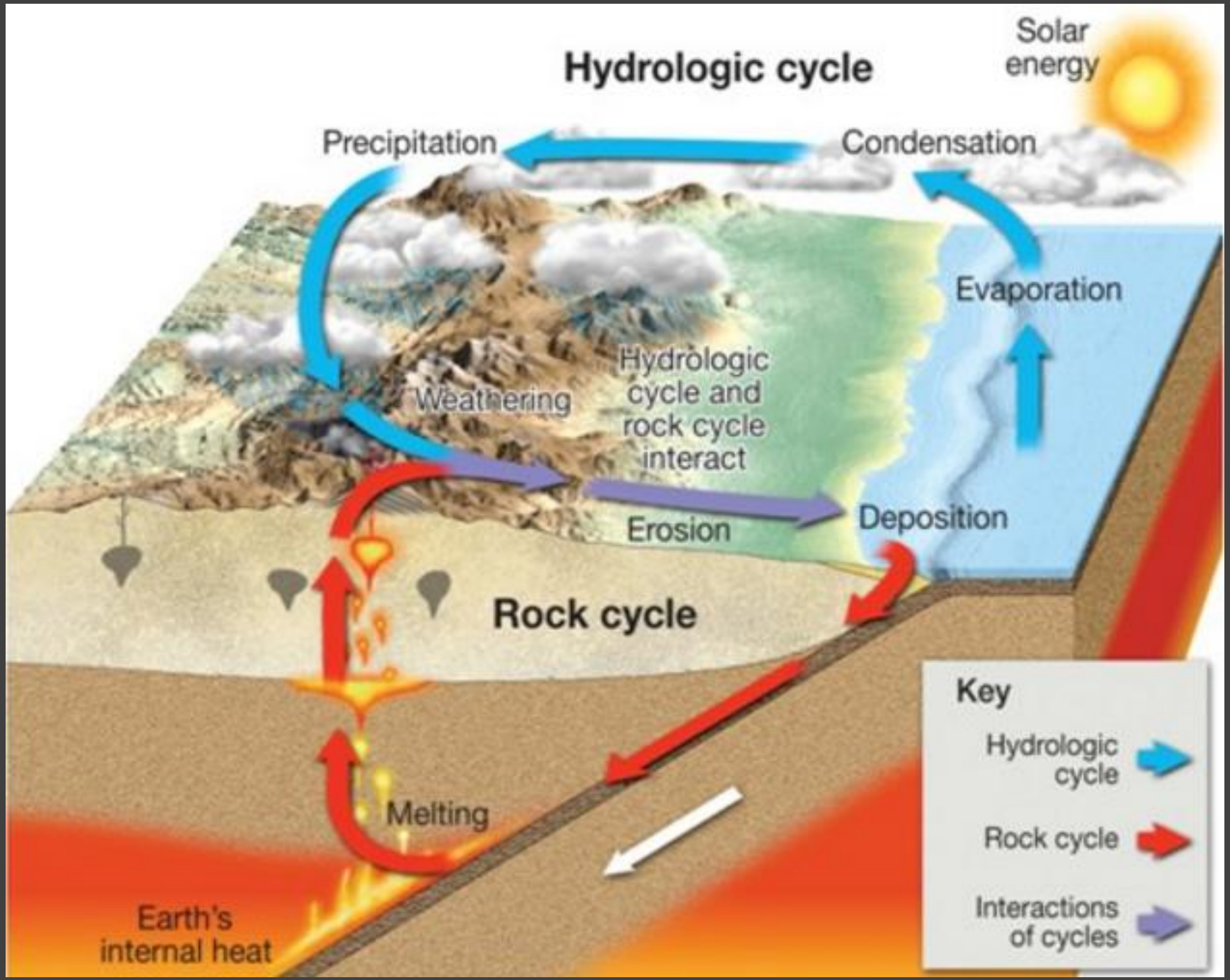
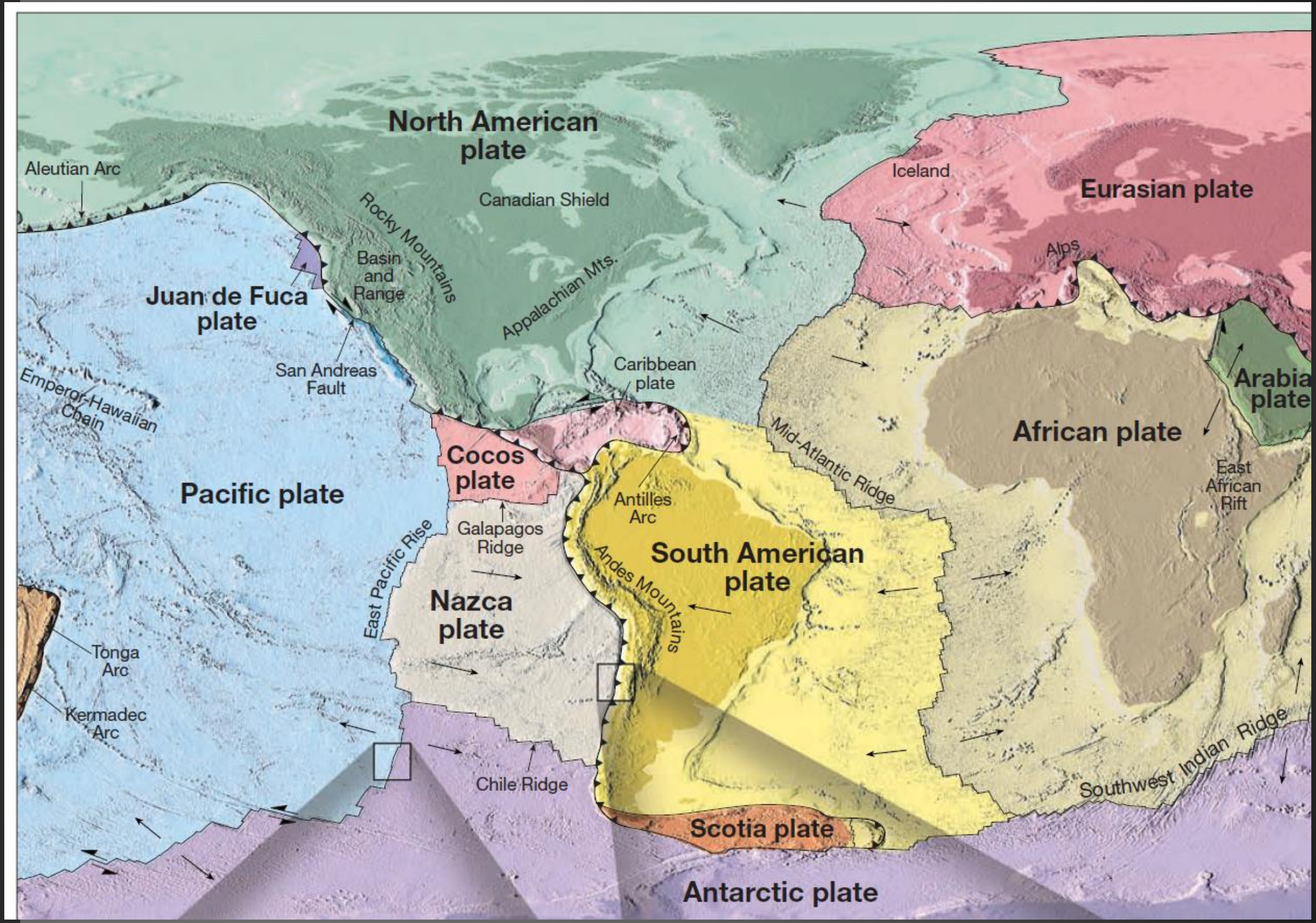
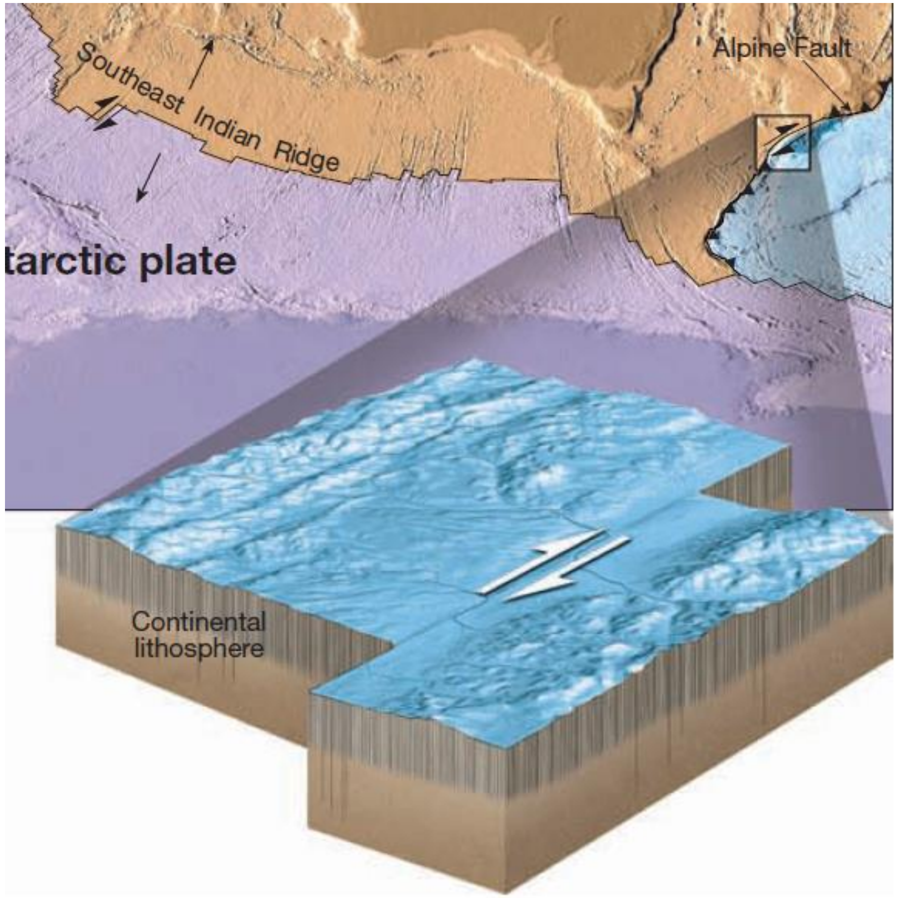


Plate Tectonic theory





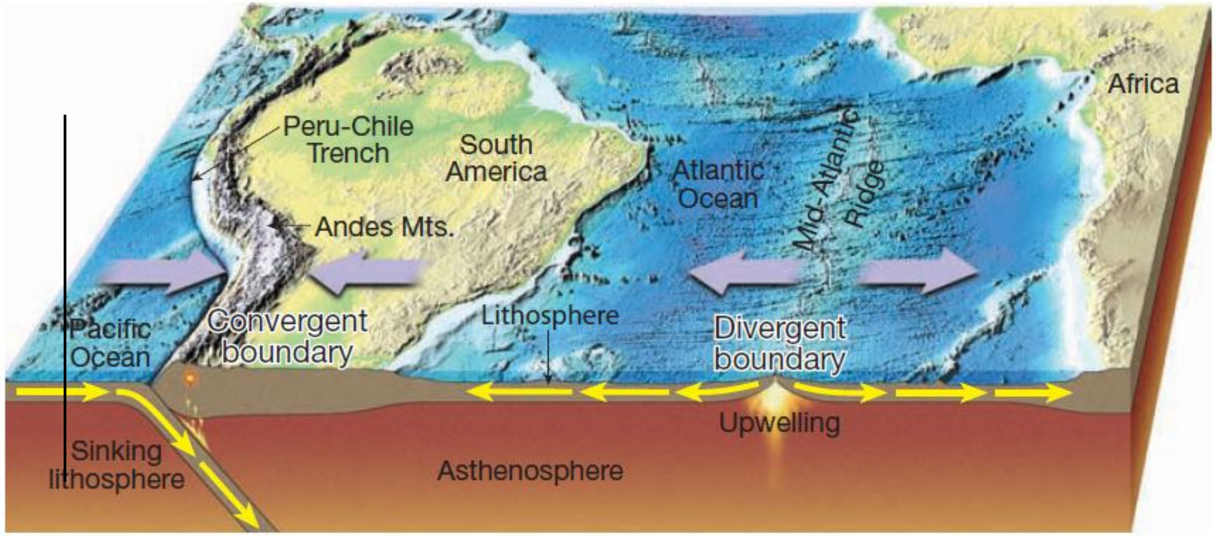


PLATE BOUNDARIES

Engineering Geology

American Geological Institute Glossary:

"The application of geological sciences to engineering practice for the purpose of assuring that the geologic factors affecting the location, design, construction, operation, and maintenance of engineering works are recognized and adequately provided for."

International Association of Engineering Geologists:

"Engineering Geology is the science devoted to the investigation, study and solution of the engineering and environmental problems which may arise as the result of the interaction between geology and the works and activities of man as well as to the prediction and of the development of measures for prevention or remediation of geological hazards."
IAEG statutes, 1992

Engineering Geology

- **Applications of Engineering Geology:**
  - Foundation Engineering
  - Construction Materials Engineering
  - Infrastructural Engineering
  - Disaster Mitigation
  - Land-Use Applications
  - Water Resource Engineering
  - Environmental Engineering

When Mount St. Helens erupted in May 1980, the area shown here was buried by a volcanic mudflow. After just a few years, plants were reestablished, and new soil was forming.

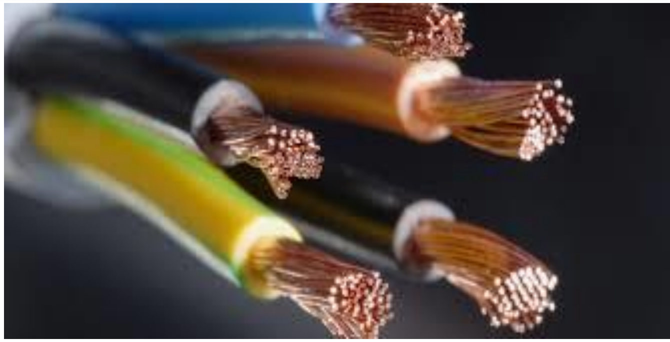
ENCE 231: Engineering Geology
Fall Semester 2019/2020

Department of Civil Engineering- Birzeit University, Palestine

Chapter 2: Minerals

Instructor: Khalil M. Qatu
Saheem Murshed

Minerals: Source of Manufactured Products



- Minerals are the source of every manufactured product.
- Known examples: aluminum in food or beverage cans, copper in wiring, gold & silver in jewelry, etc…

- Other not so known examples: graphite in lead pencils, talc in shower products, diamonds in drill bits at dentist, quartz a source of silicon for computer chips, etc…

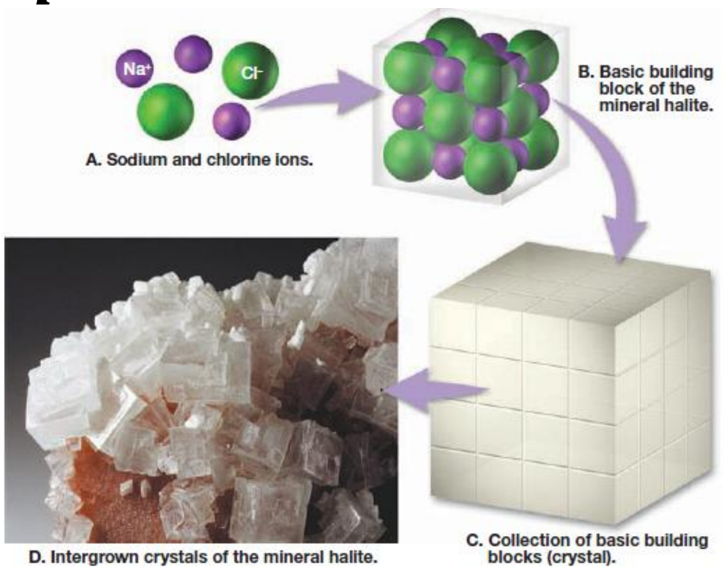
- There are more around 4,000 minerals on earth… defined so far…

Minerals: Definition & Characteristic

- The term "mineral" is used in different ways:
- In Sports & Fitness: concerned with vitamins & minerals.
- Mining Industry: minerals are anything extracted from the ground (ex: coal, iron ore, sand and gravel, etc.)
- The definition in **Geology**: ***"Any naturally occurring inorganic solid that possesses an orderly crystalline structure and a definite chemical composition."***

- **Mineral Characteristics:**

1) Naturally Occurring.
2) Solid Substances.
3) Orderly Crystalline Structure.
4) Definite Chemical Composition.
5) Generally Inorganic.



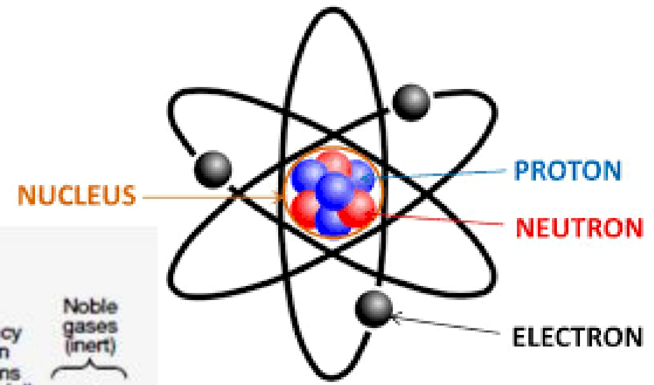
Minerals: Building Blocks of Rocks

- A Rock is a solid mass **composed of one or more minerals** combined in some form.
- **Monomineralic Rocks:** rocks almost entirely composed of one mineral (ex: limestone → calcite, salt → halite).
- **Polymineralic Rocks:** consists of several minerals (ex: granite has several minerals in aggregate form).
- However, some rocks are composed of non-mineral matter (ex: obsidian, pumice, coal).

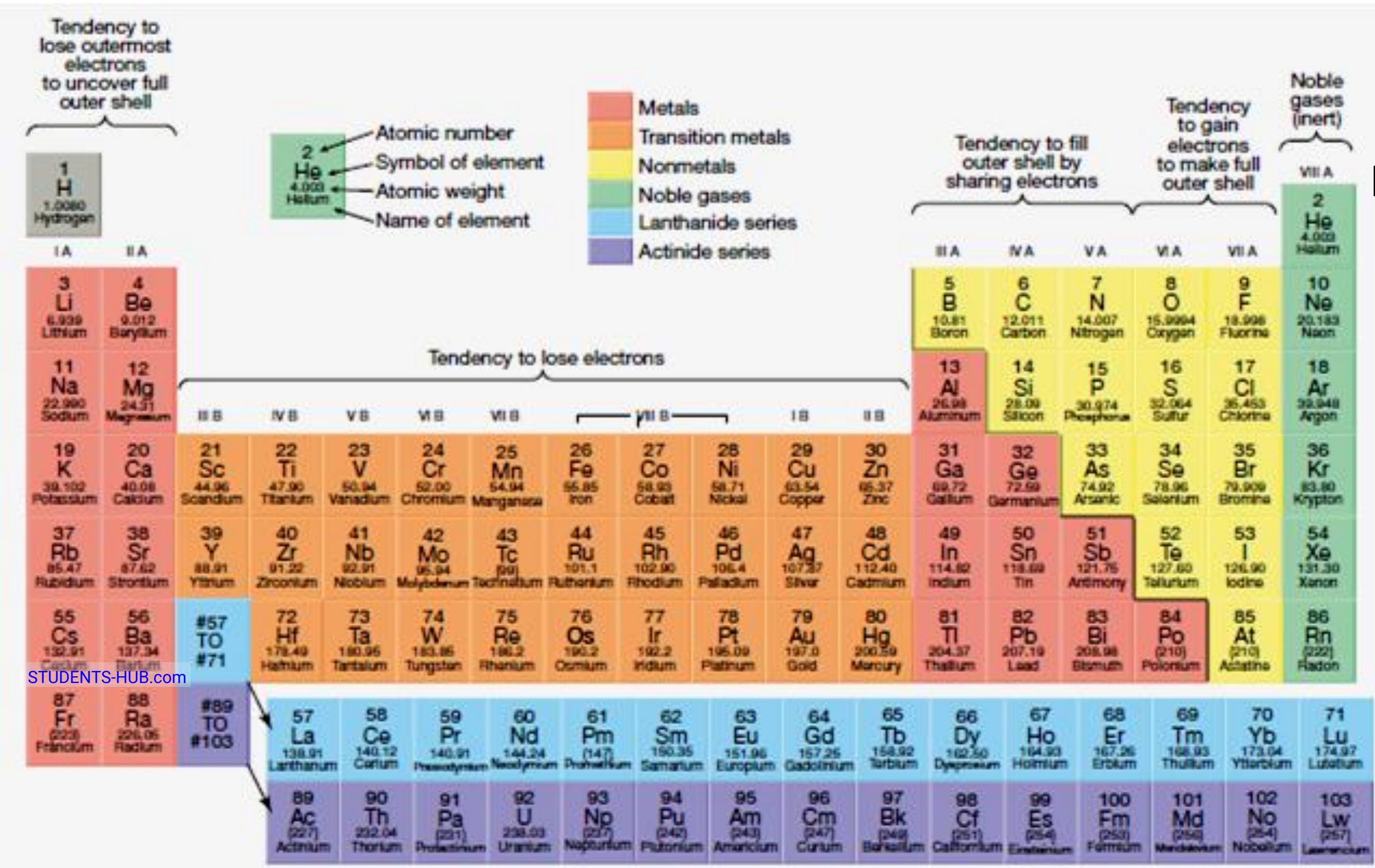
FIGURE 2.3 Most rocks are aggregates of two or more minerals. Shown here is a hand sample of the igneous rock granite and three of its major constituent minerals. *(Photos by E. J. Tarbuck)*

Minerals: Elements, Atoms, & Chemical Bonding

What makes up an atom?

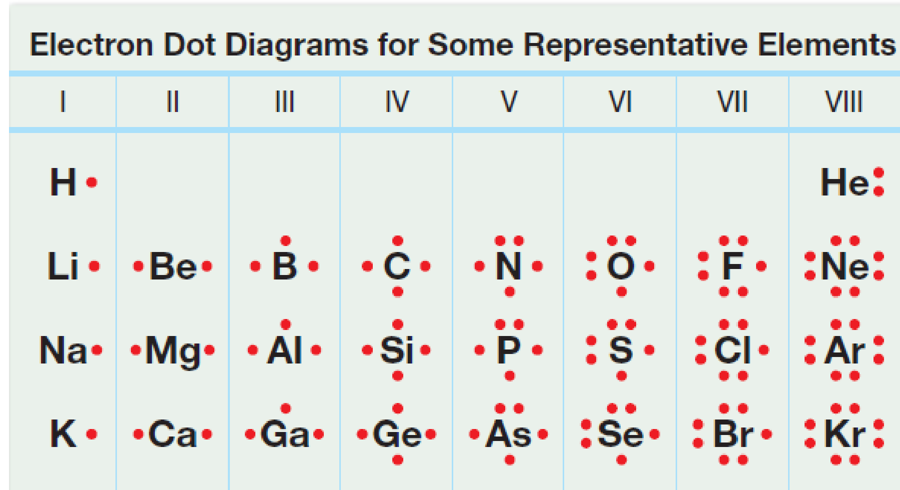


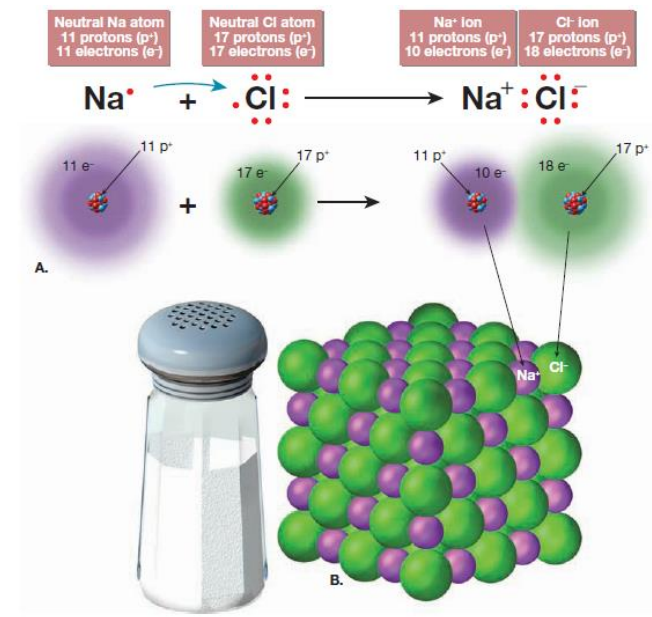
Protons (+)= electrons (-)

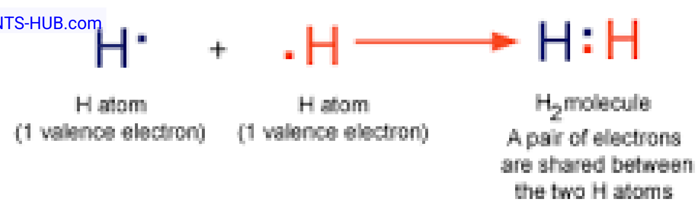


Minerals: Why Atoms Bond

- **Principle Shells: Valence electrons** are the electrons in the outermost shell in an atom. The number of valence electrons determines its stability & whether the atom will bond with other atoms.
- **Ionic Bond:** when electrons are transferred.
- **Covalent Bond:** electrons are shared.

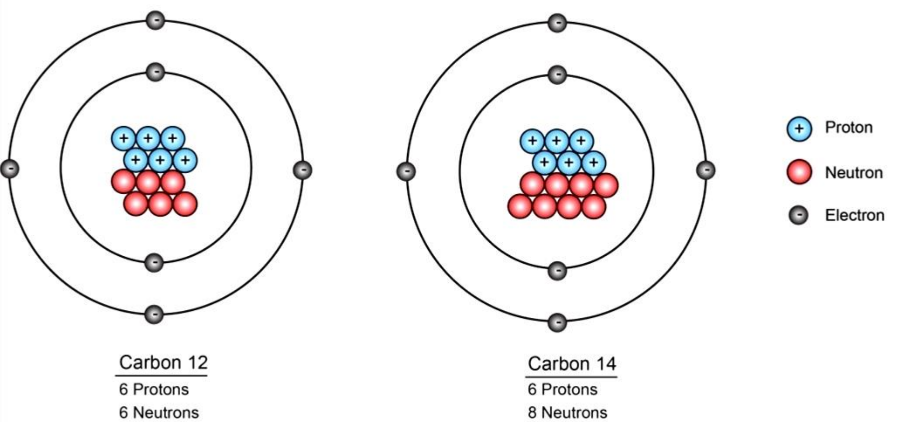


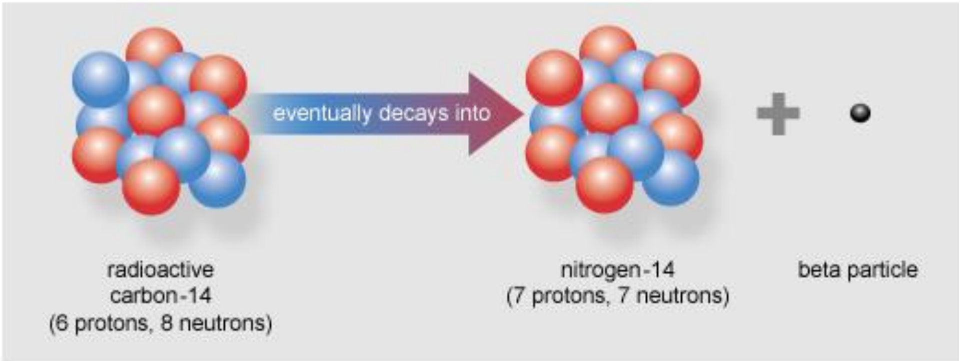




Minerals:
Isotopes & Radioactive Decay

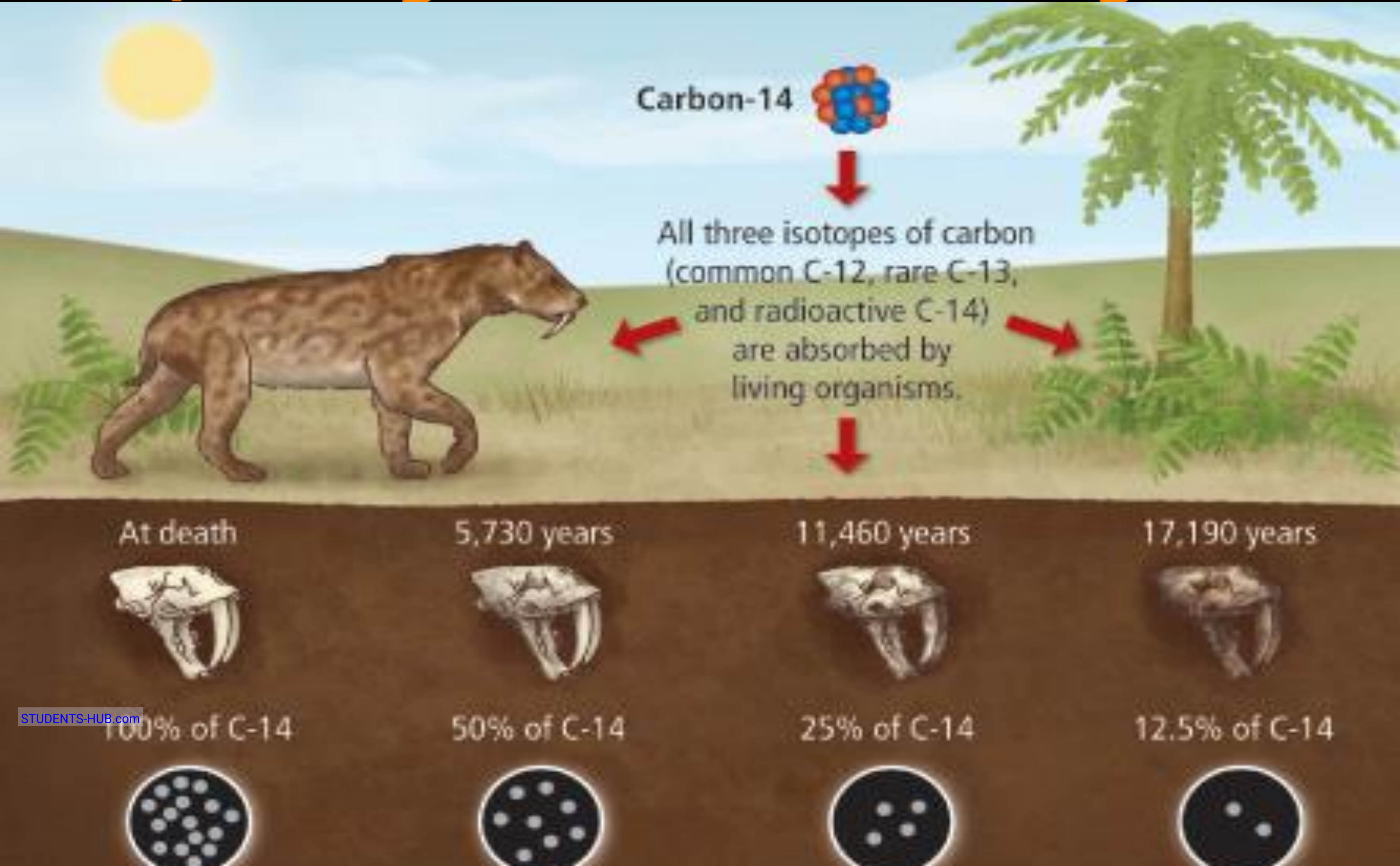
- Atoms of the same element have the same number of protons, but may have a different number of neutrons (isotopes of the element).





All carbon-14 decays into nitrogen, but the level of carbon-14 on Earth is relatively constant because cosmic rays constantly produce new radioactive carbon from nitrogen in the upper atmosphere.

Minerals: Isotopes & Radioactive Decay (C-14 Dating/ Radioactive Dating)



Properties of Minerals

- Each Mineral has a definite chemical composition and orderly arrangement of atoms, which gives it **a unique set of physical properties**.
- **Primary Physical Properties** used to identify minerals:

1) Crystal Form
2) Luster
3) Color
4) Streak
5) Hardness
6) Cleavage
7) Density & Specific Gravity

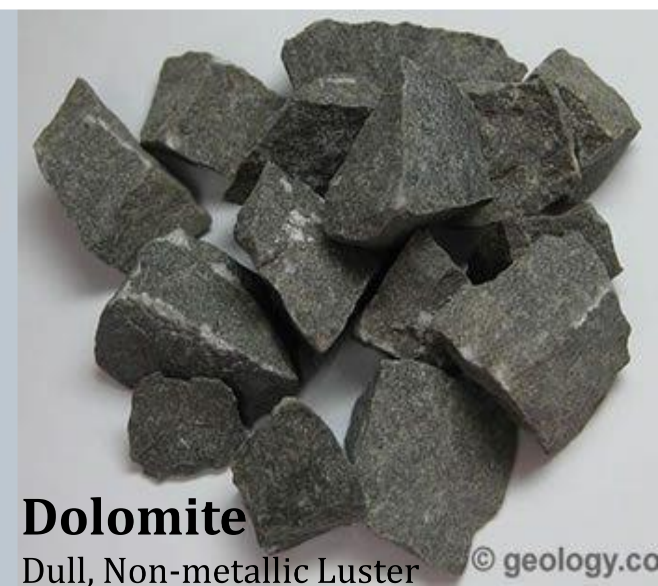
- **Secondary Properties:** magnetism, taste, feel, smell, elasticity, malleability, double refraction, & chemical reaction to hydrochloric acid (HCl).

Primary Physical Properties: 1) Crystal Form

- The **Crystal Form** reflects the internal orderly arrangements of atoms in a particular mineral.
- When enough space & time are available to the mineral, its crystal faces will form well.
- When space & time are NOT Available, the result is an intergrown mass of small, jammed crystals that are not clearly visible to the unaided eye.

Primary Physical Properties: 2) Luster

- **Luster** is the appearance or quality of light reflected from the surface of a mineral.
- Minerals that have the appearance of metals are described as having a **“Metallic Luster”.**
- Other **non-metallic luster** include: Vitreous or Glassy (such as quartz), pearly, silky, resinous, and earthy (dull).



Luster:

the way a mineral reflects light

- plastic, dull, metallic, waxy, pearly, glassy, silky, earthy

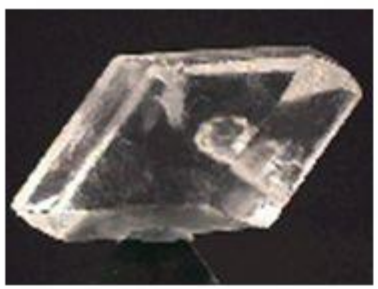
waxy

pearly

metallic

metallic, earthy

dull



glassy, vitreous

resinous, plastic

silky, fibrous

Primary Physical Properties: 3) Color

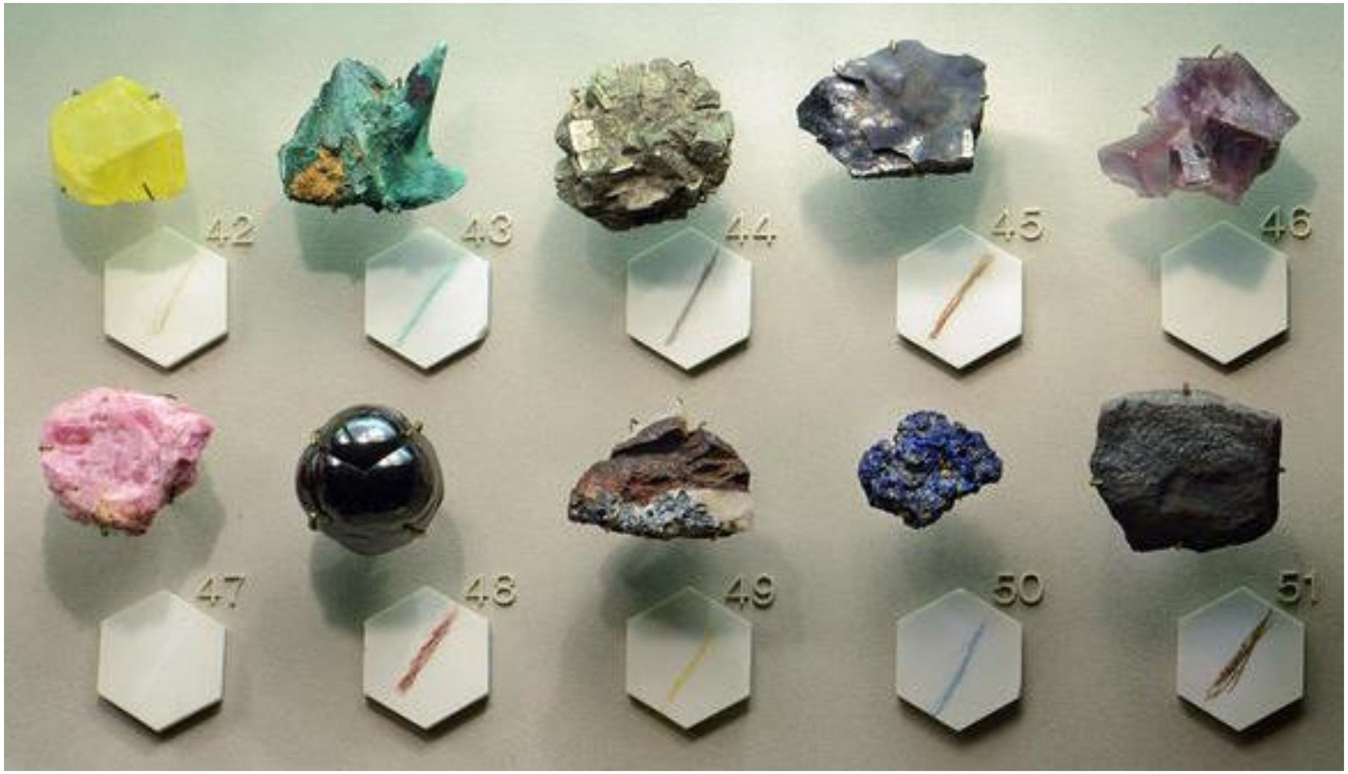
- **Color** is NOT a reliable diagnostic property, but may help in certain cases.

Quartz in Variable Colors

FIGURE 2.10 Quartz. Some minerals, such as quartz, occur in a variety of colors. These samples include crystal quartz (colorless), amethyst (purple quartz), citrine (yellow quartz), and smoky quartz (gray to black). *(Photo courtesy of E. J. Tarbuck)*

Primary Physical Properties: 4) Streak

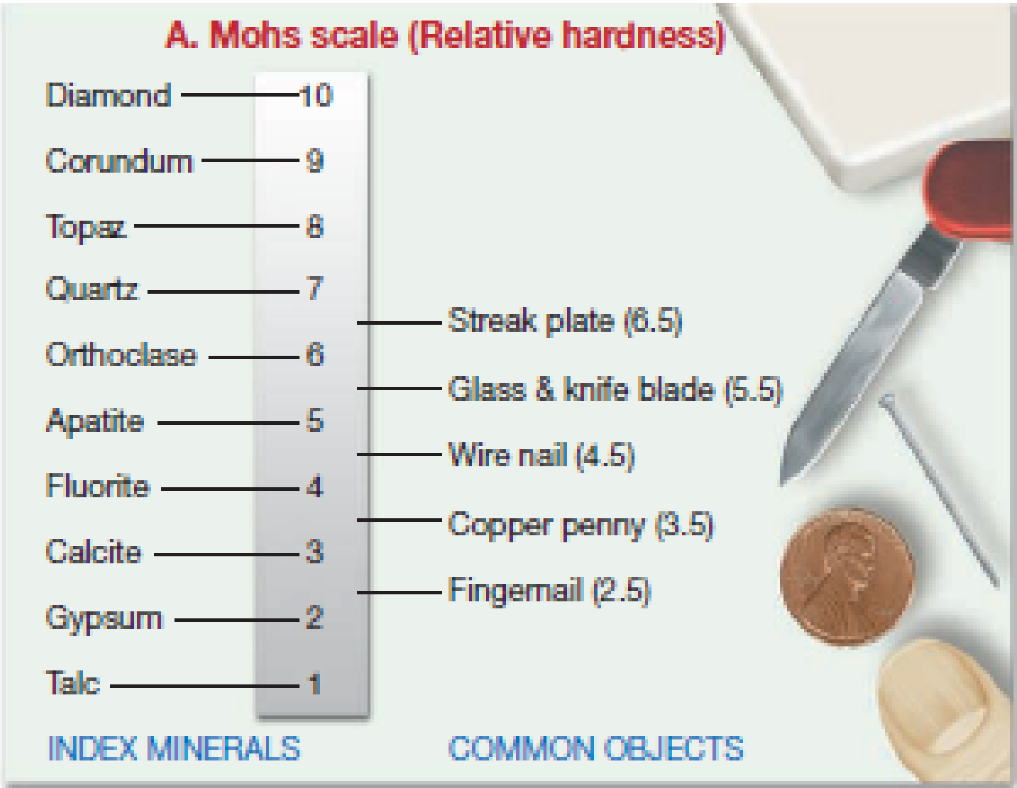
- **Streak** is the color of a mineral in its powdered form, which is much more reliable. A mineral in different colors will have the same color streak.



Primary Physical Properties: 5) Hardness

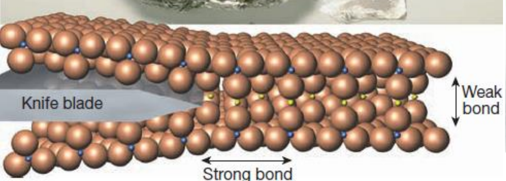
- **Hardness** is one of the most useful diagnostic properties. It is a measure of the resistance of a mineral to abrasion or scratching. It is determined by rubbing it with another mineral of known hardness.

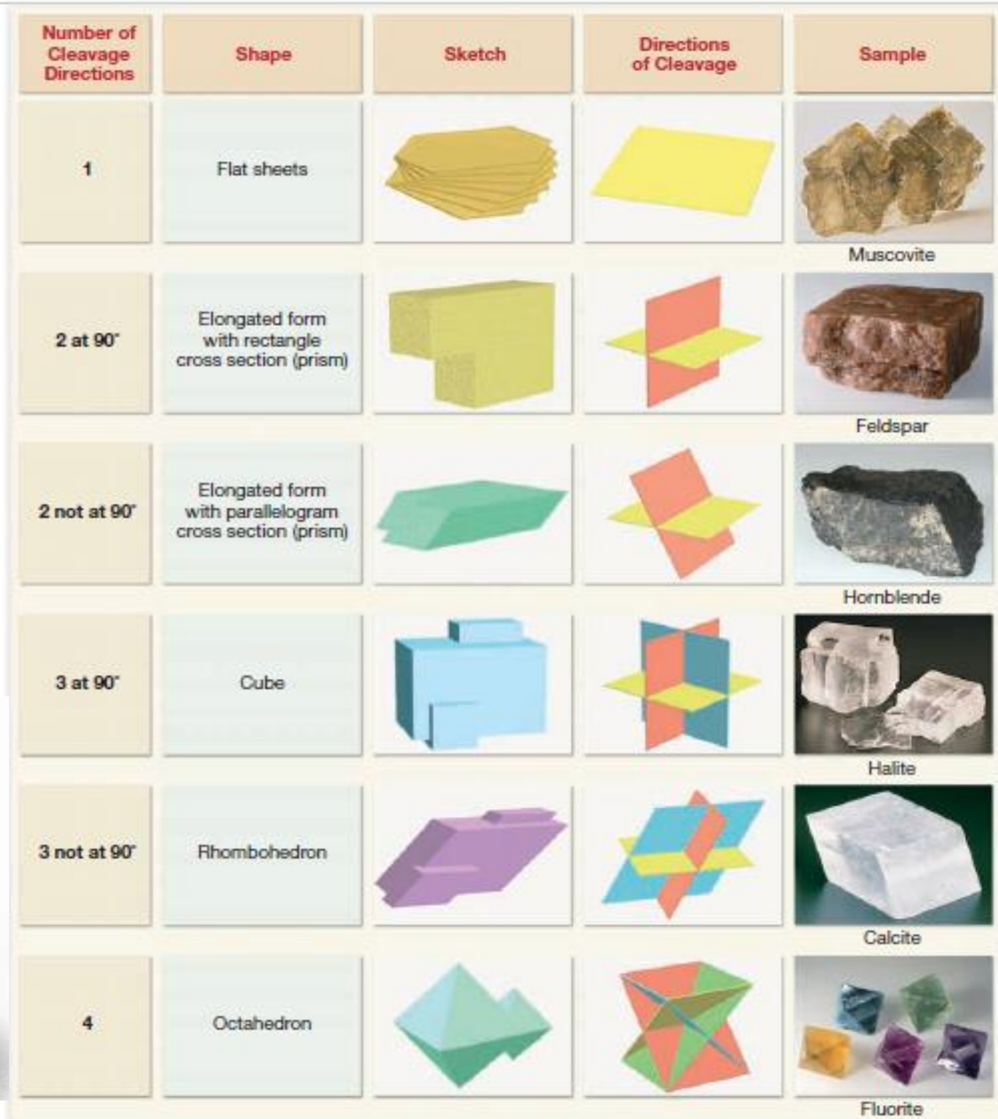
- **Mohs Hardness Scale**:
  A scale from 1 (softest) to 10 (hardest).
  Example of Gypsum & Calcite.



Primary Physical Properties: 6) Cleavage

- **Cleavage:**
  Depending on the chemical bonding, a mineral will break along the weak bonds when it is stressed. The planes it breaks along are called “Cleavage Planes”. They appear as smooth surfaces with the same geometry when breakage occurs.

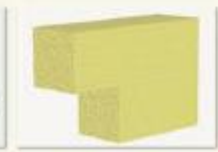


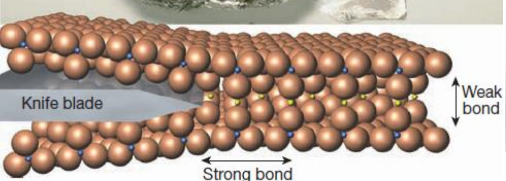


Number of Cleavage Directions	Shape	Sketch	Directions of Cleavage	Sample
1	Flat sheets			Muscovite
2 at 90°	Elongated form with rectangle cross section (prism)			Feldspar
2 not at 90°	Elongated form with parallelogram cross section (prism)			Hornblende
3 at 90°	Cube			Halite
3 not at 90°	Rhombohedron			Calcite
4	Octahedron			Fluorite

Primary Physical Properties: 6) Cleavage

- **Cleavage:**
- Minerals may cleave along 1, 2, 3 or more planes. If more than 1, we describe the angle between the different cleavage planes
- However, this is not to be confused with crystal faces!
- Some mineral will not cleave but may break into pieces that do resemble each other (Ex: Quartz and Conchoidal Fracturing)

Number of Cleavage Directions	Shape	Sketch	Directions of Cleavage	Sample
1	Flat sheets			 Muscovite
2 at 90°	Elongated form with rectangle cross section (prism)			 Feldspar
2 not at 90°	Elongated form with parallelogram cross section (prism)			 Hornblende
3 at 90°	Cube			 Halite
3 not at 90°	Rhombohedron			 Calcite
4	Octahedron			 Fluorite

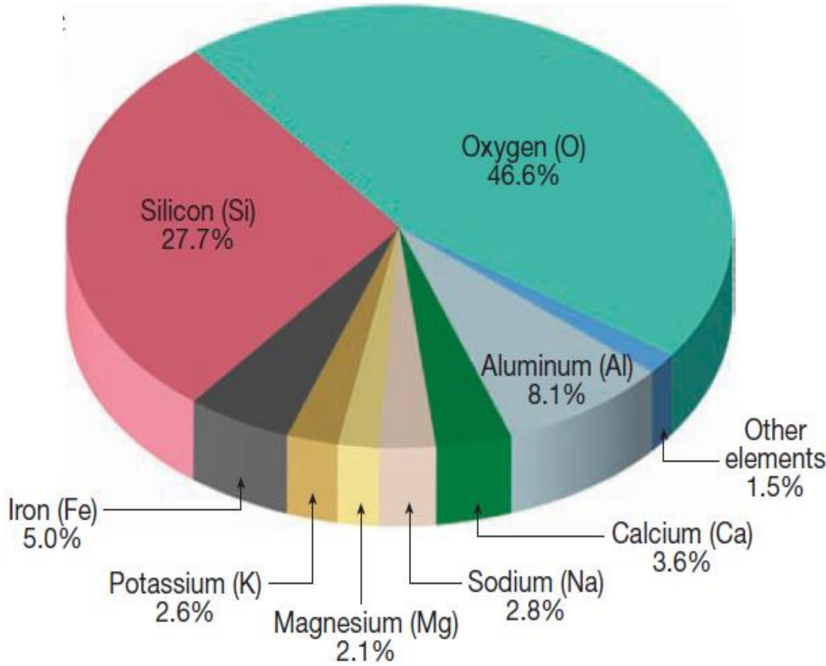


Primary Physical Properties: 6) Density & Specific Gravity

- Density is an important property in defining matter, including minerals, that is expressed in grams/cubic centimeter (g/cm3).
- Specific Gravity (unitless) is used in place of density as it is easier to find or estimate. It compares the weight of a mineral compared to the same volume of water.
- Rock-forming minerals that weigh similar to common rocks, we estimate that it has a Specific gravity of 2.5-3.
- Some metallic minerals weigh much more than common rock (ex: Galena Sg= 7 , or pure 24-kurot gold =20 or so)

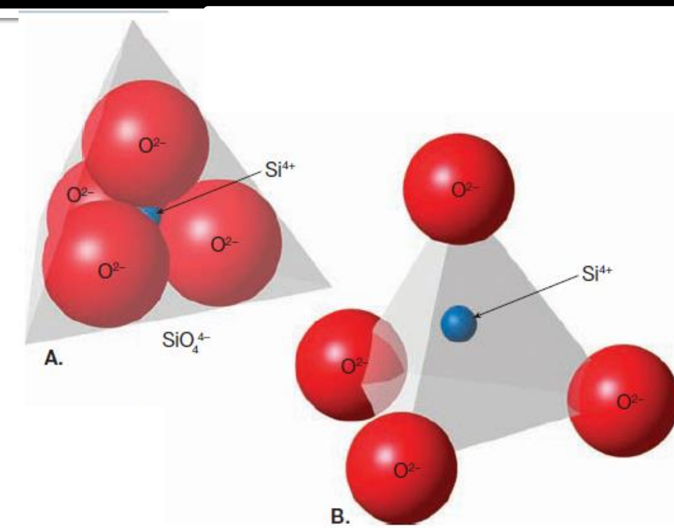
Mineral Groups

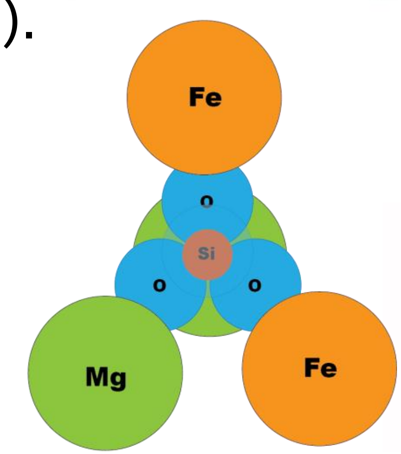
- There are nearly 4,000 mineral, but only a few dozen are abundant. They are the **"Rock-Forming Minerals"**.
- Only **8 elements** make up the bulk of these minerals and represent 98% of the continental crust (by weight).
- The elements are:
  - Oxygen (O) [46%] & Silicon (Si) [27.7%]→ combine together to form the most abundant mineral group, the **Silicates**.
  - Other Elements: Aluminum (Al), Iron (Fe), Calcium (Ca), Sodium (Na), Potassium (K), & Magnesium (Mg).



Mineral Groups: Silicates

- Silicate minerals make up 90% of the Earth's crust. They occur when Silicon & Oxygen bond (covalent) to form the **Silicon-oxygen tetrahedron (SiO_4^{-4})**.
- "Tetra-" is derived from ancient Greek meaning "four". This signifies the structure of ionic bonding (i.e. four Si^{+4} ions per O^{-2}).
- These tetrahedra are not chemical compounds, but rather complex ions having a net charge of (-4). To become electrically balanced/ neutral, these complex ions bond to other positively charged elements such as Mg, Ca, Fe, K, Na, K, etc.





Mg or Fe bond with the outer oxygens to form a single tetrahedron → the mineral **Olivine**

Silicate Structures

- Other than bonding with positive ions, the tetrahedra may link with themselves in a variety of ways (**through sharing of oxygen**), forming: single chain, double chain, sheet, & 3-D network structures.

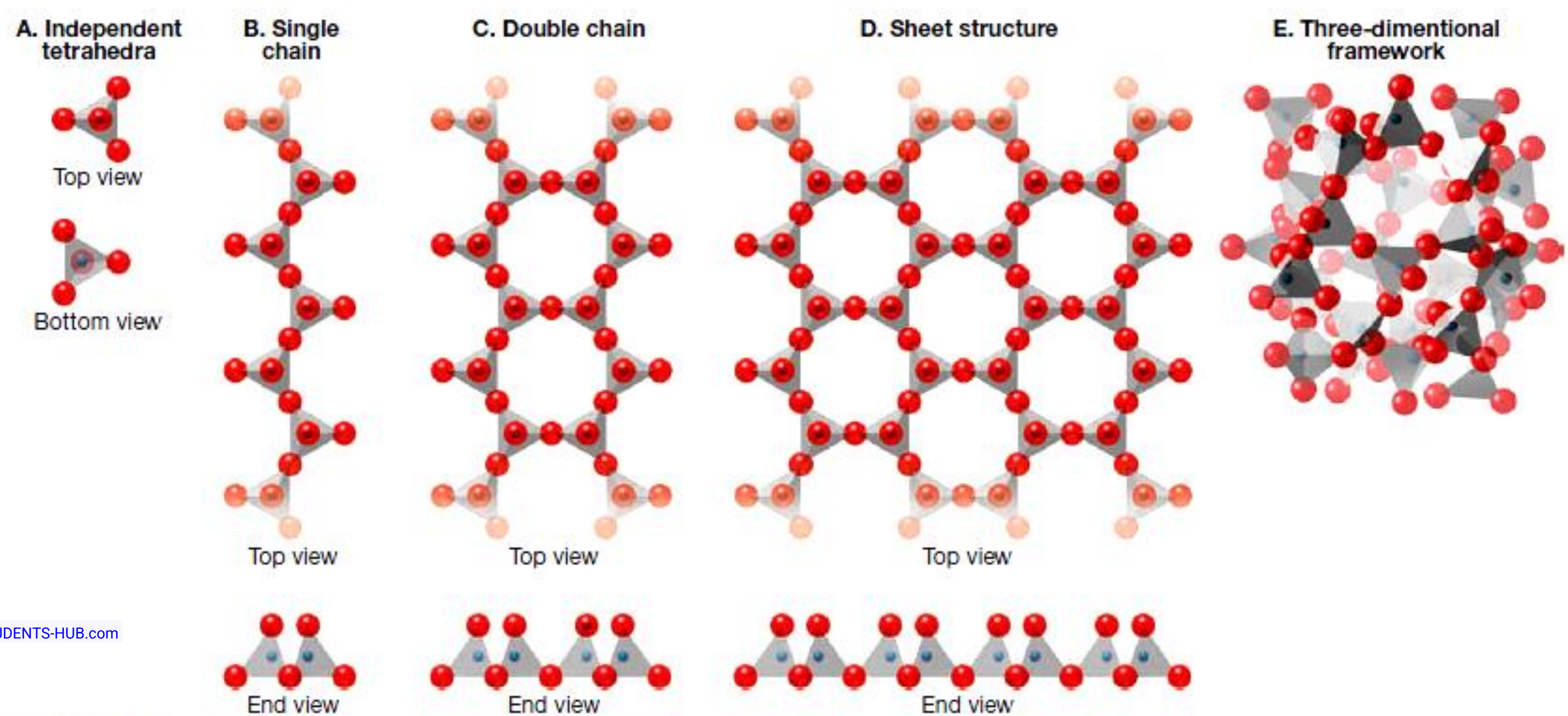
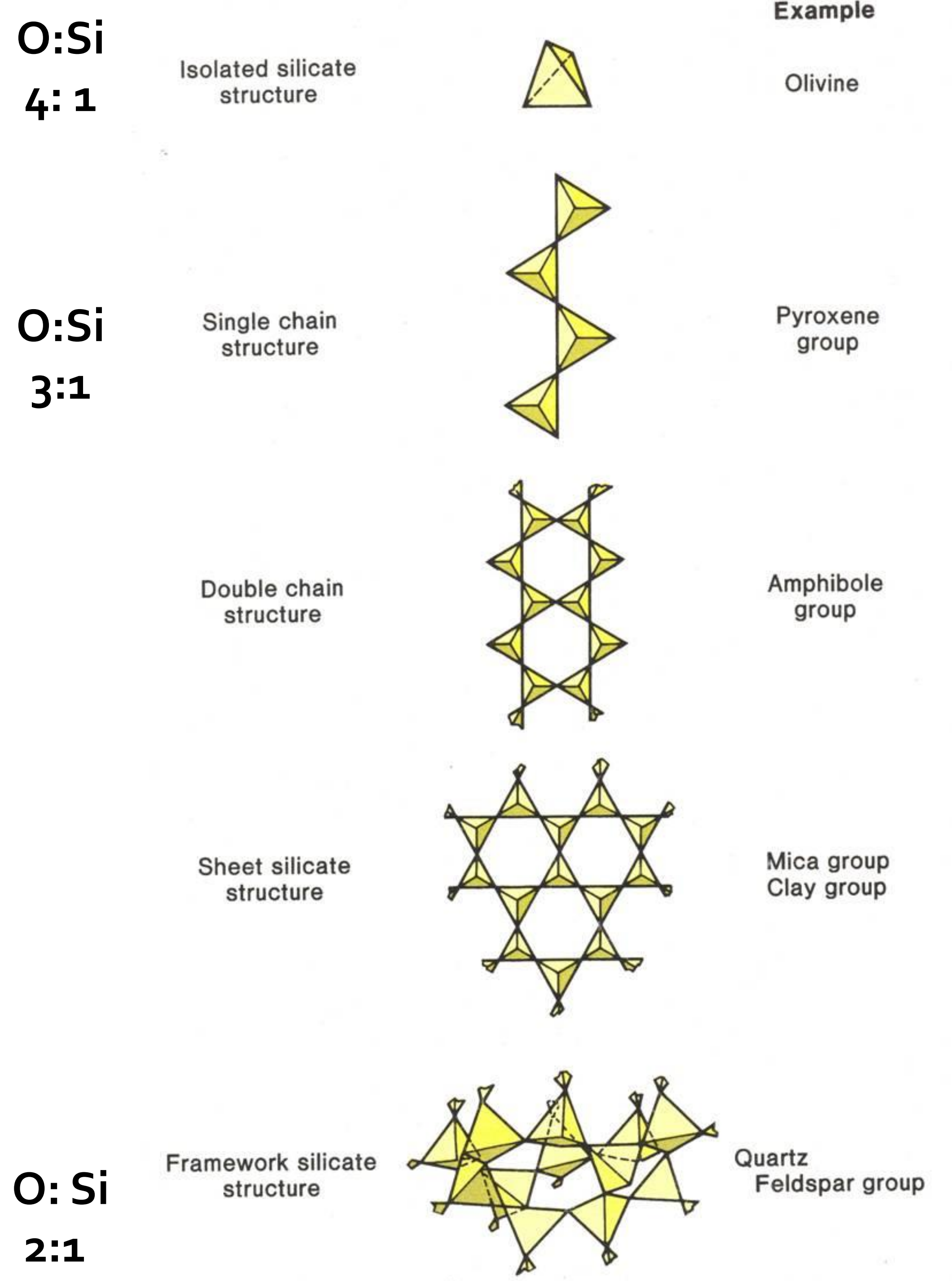
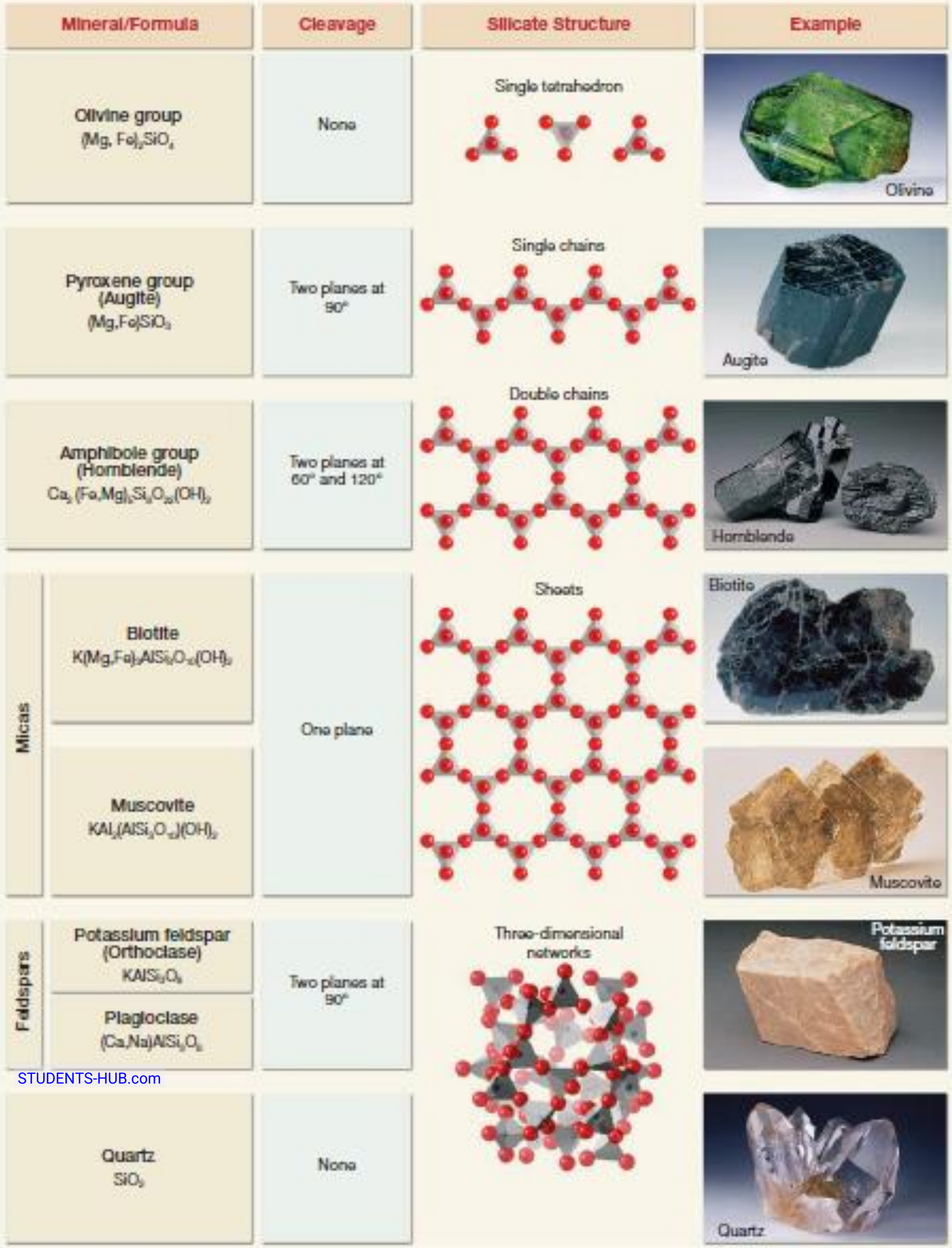


FIGURE 2.22 Five types of silicate structures. **A.** Independent tetrahedra. **B.** Single chains. **C.** Double chains. **D.** Sheet structures. **E.** Three-dimensional framework.

- So, in each of the silicate structures the **ratio of oxygen ions to silicon ions** differs.
- Consequently, as more of the oxygen ions are shared, the % of silicon increases. Therefore, silicates are described as either having "high" or "low" silicon content.



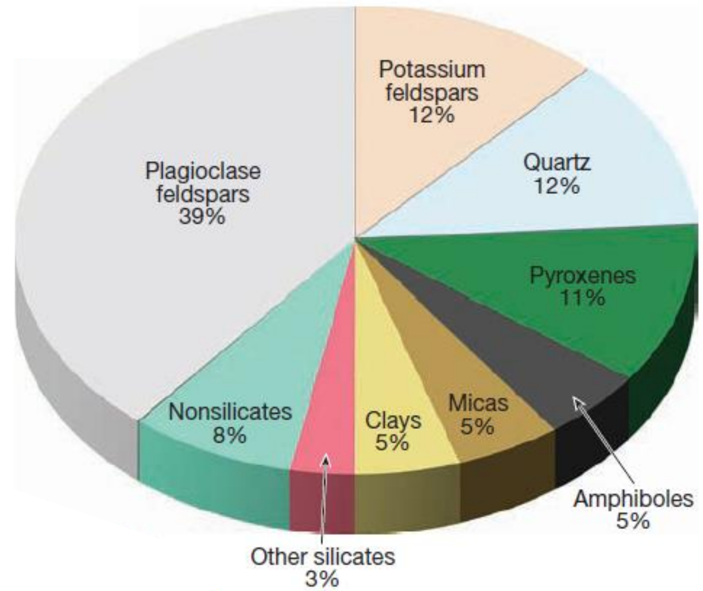


Example Silicates

- Ions with approx. the same size & charge are able to substitute freely for one another. Example: Fe+2 and Mg+2 can substitute without changing the mineral crystal structure (see Olivine).
- Note that Aluminum also often substitutes for the Silicon in the silicon-oxygen tetrahedron!!!

Common Silicate Minerals

- We now know that the building block for silicates is **SiO_4^{-4}.** Each group of silicates has a particular structure & because Si-O bond are strong covalent bonds, the silicate mineral tend to **cleave** (break) between the Si-O bond rather than across them.



- **Feldspar Group (Orthoclase, Plagioclase):**
  Most abundant silicate (comprising 50% of earth's crust).

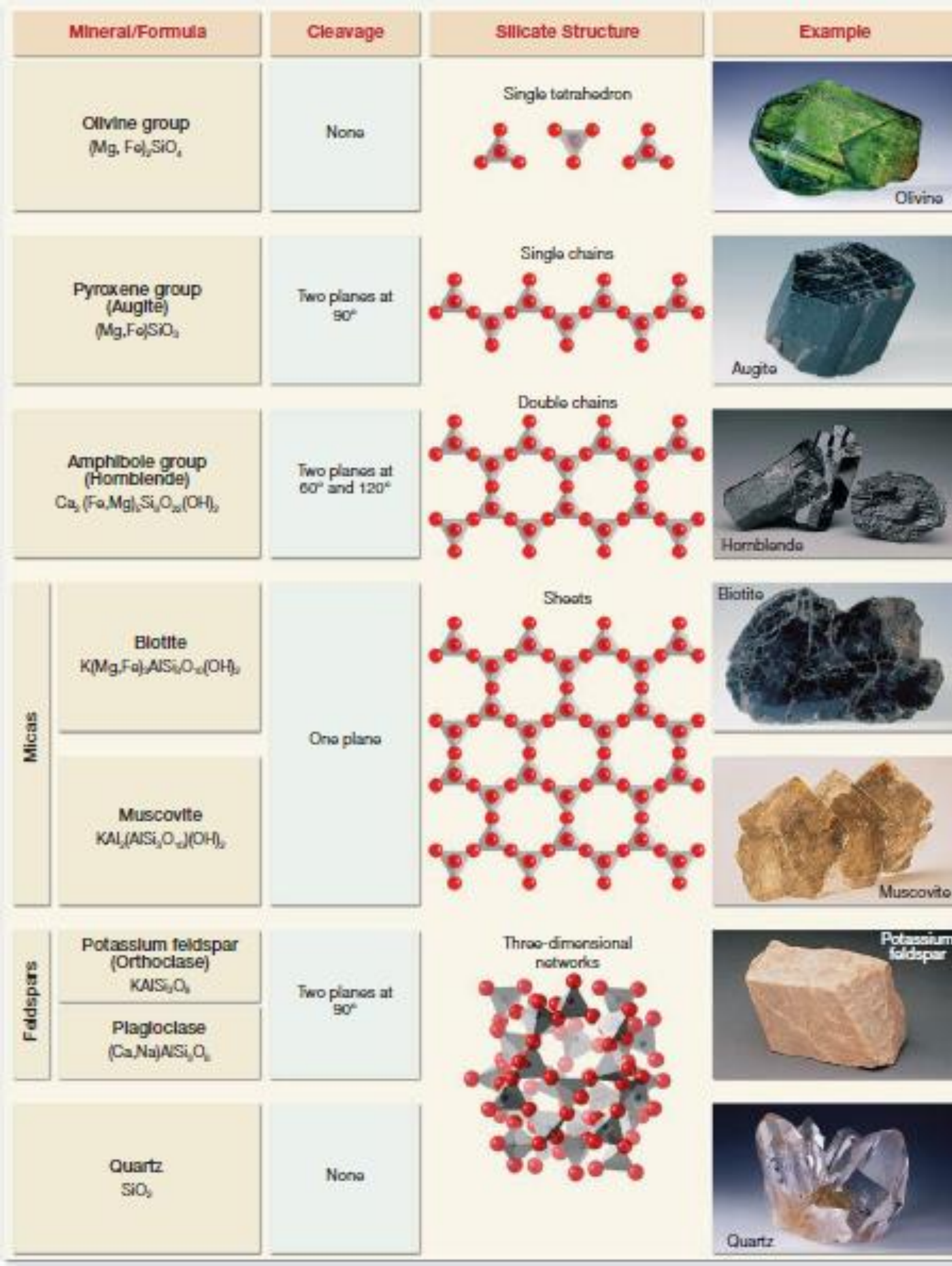
- **Quartz:**
  Second most abundant silicate & the only common mineral made up completely of silicon and oxygen (SiO_2).

Other Common Silicates

- Mica: Biotite, Muscovite
- Amphibol (Hornblend)
- Pyroxene (Augite)
- Olivine

Biotite

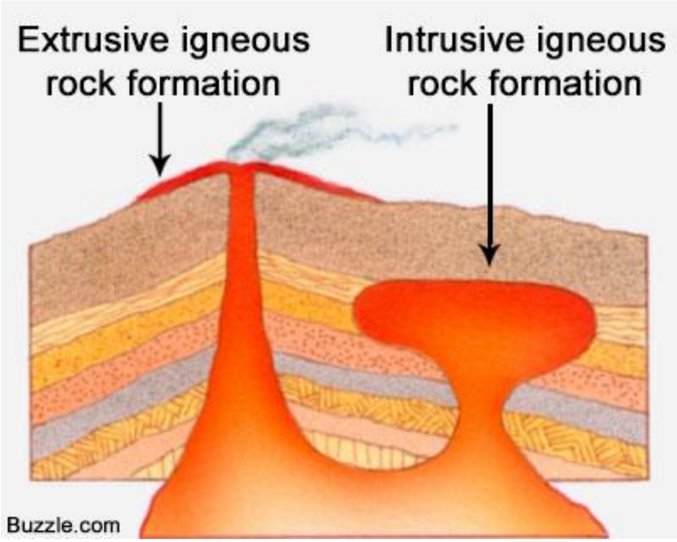
Sheet Structure= thin sheet cleavage



	Mineral/Formula	Cleavage	Silicate Structure	Example
	Olivine group $(Mg, Fe)_2SiO_4$	None	Single tetrahedron	Olivine
	Pyroxene group (Augite) $(Mg,Fe)SiO_3$	Two planes at 90°	Single chains	Augite
	Amphibole group (Hornblende) $Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	Two planes at 60° and 120°	Double chains	Hornblende
Micas	Biotite $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	One plane	Sheets	Biotite
Micas	Muscovite $KAl_2(AlSi_3O_{10})(OH)_2$	One plane	Sheets	Muscovite
Feldspars	Potassium feldspar (Orthoclase) $KAlSi_3O_8$	Two planes at 90°	Three-dimensional networks	Potassium feldspar
Feldspars	Plagioclase $(Ca,Na)AlSi_3O_8$	Two planes at 90°	Three-dimensional networks	
	Quartz SiO_2	None	Three-dimensional networks	Quartz

Silicates Formation

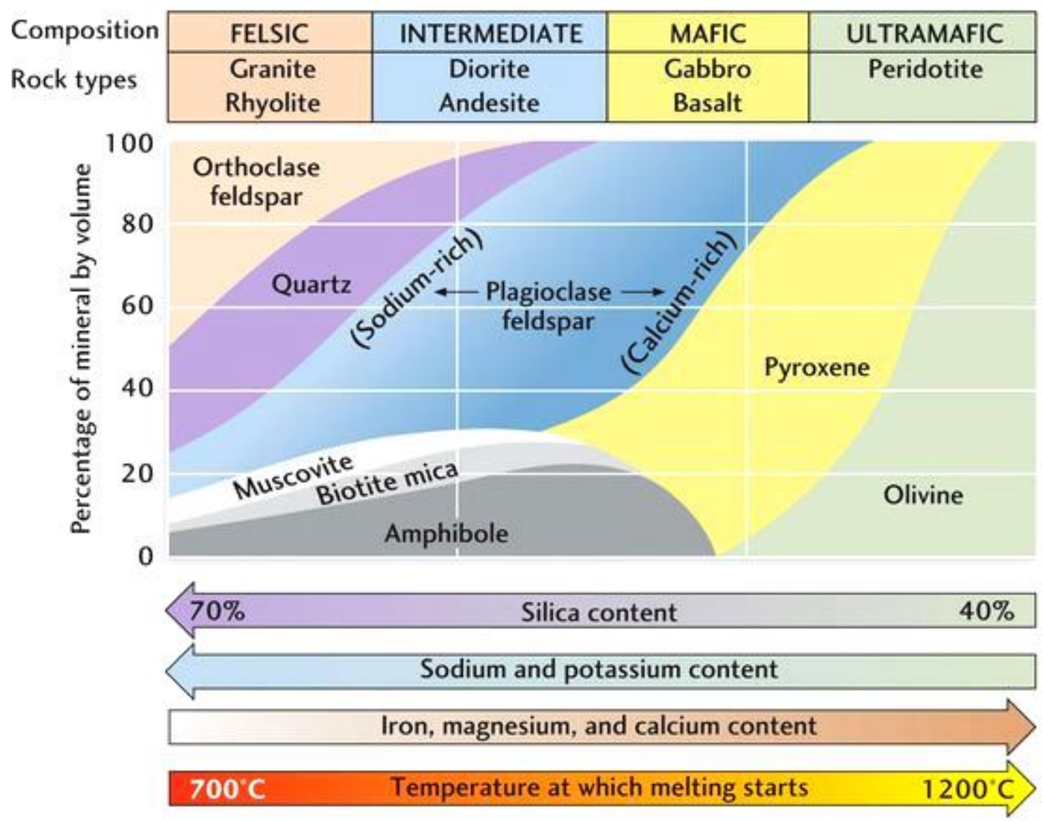
- Most Silicate minerals for as molten rock is cooling **"Crystallization"**.
- Cooling may occur near the at or near the Earth's surface (low temp. & pressure) or at great depth (high temp. & pressure).
- The Environment during crystallization and the chemical composition of the molten rock determine the type of mineral produced.
  Ex: Olivine crystallizes at high temp., while Quartz at low temp.
- Some silicate minerals may even form from the weathering of older minerals on the surface. Others under extreme pressures during mountain building.
- In Conclusion, each silicate mineral has a structure & chemical composition that ***indicate the conditions of its formation.***



Formation of Minerals: Bowen's Reaction Series

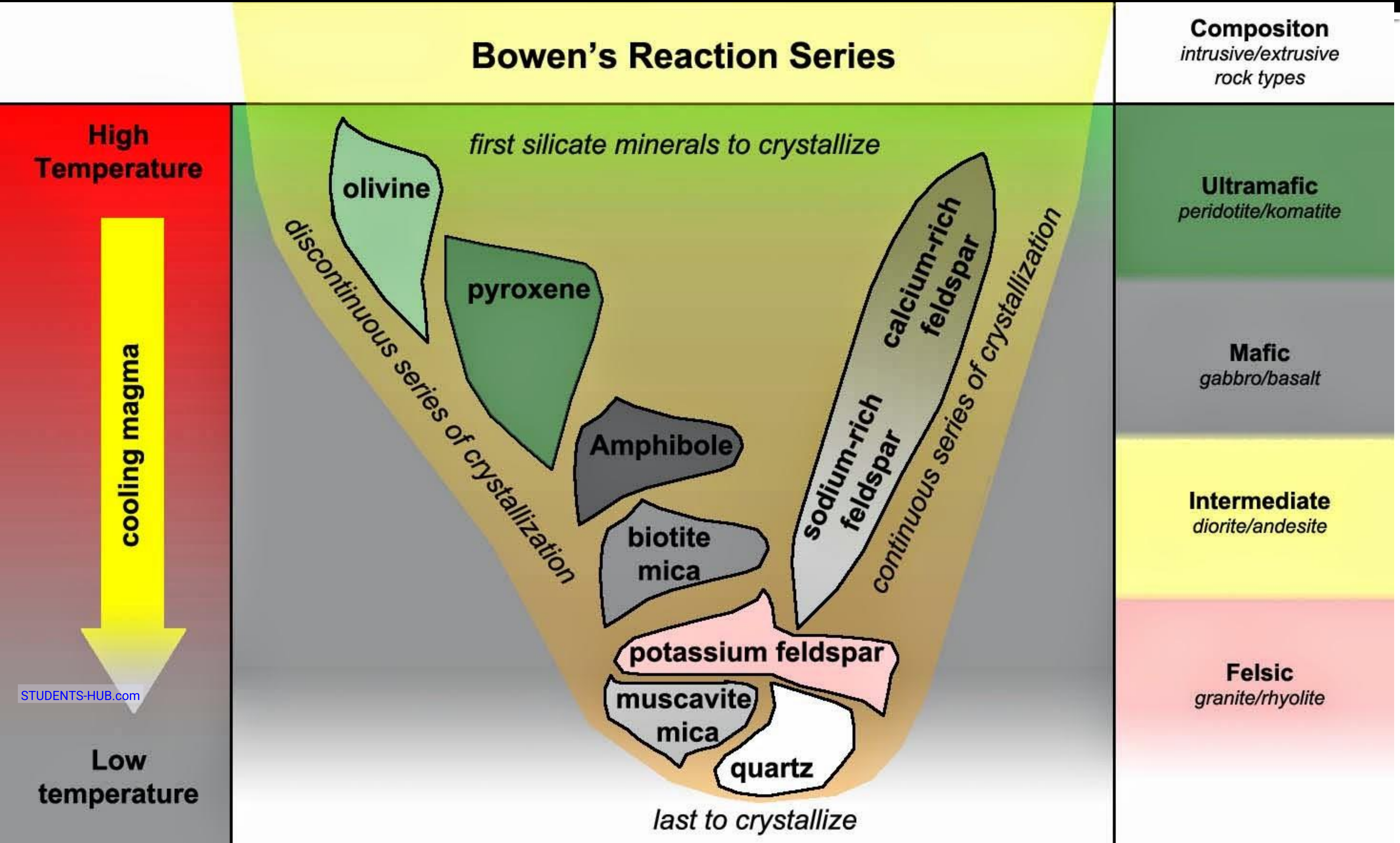
- Bowe's experiments in the lab showed that:

1) All magma components cool at 200°c.
2) Minerals in magma cool (i.e. crystallize/ form) in a systematic manner, based on their melting points.
3) Ultramafic→ Mafic or Basaltic → Intermediate or Andesitic → Felsic or Granitic.



Olivine→ Biotite→ K-Feldspar→ Muscovite → Quartz

Bowen's Reaction Series showing the sequence in which minerals crystallize from a magma



Silicate Groups: Light Silicates

- Silicates are divided into two major groups based on chemical composition.

A) The Light Silicates "non-ferromagnesian":

They are light in color & a specific gravity of 2.7, which is attributed to the limited amount of iron & magnesium. Instead they contain varying amounts of Al, K, Ca, & Na.

- **Feldspar Group:** the most abundant, partially due to the wide range of temperatures & pressures they can form at. The are hard (6 on Mohs Scale), have glassy to pearly luster, & cleavage along 2 planes at 90°.

Types of Feldspar/ Properties	K- Feldspar (Orthoclase)	Plagioclase Feldspar
Chemical comp.	Contains K	Contains Na, Ca
Color	Light cream to salmon pink	White to medium grey
Striations (multitude of parallel lines on cleavage)	NO	YES

Silicate Groups: Light Silicates

The Light Silicates "non-ferromagnesian" (continued):

- **Quartz:** Entirely made of SiO_2, hence called "silica". It is hard (7 on Mohs scale), so it is resistant to weathering. Its has no cleavage, but rather when broken goes through conchoidal fracture. When pure & without interference, quartz forms hexagonal crystals with pyramid- shaped ends.
- **Muscovite:** A common member of the mica family. Has a light color and is pearly in luster. It is very shiny so it can be identified by the sparkle it gives to rocks (like glitter).
- **Clay Minerals:** A range of complex minerals, like mica, that have sheet stuctures. Unlike other common silicates, they form on the surface as a result of chemical weathering (making up a large % of soil).

Silicate Groups: Heavy Silicates

B) The Dark Silicates "ferromagnesian":

As the name implies, they are dark and they contain iron "ferro" & magnesium "magnesian" in their structure. This makes them heavy, with a specific gravity of 3.2-3.6.

- **Olivine Group:** A family of high-temp. silicate minerals that are black to olive green in color and typically forms small granular crystals. Has a glassy luster, conchoidal fractures (single tetrahedron).
- **Pyroxene Group:** Most common member is Augite, a black mineral with 2 cleavage planes meeting at nearly 90 degrees (single chain).

  It is the dominant mineral in basalt.

Silicate Groups: Heavy Silicates

B) The Dark Silicates “ferromagnesian” (continued):

- **Amphibole Group:** Hornblende is the most common member, which is dark green to black, has 2 cleavage planes at 60 & 120 degrees, has similar appearance to Augite, & is found in igneous rocks.
- **Biotite:** A dark iron-rich member of the mica. It has a sheet structure that gives it an excellent cleavage in one direction. Its dark shiny appearance help distinguish it from other dark silicates. It is common in igneous rocks like granite.

Important Non-Silicate Minerals

- **Carbonates:**

Composed of the carbonate ion (CO_3^{-2}).

The two most common carbonates are **calcite ($CaCO_3$)** and **dolomite ($CaMg(CO3)_2$)**. They both have glassy luster & a hardness of 3-4.

They are hard to tell apart, but a way is to use dilute hydrochloric acid; calcite reacts very quickly (fizzes!) while dolomite reacts much slower.

When they are the dominant mineral, calcite forms the rock **"limestone"** and dolomite **"dolostone",** two very common sedimentary rocks.

Limestone has many uses including in Palestine: road aggregate, as building stone, & as the main ingredient in Portland cement.

Other Non silicates

- **Halides:** nonsilicates minerals frequently found in sedimentary rocks (ex: halite or salt NaCl).
- **Oxides (O^{-2})**
- **Sulfides (S^{-2})**
- **Sulfates (SO_4^{-2}):** ex: Gypsum used in plaster.
- **Native Elements** (such as gold, silver, diamond, etc.)

ENCE 231: Engineering Geology
Fall Semester 2017/2018

Department of Civil Engineering- Birzeit University, Palestine

Chapter 3: Igneous Rocks

Instructors: Saheem Murshid
Khalil M. Qatu

Igneous Rocks

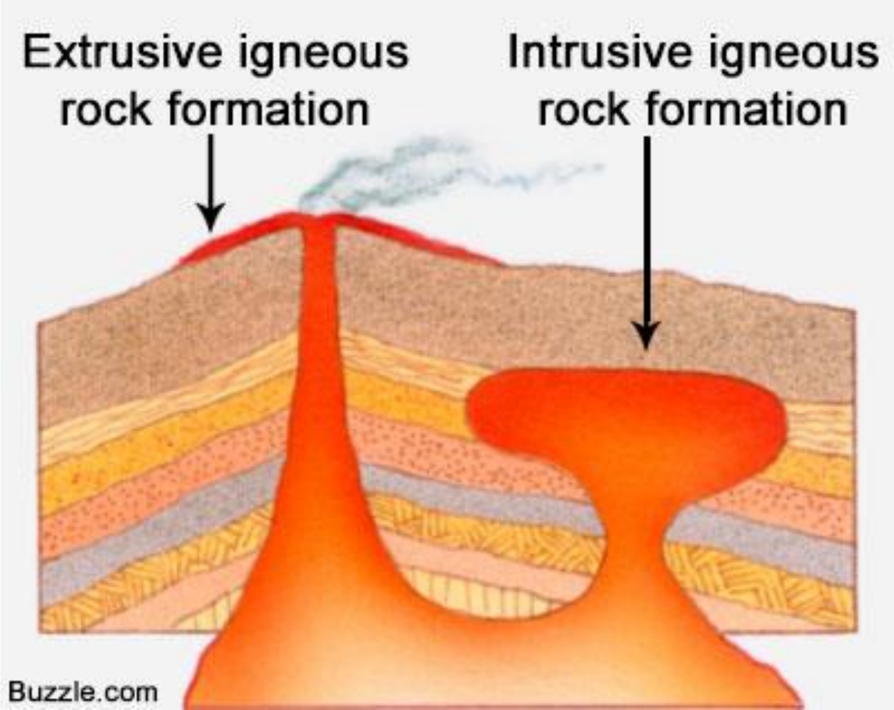
- Igneous Rocks (from latin "*ignis*", or fire) form as molten rock (Magma) cools and solidifies.

Magma: the Parent Material of Igneous Rocks

- Magma is the parent material of igneous rocks and it forms by a process called **partial melting**, which occurs at various levels within earth's crust & upper mantle (up to a depth of about 250 km).
- Magma that reaches earth's surface is called **Lava**. This happens due to magma's buoyancy, as it is less dense than surrounding rocks.
- When magma breaks through to the surface it can either be an explosive event/ eruption or a flow of liquid lava.

Extrusive vs. Intrusive Igneous Rocks

- **Extrusive Igneous Rocks (Volcanic):**
  Form when magma (lava) cools & solidified at the surface.
- **Intrusive Igneous Rocks (Plutonic):**
  Form when magma crystallizes at depth.
  This may be exposed at the surface through uplift & erosion.



Phases & Chemical Composition of Igneous Rocks

- **Liquid Component/ "Melt":** composed of ions of element commonly found in earth crust. Melt is mostly made up of silicon & oxygen that combine to form silica (SiO_2). Melt also contains (in lesser amount) Al, K, Ca, Na, Fe & Mg.
- **Solid Component:** composed of silicate minerals that have already crystallized from the melt. As a magma body cools, the size & number of crystals (solids) increase.
- **Gaseous Component/ "Volatiles":** the water vapor (H_2O), carbon dioxide (CO_2), and sulfur dioxide (SO_2) are the most common gases found in magma. Volatiles are materials that <u>readily vaporize</u> to form a gas <u>at the surface</u> (a low pressure environments).

From Magma to Crystalline Rock

- In a magma, ions & groups of ions move freely & randomly, join together and break apart constantly. **As the magma cools, the ions move more slowly, move closer & closer together, and eventually join together into orderly crystalline structures.** This process is called **Crystallization**.
- Since magma is predominantly composed of Si & O, **silicon-oxygen tetrahedra** (the basic building blocks of silicate minerals) form first. As magma cools more, the tetrahedra join with each other as well as other ions to form a variety of silicate minerals.

Classification of Igneous Rocks

- The crystallization of magma is much more complex than described here. The chemical composition of a melt/magma will change after the first minerals are formed (as they steal ions). So, the same magma will form a wide variety of minerals and rocks.
- However, it possible to classify igneous rocks based on mineral composition and the conditions they formed under (the environment).
- The environment of crystallization can be identified through the **size, shape & arrangement of mineral grains** (called **Texture**).

- So, we classify Igneous rocks by
  1) the Texture & 2) Mineral Composition.

Igneous Rock Textures: Rate of Cooling

- **Factors Affecting Mineral Crystal Size:**

1) The rate of magma cooling (the most important)
2) the amount of silica present
3) the amount of dissolved gases in the magma

- **Rate of Cooling:**

Slow Cooling: **The slower the cooling→ the larger the mineral crystals** are (but fewer in number).
A large body of magma located at depth may take hundreds of thousands of years to cool. Ions have time to move freely to eventually join to form one of the existing & preferred crystalline structures.
Fast/Rapid Cooling: as in the case of thin lava flows, the ions quickly lose their mobility & readily combine to form crystals (numerous but small intergrown crystals). High competition on ions because of short timeframe.

Extremely Fast Cooling: When molten rock is **quenched** quickly there is no time for ions to arrange into a crystalline network. Rocks that consist of unordered ions are referred to as **Glass**.

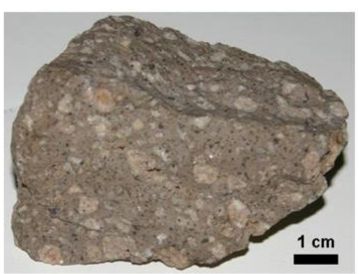
Igneous Rock Textures

Texture:

- Texture is how the rock look & feels.
- Texture is based on the size, shape, & distribution of minerals in a rock.

glassy | aphanitic | phaneritic | pegmatitic

6 Major Igneous Rock Textures



porphyritic

vesicular

Igneous Rock Textures: 1) Aphanitic

1) Aphanitic (fine-grained) Texture:

- Igneous rocks that **form at the surface** where small masses of magma cool rapidly.
- **The minerals are so small** that they can only be identified using a microscope, so they are **characterized by the color**: Light, intermediate, or dark in color. [Light colored are those containing light non-ferromagnesian silicate minerals]
- It common for gas bubbles to leave voids/holes on the surface of rocks (freeze as lava cools fast). They can be spherical or elongated & are called **"Vesicles"**.

Ex: Rhyolite Andesite Basalt

Igneous Rock Textures: 2) Phaneritic

2) Phaneritic (coarse or large-grained) Texture:

- Igneous rocks that **form far below the surface** when large masses of magma slowly cool.
- The minerals are **coarse-grained (large).** They are intergrown & can be individually identified without a microscope (although a small magnifying lens may be used in the field).
- Exposure at surface happens with either uplift or when erosion removes overlying layers.

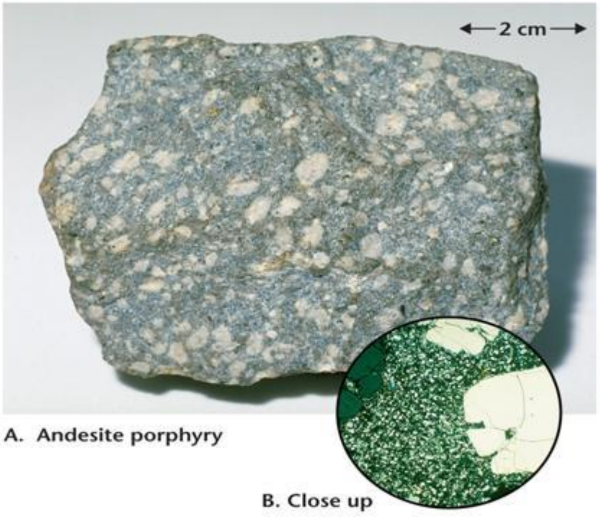
Ex: **Granite** **Diorite** **Peridotite**

Igneous Rock Textures: 3) Prophoritic

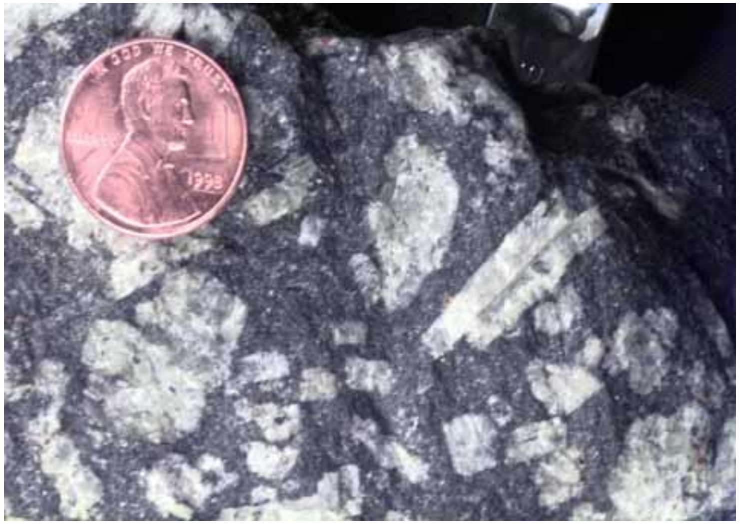
3) Porphyritic Texture:

- Igneous rocks that **form at depth** when large masses of magma **cool over a long span of time**(10s-100s of thousands of years) **but at different rates**.
- Large crystals form even before others form & with a change in environment (ex: volcanic eruption), the remaining liquid or lava cools quickly. The result is rocks that have **large crystals (Phenocrysts)** in a **matrix of smaller crystals (Groundmass)**. A rock with such a texture is termed Porphyry.

Ex: Rhyolite Porphyry



Andesite Porphyry



Basalt Porphyry

Igneous Rock Textures: 4) Glassy

4) Glassy Texture:

- Igneous rocks that **form when magma cools rapidly.** The magma is quenched, so **the ions do NOT have time to form orderly crystalline** (they "freeze").

Example Environment: A volcanic eruption (molten rock is ejected into the atmosphere).

Example Rock: **Obsidian**

Galssy Textures are most often produced in high silica content magmas (felsic or Granitic magmas)

Igneous Rock Textures: 5) Pyroclastic

5) Pyroclastic (fragmental) Texture:

- Igneous rocks that **form from the consolidation of individual rock fragments that are ejected during a violent volcanic eruption.**

- **Pyroclastic Rocks resemble sedimentary rocks in texture** (because they are made up of fragments and not crystals).

Tuff

Tambora Indonesia: largest volcanic eruption recorded in 1815 "the year without a summer"

Igneous Rock Textures: 6) Pegmatitic

6) Pegmatitic Texture:

Forms under special conditions, containing exceptionally coarse (large) mineral crystals, at least 1 cm in diameter but up to a few meters!

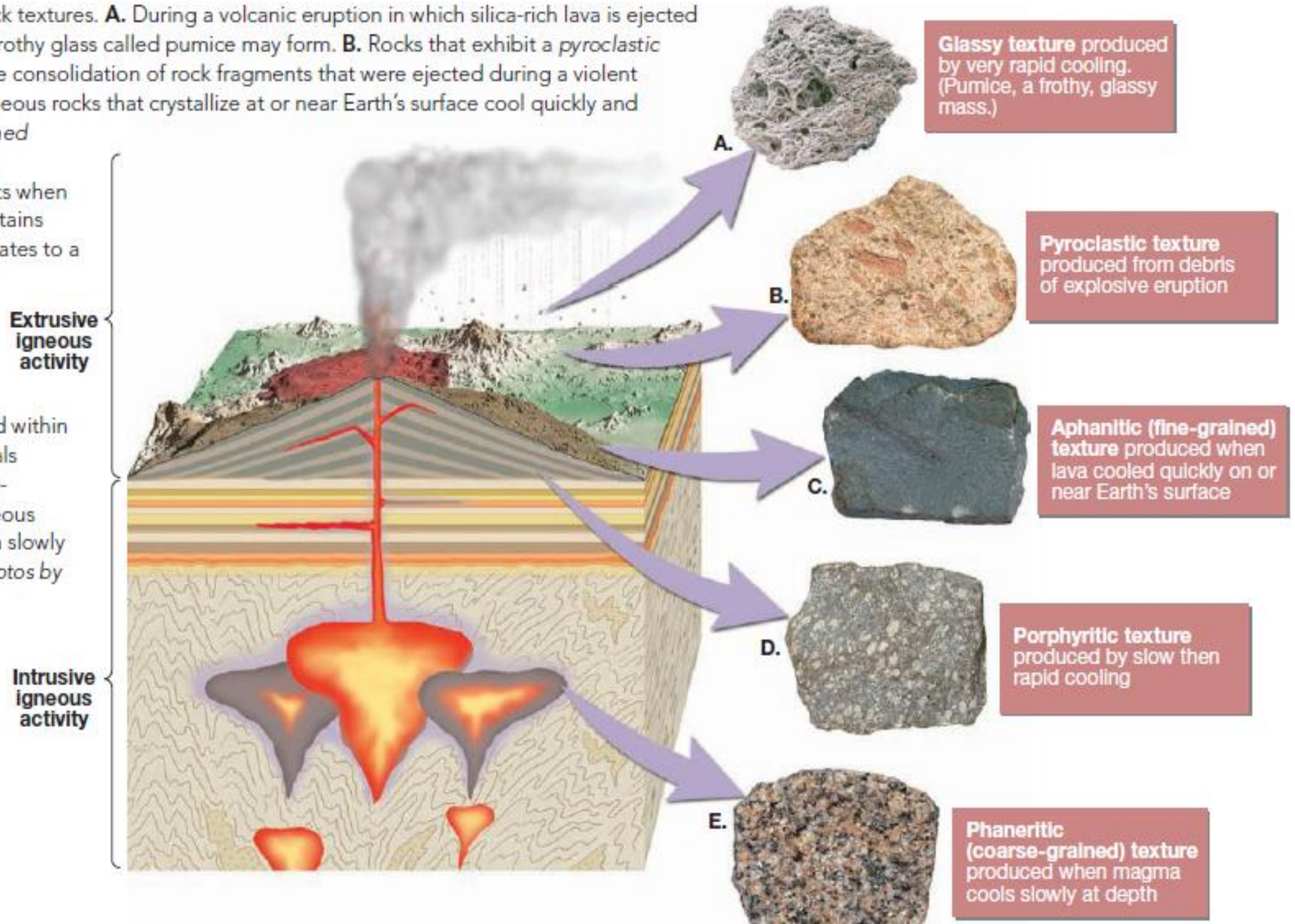
Crystallization Environ.:

They form in the late stages of crystallization when the magma melt is very fluid (containing water & other volatiles such as chlorine, fluorine, & sulfur). This allows the ions to move more freely & form large crystals. They are granitic/felsic in composition.

Their large size is NOT a result of long cooling, but the consequence of a fluid rich environment.

Igneous Rock Textures

FIGURE 3.4 Igneous rock textures. **A.** During a volcanic eruption in which silica-rich lava is ejected into the atmosphere, a frothy glass called pumice may form. **B.** Rocks that exhibit a *pyroclastic texture* are a result of the consolidation of rock fragments that were ejected during a violent volcanic eruption. **C.** Igneous rocks that crystallize at or near Earth's surface cool quickly and often exhibit a *fine-grained* (*aphanitic*) *texture*. **D.** A *porphyritic texture* results when magma that already contains some large crystals migrates to a new location where the rate of cooling increases. The resulting rock consists of larger crystals (*phenocrysts*) embedded within a matrix of smaller crystals (*groundmass*). **E.** *Coarse-grained* (*phaneritic*) igneous rocks form when magma slowly crystallizes at depth. *(Photos by E. J. Tarbuck)*



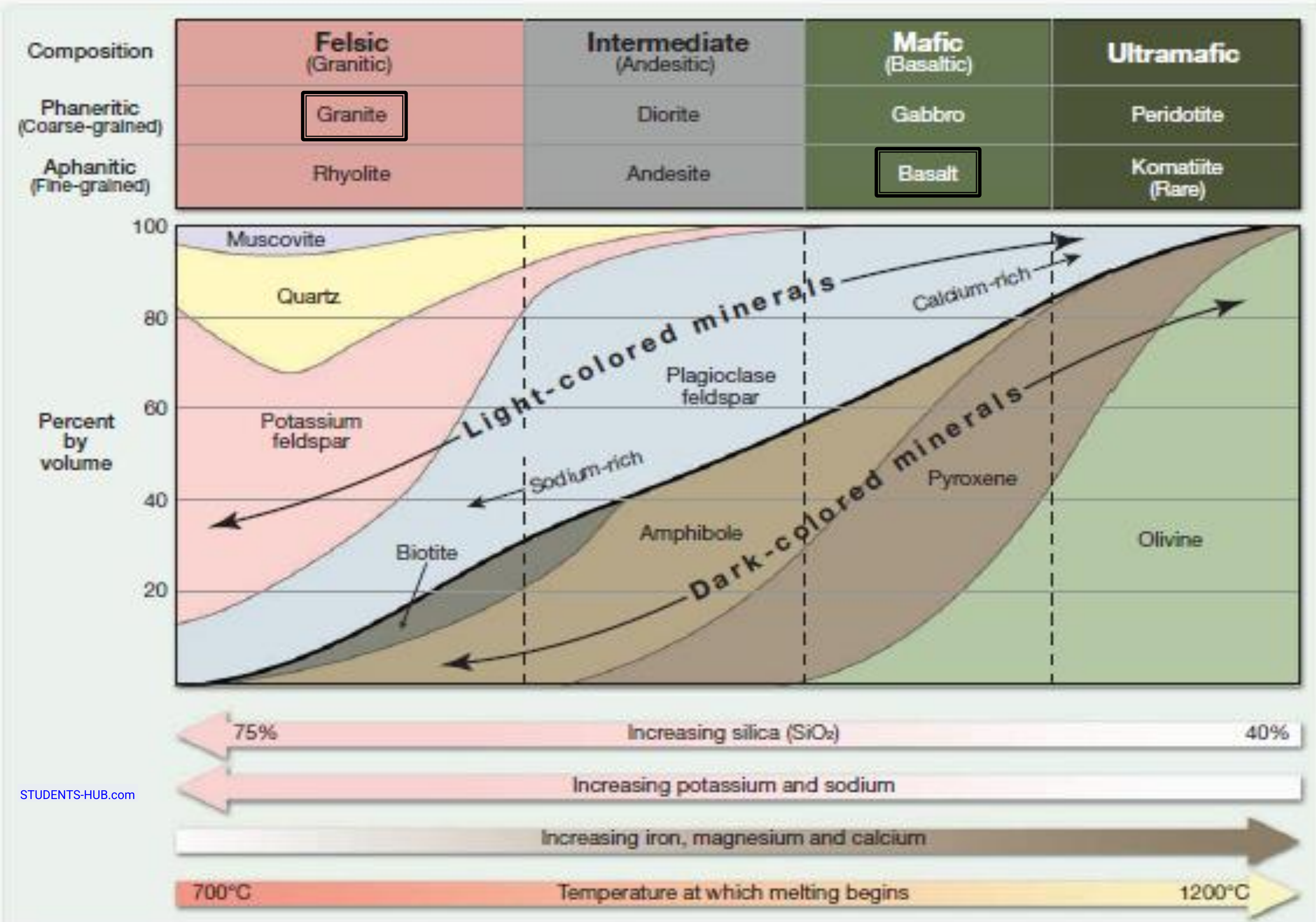
Classification of Igneous Rocks

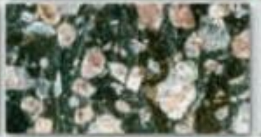
- We classify/ Name Igneous Rocks based on:

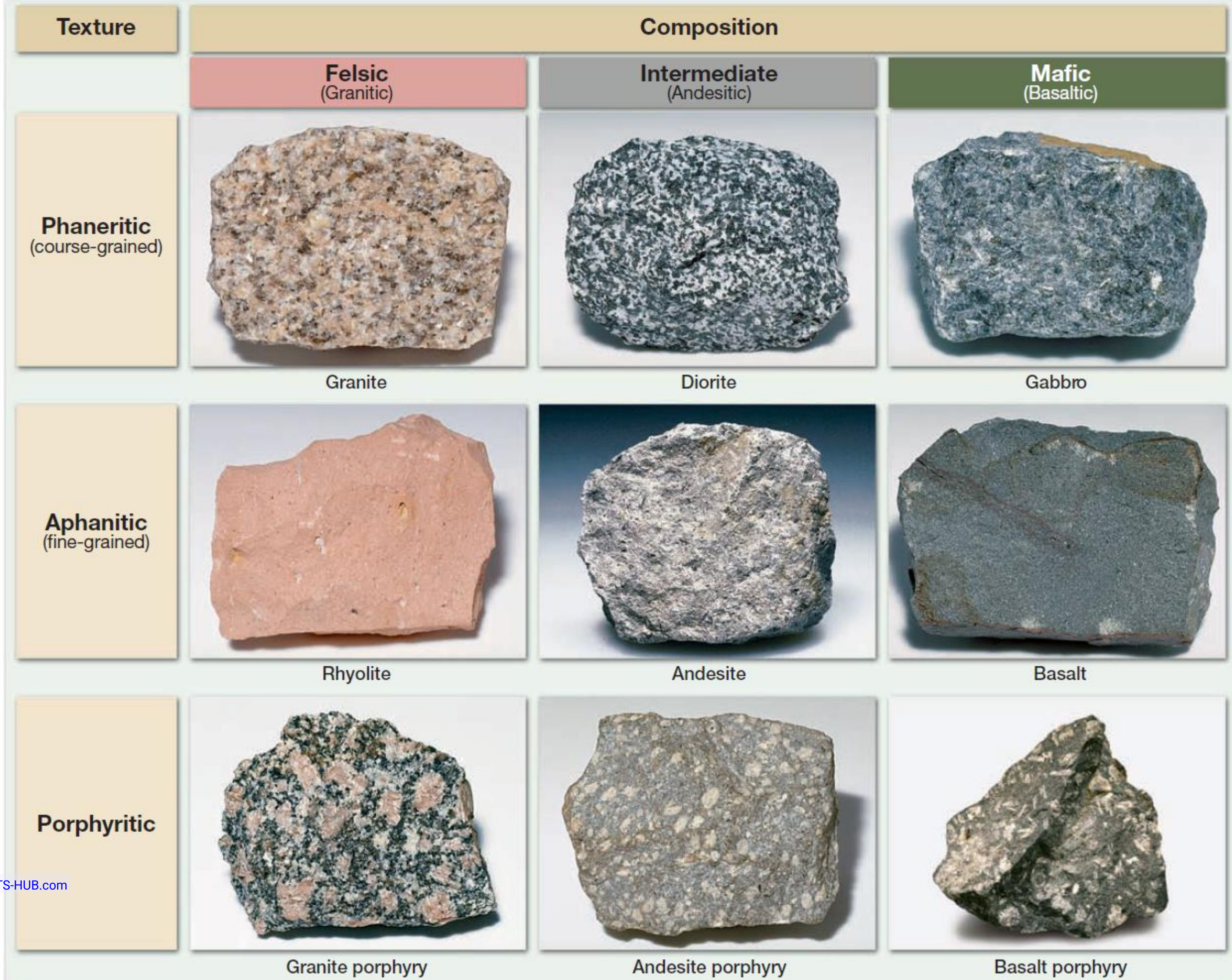
1) **Texture** (depends mainly on rate of cooling) √
2) **<u>Mineral Composition</u>** (depends on chemical composition) 

We will now discuss the different Igneous compositions (mineral composition)…

FIGURE 3.3 Mineralogy of common igneous rocks and the magmas from which they form. (After Dietrich, Daily, and Larsen)



Chemical Composition			Felsic (Granitic)	Intermediate (Andesitic)	Mafic (Basaltic)	Ultramafic
Dominant Minerals			Quartz Potassium feldspar Sodium-rich plagioclase feldspar	Amphibole Sodium- and calcium-rich plagioclase feldspar	Pyroxene Calcium-rich plagioclase feldspar	Olivine Pyroxene
Accessory Minerals			Amphibole Muscovite Biotite	Pyroxene Biotite	Amphibole Olivine	Calcium-rich plagioclase feldspar
TEXTURE	Phaneritic (coarse-grained)		**Granite**	**Diorite**	**Gabbro**	**Peridotite**
TEXTURE	Aphanitic (fine-grained)		**Rhyolite**	**Andesite**	**Basalt**	**Komatiite** (rare)
TEXTURE	Porphyritic		"Porphyritic" precedes any of the above names whenever there are appreciable phenocrysts			Uncommon
TEXTURE	Glassy		**Obsidian** (compact glass) **Pumice** (frothy glass)			
TEXTURE	Pyroclastic (fragmental)		**Tuff** (fragments less than 2 mm) **Volcanic Breccia** (fragments greater than 2 mm)			
Rock Color (based on % of dark minerals)			0% to 25%	25% to 45%	45% to 85%	85% to 100%


Texture
Composition
Felsic
(Granitic)
Intermediate
(Andesitic)
Mafic
(Basaltic)
Phaneritic
(course-grained)
Granite
Diorite
Gabbro
Aphanitic
(fine-grained)
Rhyolite
Andesite
Basalt
Porphyritic
Granite porphyry
Andesite porphyry
Basalt porphyry

Igneous Compositions

- Igneous Rocks are divided into groups according to the amount of light-colored silicate minerals in them (Or amount of Silica).
- Referring to diagram in previous page, Igneous rocks will be divided as follows:

1) Felsic (Or Granitic) **[Highest Silica Content]**
2) Intermediate
3) Mafic (Or Basaltic)
4) Ultramafic **[Least Silica Content]**

Igneous Compositions: Granitic vs. Basaltic Compositions

Igneous Rocks

- Granitic (Felsic)
- Intermediate
- Basaltic (Mafic)
- Ultramafic

Granitic (Felsic)

- Almost entirely composed of light-colored silicates (quartz & feldspar).

[SILICA RICH]

- Referred to as having **Granitic composition** or **Felsic Rocks** (feldspar + silica or quartz).

- Light in color & density.

- Major constituents of Earth's crust.

Basaltic (Mafic)

- Contain substantial amount of dark silicate minerals & calcium rich plagioclase feldspar (but no quartz).

[SILICA POOR]

- **Referred to as having basaltic composition or Mafic Rocks** (Magnesium + Ferrum or iron).

- Darker & greater in density than granitic rock

- Major constituent of ocean floor.

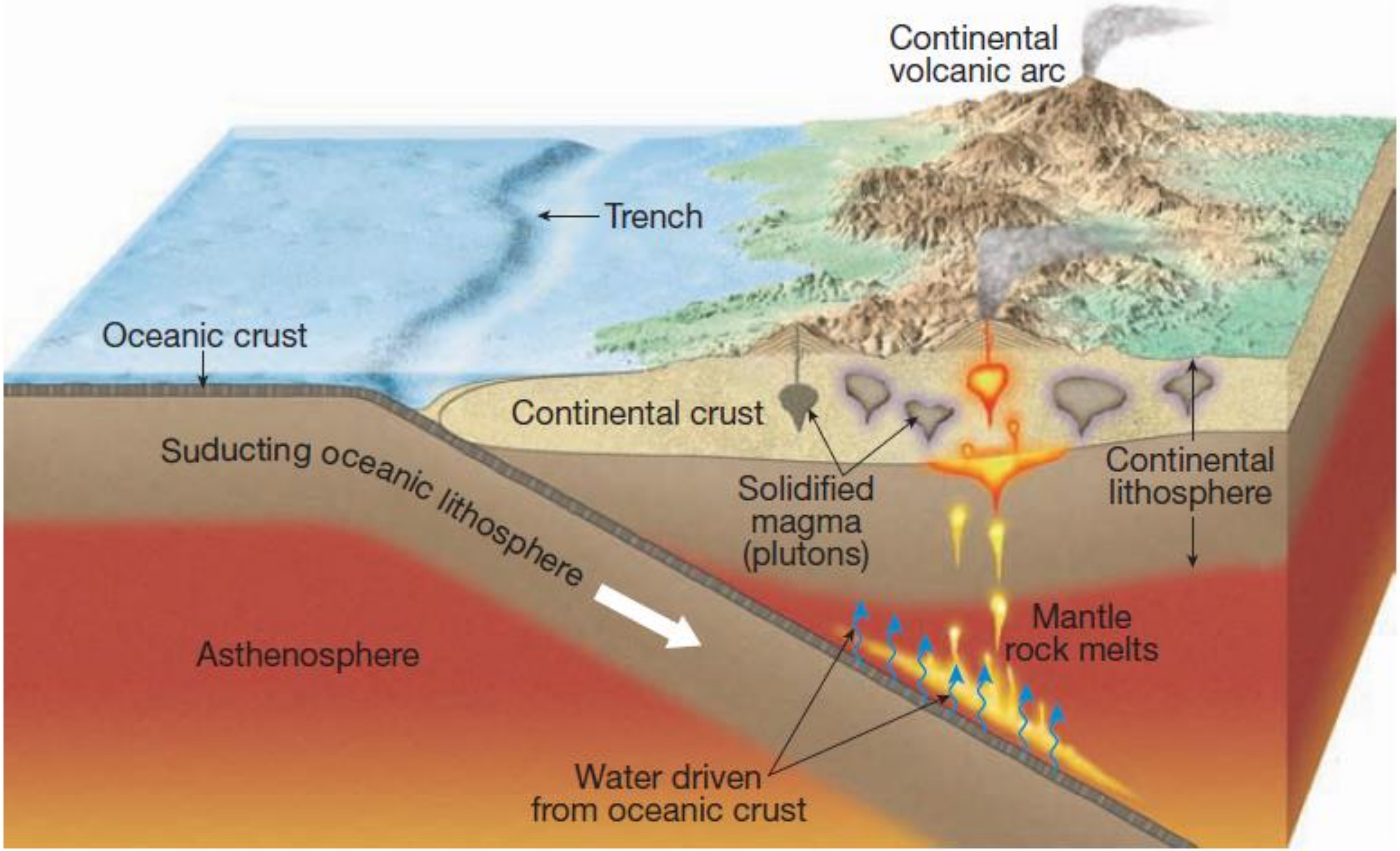


FIGURE 3.19 As an oceanic plate descends into the mantle, water and other volatiles are driven from the subducting crustal rocks into the mantle above. These volatiles lower the melting temperature of hot mantle rock sufficiently to trigger melting.

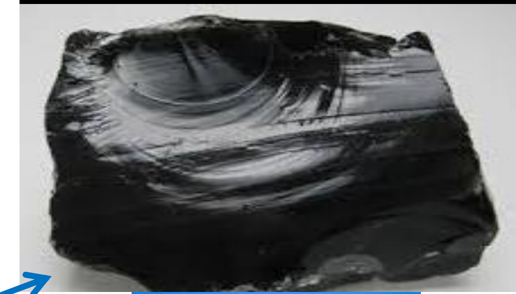
Naming Igneous Rocks: Felsic

- <u>**Granitic Rocks (Felsic):**</u>

➢ **Granite:** the best known of all igneous rocks due to its beauty (used as kitchens tops) & abundance. A <u>Phaneritic textured</u> (coarse- grained) igneous rock composed of <u>Quartz (~ 25%) & Feldspar (~65%)</u> [K-Feldsp. & Na-Feldsp.]

➢ **Rhyolite:** Similar to Granite, it is also rich in <u>light-colored silicates</u>. However, it has an <u>Aphanitic texture</u> (fine-grained), because it is the extrusive equivalent of granite as it cools rapidly. Also has glassy fragments & voids indicating this rapid cooling.

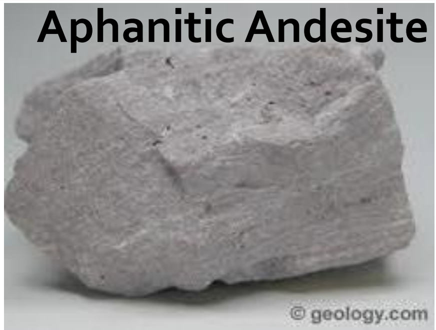
➢ **Obsidian:** A glassy textured rock. <u>Although it is dark-colored, it is a felsic rock (high silica)</u> that forms when lava is quenched/ cools quickly.

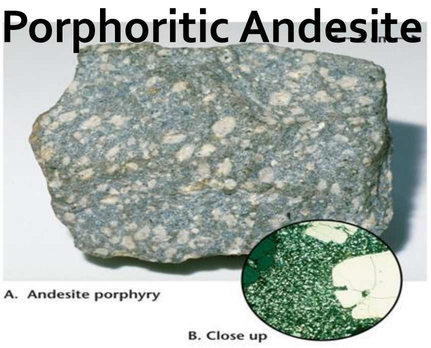


➢ **Pumice:** A grey-colored, glassy-textured felsic rock (high silica) that forms when <u>large amounts of gas escape through lava</u>. It floats on water!

Naming Igneous Rocks: Intermediate

- **<u>Intermediate (Andesitic):</u>**
  - Andesite: A medium-gray, fine-grained (<u>Aphanitic</u>) rock of volcanic origin. Its named after the Andes Mountain where it is abundant. Andesite also commonly exhibits a <u>Porphoritic Texture</u>.
  - Diorite: a coarse-grained (Phaneritic) plutonic/ intrusive igneous rock. It is distinguished from Granite by its mineral composition→ lacking quartz crystals (the salt & pepper look is sodium feldspar & amphibole).





Naming Igneous Rocks: Mafic

- **Mafic (Basaltic) Rocks:**
  Contain low silica, high iron, magnesium, calcuim. They are darker and denser than felsic rocks.

- **Basalt:** very dark green- black fine-grained (Aphanitic) volcanic rock composed primarily of pyroxene & Ca-rich fedspar, & lesser amounts of amphibole & olivine. May also be Porphyritic. It is the most common extrusive rock & major constituent of oceanic floor (upper layer).

- **Gabbro:** An instrusive→ coarse- grained (Phaneritic) equivalent of basalt. Contains same minerals as balsalt & also a major constituent of oceanic crust.

Naming Igneous Rocks: Ultramafic

- **Ultramafic (Basaltic) Rocks:**
  Composed entirely of ferro-magnesian minerals such as **Olivine (largest portion)**, Pyroxene, and some Ca-rich Plagioclase Feldspar.

- **Peridotite:** A major constituent of the upper mantle.

Naming Igneous Rocks: Other

- **Pyroclastic Rocks:** (A Texture NOT a Composition)

Forms from the joining of fragments in a violent volcanic eruption.

- **Tuff:** composed mainly of tiny ash-sized fragments that later cemented together. If the ash was hot enough to fuse the fragments, it is called *Welded Tuff*.
- **Volcanic Breccia:** similar to Tuff, except the fragments/particles are larger than ash.

Eng. Geology: Physical & Mechanical Properties of Igneous Rocks

- We discuss the engineering properties of igneous rocks (and how it compares to those of Sedimentary & Metamorphic Rocks).
- The properties to be used are as follows:

- Specific Gravity (S.G)
- Absorption (%)
- Coefficient of Permeability (k)
- Compressive Strength (Co)
- Tensile Strength (Ct)
- Poisson's Ratio (μ)
- Young's Modulus of Elasticity (E)
- Sonic Velocity

ENCE 231: Engineering Geology
Fall Semester 2017/2018

Department of Civil Engineering-
Birzeit University, Palestine

Chapter 5: Weathering & Soils

Instructor: Saheem Murshid
Dr. Khalil M. Qatu

Earth's External & Internal Processes

- Earth is a dynamic body (constantly changing):

- **Internal Processes** (derive energy from the **interior** of the Earth): Elevate the earth's surface through mountain building & volcanoes
- **External Processes** (derive energy from the Sun): Oppose internal processes; breaking rocks apart transforming it into sediments and lowering mountains by moving debris to lower elevations. They take place at or near the earth's surface (hence called *external*) & and we discussed in chapter 1 are an integral part of the *rock cycle*.

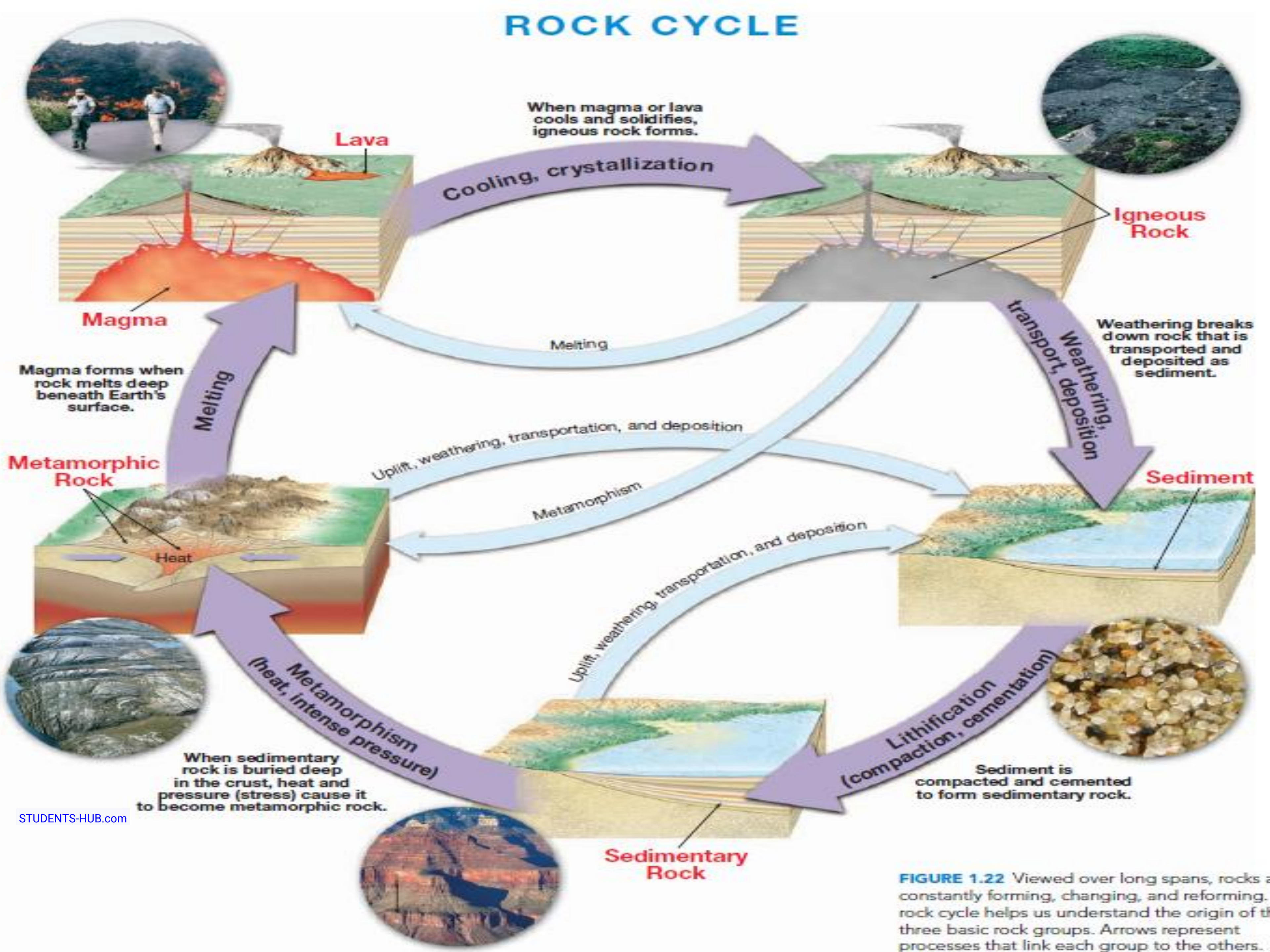


FIGURE 1.22 Viewed over long spans, rocks a constantly forming, changing, and reforming. rock cycle helps us understand the origin of th three basic rock groups. Arrows represent processes that link each group to the others.

Internal Processes

- Internal Processes include the following:

1) **Weathering:** The physical breakdown (disintegration) and chemical alteration (decomposition) of rocks at or near the surface.
2) **Mass Wasting:** The transfer of rock and soil down slope by gravity.
3) **Erosion:** The physical removal of material by mobile agents such as water, wind, or ice.

FIGURE 5.1 Arizona's Monument Valley. When weathering accentuates differences in rocks, spectacular landforms are sometimes created. As the rock gradually disintegrates and decomposes, mass wasting and erosion remove the products of weathering. *(Photo by Michael Collier)*

Weathering

- Weathering takes place all around us. It may seem like a slow insignificant process, however it is an integral part of the *Rock Cycle*, so it is an important process in the Earth System…
  Example: weathering even affects concrete structures.
- Weathering is the response of Earth's materials to a change in environment.
  Example: Intrusive/Plutonic rock uplifted & exposed.
- Weathering occurs both **when rock is mechanically fragmented (disintegrated)→ Mechanical Weathering;** and **when chemically altered (decomposed)→ Chemical Weathering**
  Example: piece of paper ripped into pieces (mechanical) or burned (chemical)

Weathering

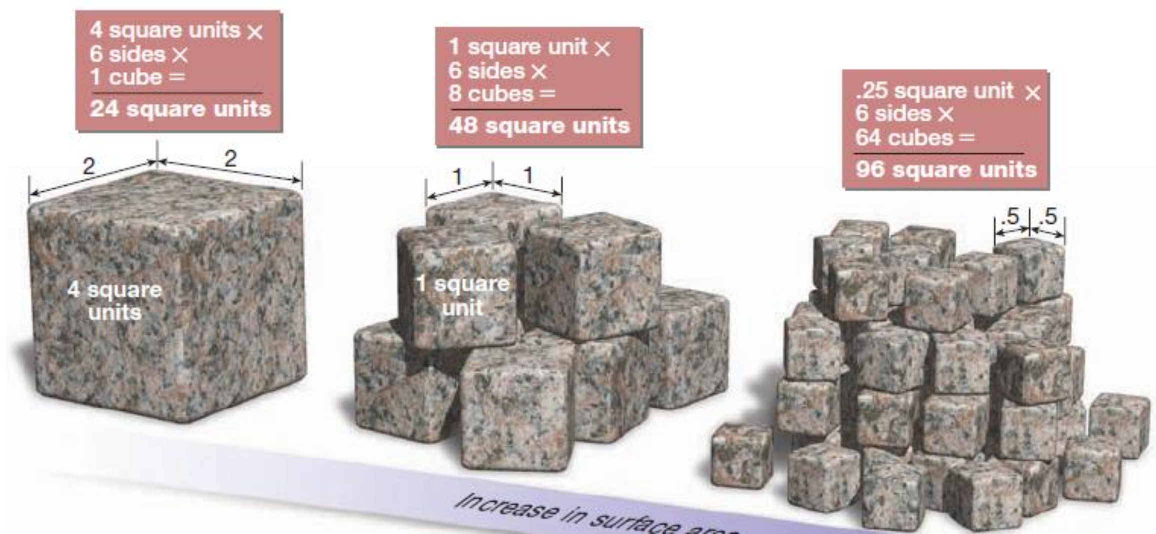
So…

- **Mechanical Weathering:** accomplished by physical forces that break rock into smaller and smaller pieces without changing the rock's mineral composition.
- **Chemical Weathering:** involves a chemical transformation of rock into one or more new compounds.

***Note:** The two types of weathering do not necessarily occur separately. They may both take place simultaneously (at the same time) or affect the rate of each other.

1) Mechanical Weathering

- When rock undergoes mechanical weathering it is broken into smaller and smaller pieces, each retaining the characteristics of the original material, so the result is many small pieces from a single large one.
- This also results in a larger surface area exposed to chemical weathering.



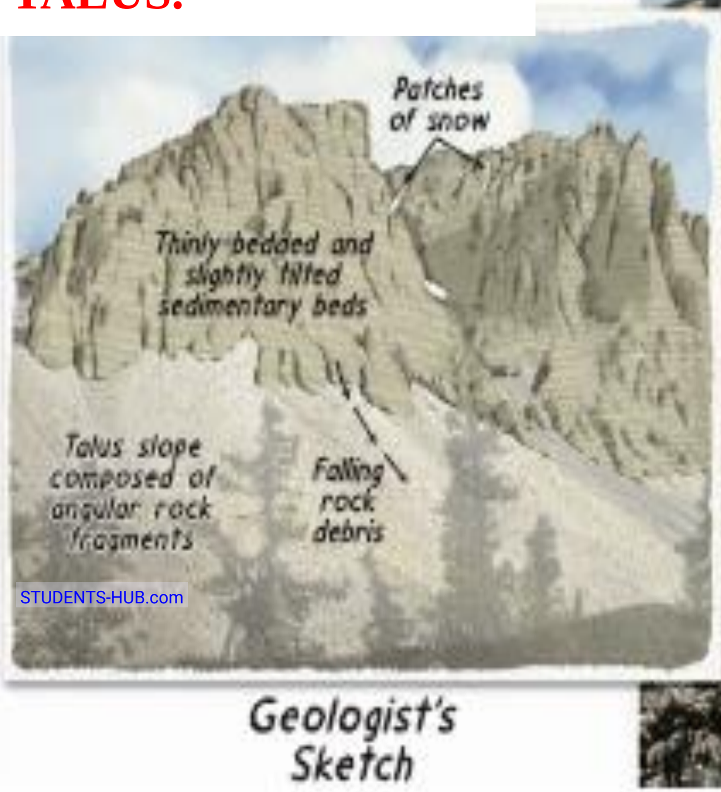
1) Mechanical Weathering:
a. Frost Wedging

- Frost Wedging is an important process of mechanical weathering.
- It occurs with repeated **freeze-thaw cycles**.
- How? Well, consider that liquid water has a unique property of expanding about 9% upon freezing, which exerts a tremendous outward force.

Ex: putting a full bottle of water in the freezer.

- Similarly, in nature water penetrates cracks in rock masses, upon freezing it expands & enlarges the openings by exerting a strong outward force. After many freeze-thaw cycles, it causes the rock to break into angular fragments.

Frost wedging is most common & effective in mountainous areas as a daily freeze-thaw cycle often exists.
Sections of the rock that fall to the base of steep mountains, forming cone-shaped debris piles called TALUS.

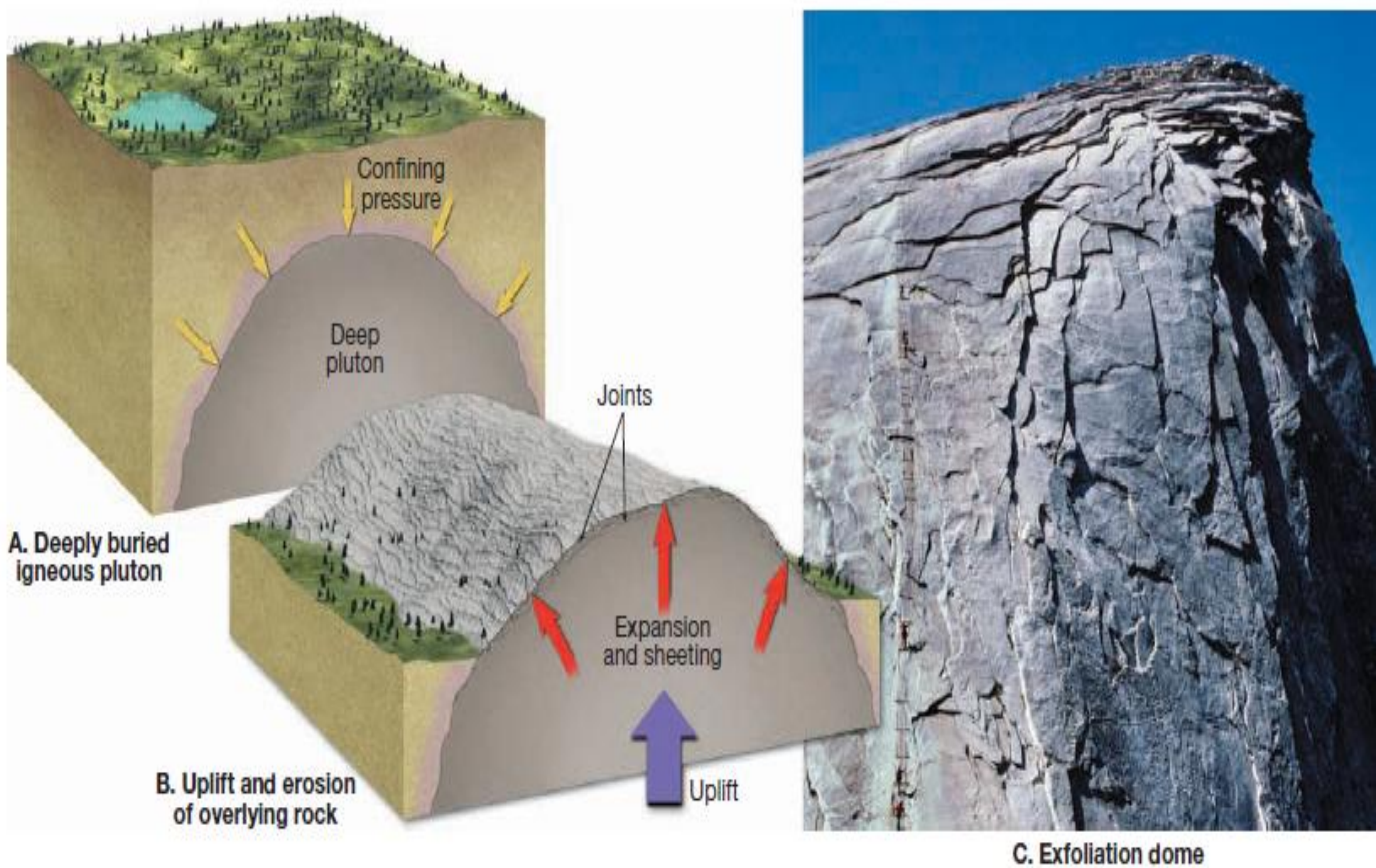


1) Mechanical Weathering:
b. Unloading

- Unloading occurs when large masses of igneous rock (particularly granites) are exposed to erosion. Large slabs begin to break loose generating an onion-like layering called **sheeting**.
- The main reason this occurs is because of **unloading** or a great reduction in pressure when overlaying rock is eroded away, so the lower rock starts expanding or moving outward, then collapsing. Also may occur in underground mines where the confining pressure is removed. the outer layers expand more than the rock below and thus separate from the rock body
- Continued weathering eventually creates structures called **exfoliation domes**.

1) Mechanical Weathering: b. Unloading

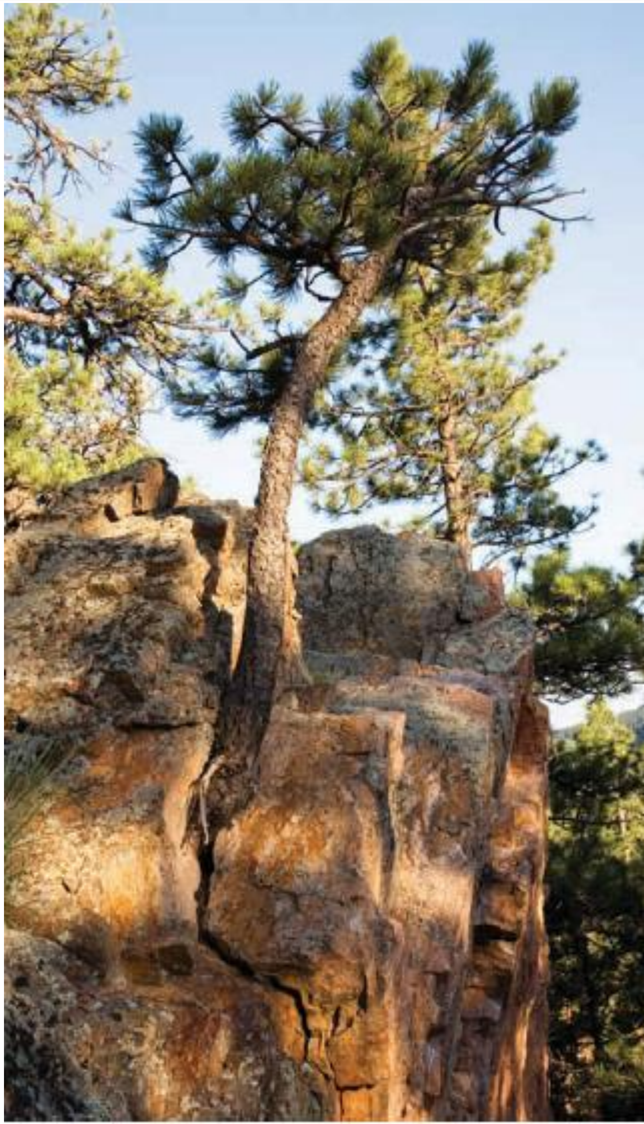
FIGURE 5.5 Sheeting is caused by the expansion of crystalline rock as erosion removes the overlying material. When the deeply buried pluton in **A.** is exposed at the surface following uplift and erosion in **B.**, the igneous mass fractures into thin slabs. The photo in **C.** is of the summit of Half Dome in Yosemite National Park, California. It is an exfoliation dome and illustrates the onionlike layers created by sheeting. *(Photo by Gary Moon/agefotostock)*



1) Mechanical Weathering:
c. Biological Activity

- **Biological or Organic Activity is the activity of organisms that can cause rocks to break. It contributes to both mechanical & chemical weathering.**
- Examples include the tree roots wedging rocks apart by growing through fractures in search for water & minerals, burrowing animals move fresh material onto the surface to be weathered, or even humans when blasting is done for mining.
- Other organisms such as fungi & lichens may produce acids that cause **decomposition** to certain rocks (chemical weathering).

- Some mineral-eating bacteria may break chemical bonds of minerals to feed on certain compounds.



2) Chemical Weathering:

- Chemical weathering involves complex processes that break down rock components as well as the internal structures of minerals (even turning them into new minerals through breaking of chemical bonds & internal structures…may add and remove elements).
- During this transformation, the original rock decomposes into substances that are stable at the surface environment.

2) Chemical Weathering:
a. H2O & Carbonic Acid

- Water is the most important agent of chemical weathering.
- Pure water is nonreactive, but it is activated with a small amount of dissolved material.

- Oxygen dissolved in water will oxidize material it comes in contact with.

Ex: Rusting of nail or iron barrel. Similarly, rock containing iron-rich minerals also oxidize.

FIGURE 5.8 Iron reacts with oxygen to form iron oxide as seen on these rusted barrels. *(Photo by Steven Robertson/iStockphoto)*

2) Chemical Weathering:
a. H_2O & Carbonic Acid: <u>Limestone Weathering</u>

- Carbon dioxide (CO_2) [from the atmosphere & decaying organisms in soil] dissolves in water (H_2O) forming carbonic acid (H_2CO_3), the same acid in soft drinks.

$$H_2O + CO_2 \rightarrow H_2CO_3 \text{ (Carbonic acid)}$$

- Carbonic acid ionizes to form the very reactive hydrogen ion (H^+) and the bicarbonate ion (HCO_3), which chemically attack or dissolve certain rocks such as limestone.
  Limestone caves form through this process.

$$CaCO_3 + (H^+ + HCO_3^-) \longrightarrow Ca^{2+} + 2HCO_3^-$$

calcite	carbonic acid	calcium ion	bicarbonate ion
Limestone			

Soreq Cave, West of Jerusalem, Palestine

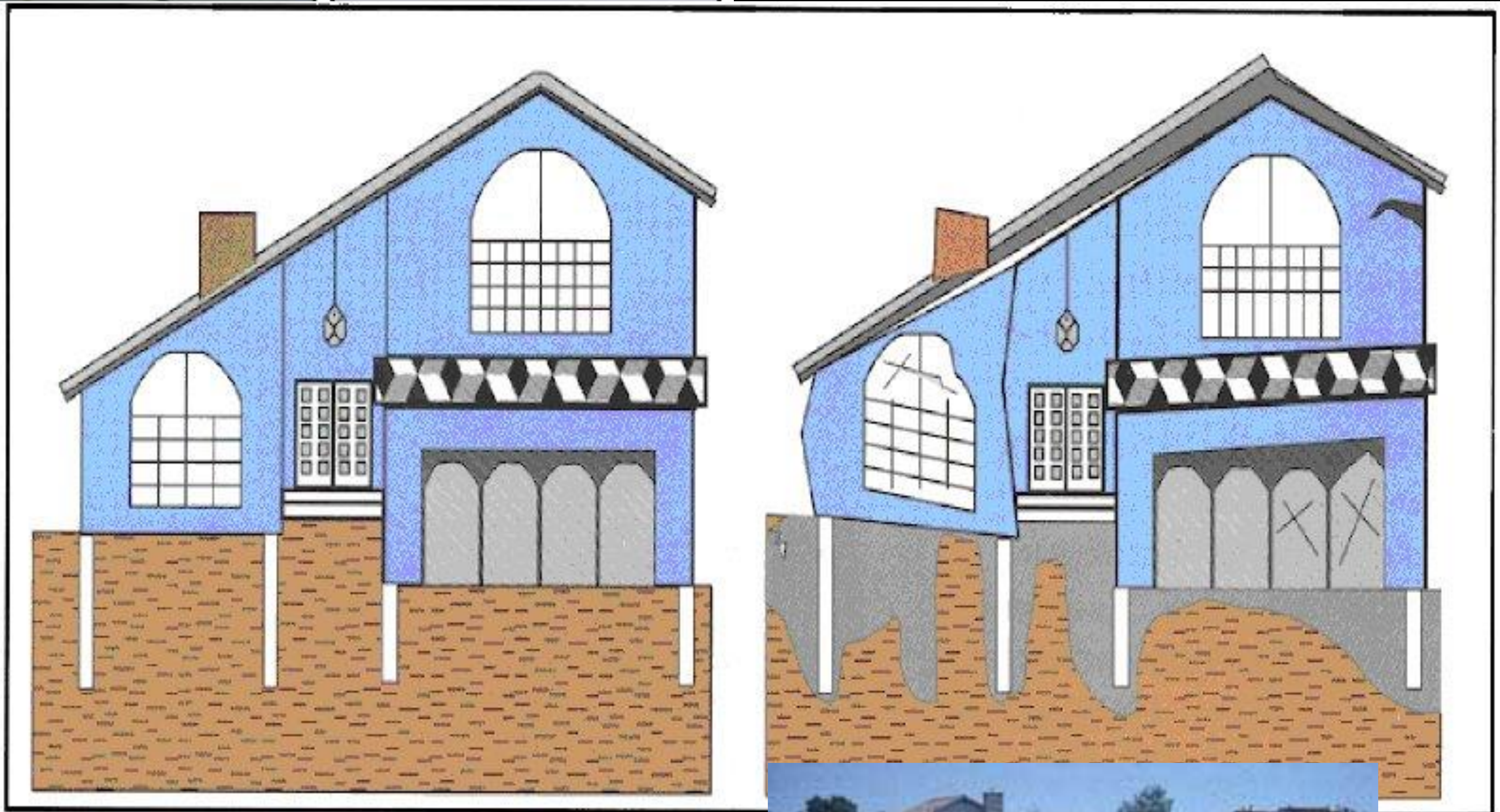
2) Chemical Weathering:
a. H2O & Carbonic Acid: Granite Weathering

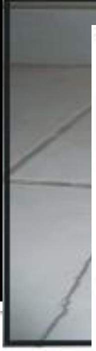
- Granite also weathers chemically via carbonic acid (H2CO3)…
- Remember that granite is mainly composed of Quartz & K-feldspar. The weathering of k-feldspar takes place as follows:

$$\underset{\text{potassium feldspar}}{2\,KAlSi_3O_8} + \underset{\text{carbonic acid}}{2(H^+ + HCO_3^-)} + \underset{\text{water}}{H_2O} \longrightarrow \underset{\text{clay mineral}}{Al_2Si_2O_5(OH)_4} + \underbrace{\underset{\text{potassium ion}}{2K^+} + \underset{\text{bicarbonate ion}}{2HCO_3^-} + \underset{\text{silica ion}}{4SiO_2}}_{\text{in solution}}$$

- In this reaction, the hydrogen ions (H+) attack and replace potassium ions (K+) in the feldspar structure, thereby disrupting the crystalline network. Once removed, the potassium is available as a nutrient for plants or becomes the soluble salt potassium bicarbonate (KHCO3) which may be incorporated into other minerals or carried to the ocean in dissolved form by streams.

- The most abundant end products of the chemical breakdown of feldspar are **residual clay minerals** (such as kaolinite, illite, montmorillonite). Clay minerals are very stable under surface conditions, so they make up a high percentage of the inorganic material in soils. Moreover, the most abundant sedimentary rock, shale, contains a high proportion of clay minerals.





E

F

G

H

Chemical Weathering:
- H_2O & Carbonic Acid: Granite Weathering

- Another product of the weathering of granite may be dissolved silica eventually precipitates as chert or flint or is carried to the ocean to be used by organisms to build hard shells.
- On the other hand, Quartz, the other main component of granite, **is *very resistant* to chemical weathering**; it remains substantially unchanged when attacked by weak acidic solutions. As a result, when granite weathers, the feldspar crystals dull and slowly turn to clay, releasing the once-interlocked quartz grains, which still retain their fresh, glassy appearance. Although some quartz remains in the soil, much is eventually transported to the sea or to other sites of deposition, where it becomes the main constituent of such features as sandy beaches and sand dunes. In time these quartz grains may become lithified to form the **sedimentary rock *Sandstone***.

Chemical Weathering: Weathering of Silicate Minerals

TABLE 5.1

Products of Weathering

Mineral	Residual Products	Material in Solution
Quartz	Quartz grains	Silica
Feldspars	Clay minerals	Silica, K^+, Na^+, Ca^{2+}
Amphibole (hornblende)	Clay minerals Limonite Hematite	Silica, Ca^{2+}, Mg^{2+}
Olivine	Limonite Hematite	Silica, Mg^{2+}

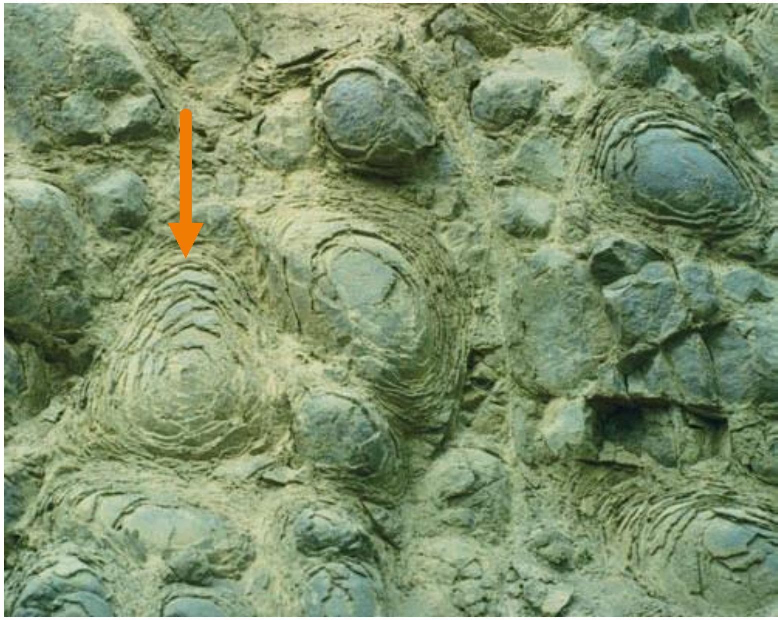
Chemical Weathering:
- Spheroidal Weathering

- Other than altering the internal structure of minerals, chemical weathering <u>also causes physical changes.</u>
- **Spherical Weathering** occurs when angular rock masses weather chemically (i.e. water enters along joints), the corners and edges of the angular blocks gradually become more rounded and tend to take on a spherical shape.

- The corners are attacked most readily because of their greater surface area, as compared to the edges and faces.

Chemical Weathering:
- Spheroidal Weathering

- Sometimes during the formation of spheroidal boulders, **successive shells separate from the rock's main body**. Eventually the outer shells break off, allowing the chemical-weathering activity to penetrate deeper into the boulder.
- This spherical scaling results because the minerals in the **rock increase in size through the addition of water to their structure** as they weather to clay. This increased bulk **exerts an outward force** that causes concentric layers of rock to break loose and fall off.
- This type of spheroidal weathering, in which shells spall off, should not be confused with the phenomenon of sheeting discussed earlier.



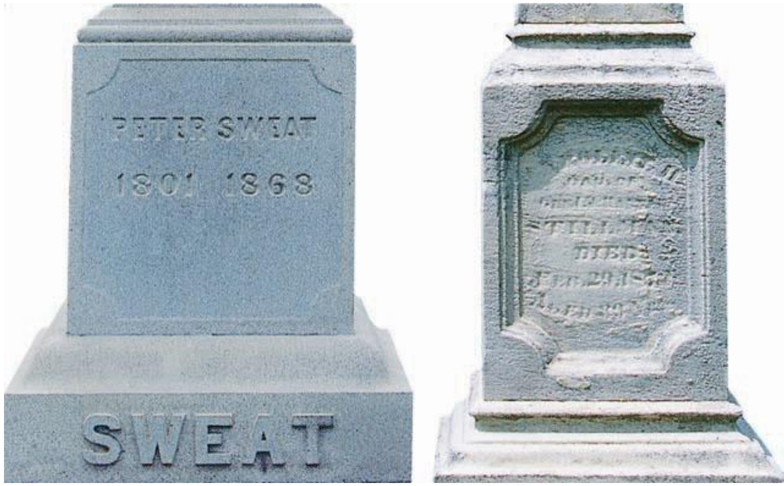
Rates of Weathering

- Rocks may weather at different rates (just like earth processes at large).
- We already saw how mechanical weathering increases the rate of chemical weathering by exposing more surface area of a rock it breaks.
- **Other Factors affecting the rate of weathering:**

1) Rock Characteristics
2) Climate

Rates of Weathering: 1) Rock Characteristics

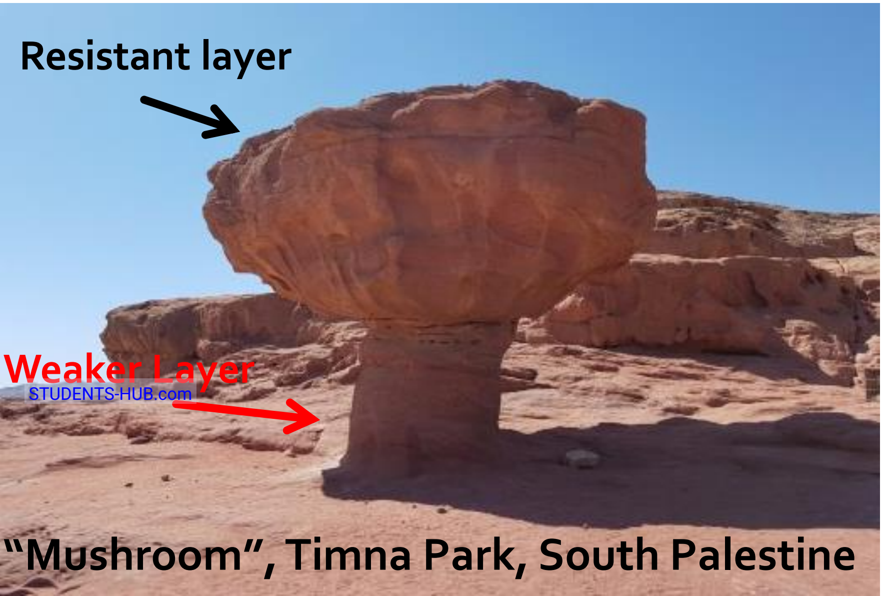
- **Rock characteristics** includes all the chemical traits of a rock, including its mineral composition and solubility.
- In rock masses joints (cracks) have an influence.
- Variation in weathering due to mineral composition is clear. For instance **granite** (composed of silicate minerals) is far more resistant to weathering than **marble** (composed of calcium carbonate). Example: the tombstone in the picture.
- **In silicates**, weathering rates are in the same order as that for crystallization according to Bowen's reaction series. Olivine (the first to crystallize) is the least resistant to chemical weathering, while quartz (the last to crystallize) is the most resistant.



Granite Marble

Rates of Weathering:
1) Rock Characteristics→ Differential Weathering

- Different Rock Characteristics (among other factors such as joints) cause rocks not to weather uniformly. When different rock type weather differently in a certain, we call the process **Differential Weathering**.



"Mushroom", Timna Park, South Palestine

Rates of Weathering: 2) Climate

- Climate affects the rates of weathering.
- As discussed earlier, **frost wedging** is most effective in cold regions with many freeze-thaw cycle.
- **Temperature & Moisture** also have an influence; regions with **warm temperature & abundant** moisture encourage chemical weathering, partly because they typically have a lot of vegetation, which feed nearby soils with decaying organic matter, from which chemically active fluids such as **carbonic & humic acids** are derived and cause weathering.

  Chemical weathering is not as effective in polar regions because fluids are locked up in ice. In deserts there isn't enough moisture for chemical weathering.

- **Human activity** may have an impact: **CO_2 emissions** into the atmosphere cause **acid rain**, which is carries out chemical weathering.

Soil

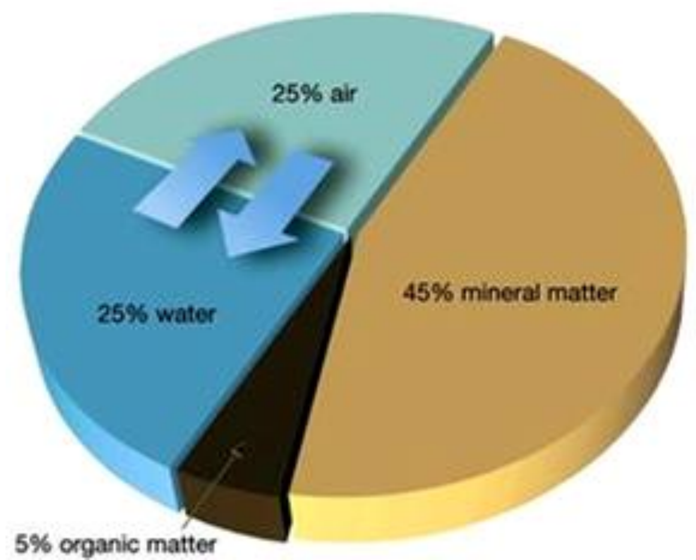
- Soil extremely important for life & in a way is an interface (boundary) between all of earth's spheres
- **Soil covers most of land surfaces and is composed of inorganic (regolith)& organic matter, water, and air.**
- **Regolith:** the layer of rock & mineral fragments produced by weathering.
  In relation to regolith, Soil is a combination of mineral and organic matter, water, and air can be perceived as the portion of regolith that supports plant growth after maturing & acquiring organic matter.

Soil Components

- Although variable from place to place, a good-quality soil's composition (**<u>by volume</u>**) is as follows:

- 45%: Disintegrated & decomposed rock (mineral matter or regolith).
- 5%: Organic matter or *humus*, the decayed remains of animal & plant life.
- 25%: Water
- 25%: Air

50%: Pore space



Soil Components

- **Organic/ humus Portion:** Important as it is the source of nutrients for plants & for the soil's ability to retain water.
- **Pores:** provide the space for water & air to circulate & feed plants.

  Soil water is far from being "pure" as it is a complex solution containing many soluble nutrients supplied to plants in a form they can use. It also provides necessary moisture for chemical reactions that sustain life.

  Soil Air in the pores is the source of necessary oxygen & carbon dioxide for microorganisms and plants.

Controls of Soil Formation

- Soil is the product of complex and interrelated factors & processes. The most important are:

- **Parent Material**
- **Time**
- **Climate**
- **Plants & Animals**
- **Topography (التضاريس)**

Controls of Soil Formation: 1) Parent Material

- **Parent Material:** It is the source of mineral matter, from which soils develop. It gets weathered/eroded through physical & chemical changes as the processes of soil formation progress.
- The source of parent material may be:

- **Underlying Bedrock**→ Produce ***"Residual Soils"***
- **Unconsolidated Sediment/deposits**→ Produce ***"Transported Soils"***

- The nature of parent material influences soil as follows:

  1) Rate of weathering: Consequently, rate of soil formation. Recall how different rocks have diff. resistances to weathering (Granite vs. Marble). Also note that unconsolidated deposits weather much more easily.

  2) The Chemical Makeup: affects the fertility of soils & the plants it can support.

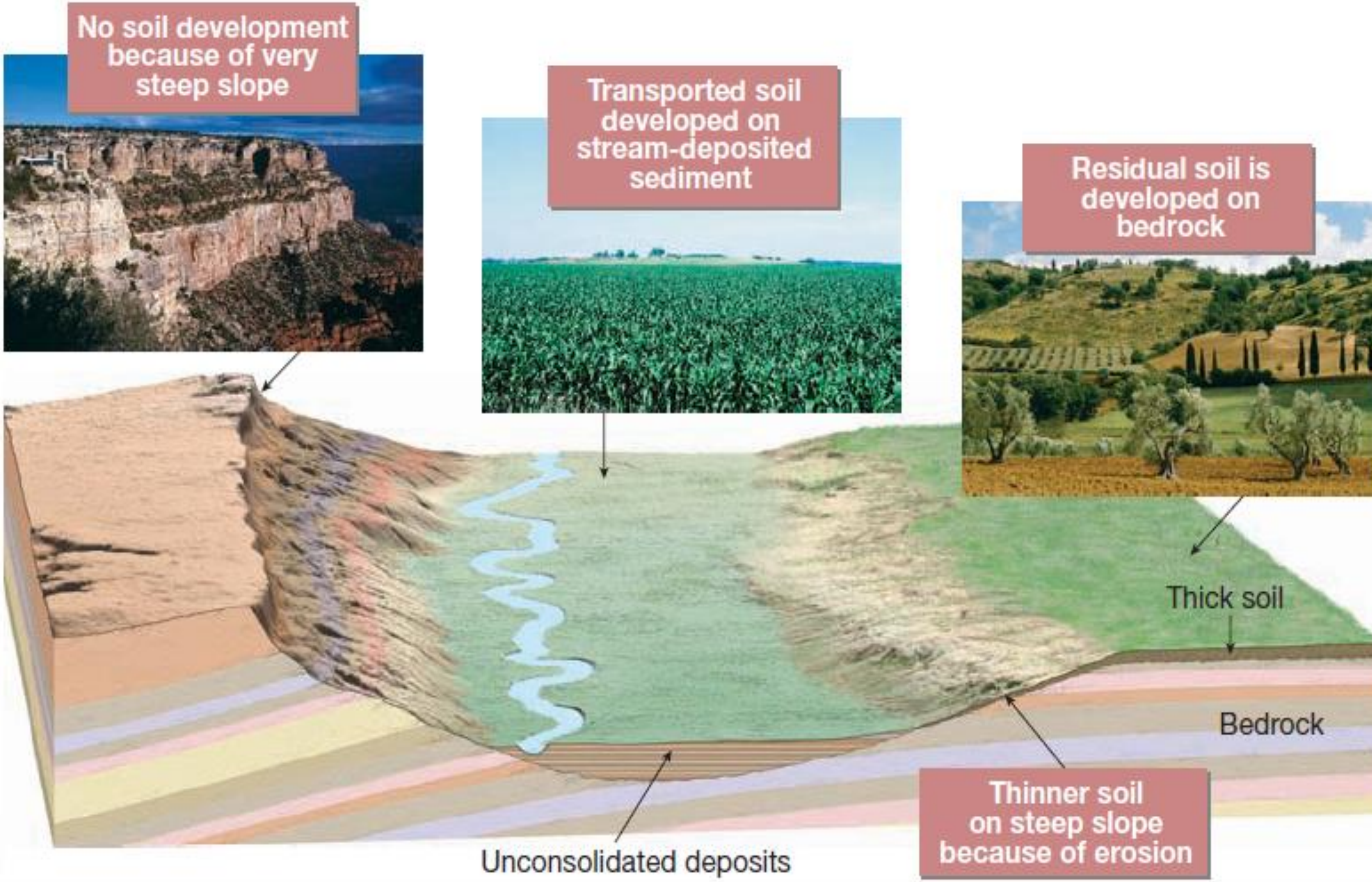


FIGURE 5.15 The parent material for residual soils is the underlying bedrock, whereas transported soils form on unconsolidated deposits. Also note that as slopes become steeper, soil becomes thinner. *(Left and center photos by E. J. Tarbuck; right photo by Grilly Bernard/Getty Images, Inc./Stone Allstock)*

Controls of Soil Formation: 2) Time

- The amount of time required for various soils to evolve cannot be specified, because the soil-forming processes act at varying rates under different circumstances.

- However, as a rule, the length of time these processes have been operating determines the nature of the soil:
- The shorter the time of weathering→ **the more the soil resembles the parent material** (i.e. the parent material determines to a large extent the characteristics of the soil).
- The longer the time of weathering→ **the thicker the soil becomes and the less it resembles the parent material.**

Controls of Soil Formation: 3) Climate

- The most influential control of soil formation.
- Variations in **temperature & precipitation (rain)** determine whether chemical or mechanical weathering will dominate. Additionally, they influence the rate & depth of weathering.
  - Hot & Wet Climate → Produces a thick layer of chemically weathered soil
  - Cold & Dry Climate → Produces a thin layer of mechanically weathered soil
- Furthermore, the amount of precipitation influences the amount of materials removed (leached) from the soil, which determines the fertility of the soil, and ultimately the nature of vegetation & animal life.

Controls of Soil Formation: 4) Plants & Animals

- The biosphere plays an important role; the types & abundance or organisms influences the physical & chemical properties of the soil, primarily the organic content of the soil.
  Soils can be described by the environment & the vegetation it generates. Examples include Forrest Soil, Desert Soil, Prairie Soil (مرج), & Tundra Soil(سهل اجرد).
- **Organic Content:** Plants are the primary source of organic material (animals & microorganisms to a lesser extent). When organic material decomposes (تتحلل), important nutrients are supplied to other plants, animals & microorganisms (i.e. soil becomes more fertile).

Controls of Soil Formation: 4) Plants & Animals

- The decay of plant & animal remains forms various complex organic acids, that contribute to weathering processes & make it faster.
- Organic matter also helps the soil retain water.
- **Microorganisms** (like bacteria & fungi) play an active role in the decay of organic remains→ converting them into a new material *"Humus".* Certain microorganism even increase the fertility of soil by converting atmospheric nitrogen into soil nitrogen.
- **Earthworms** on the other hand feed on organic matter and certain minerals, mix the soil, and burrowing holes that help water & air penetrate the soil.

Controls of Soil Formation: 4) Topography

- Change in topography affects soils even in a small area. The length, orientation and steepness of a slopes, water drainage conditions & amount of sunlight all have consequence:

- **Steep slopes** encounter significant erosion & mass wasting, so they do not support the accumulation of soil or water on them. The result is a thin layer of soil or non & little to no vegetation.
- On the contrary, **waterlogged (poor drainage) bottomlands** form soils that are **thick** (due to accumulation of sediments) **& dark** (due to high content of organic matter that is not allowed to decay from saturated conditions).

The ideal terrain for soil development is a **flat-to-undulating upland surface where there is good drainage**, minimum erosion, and sufficient infiltration of water into the soil.

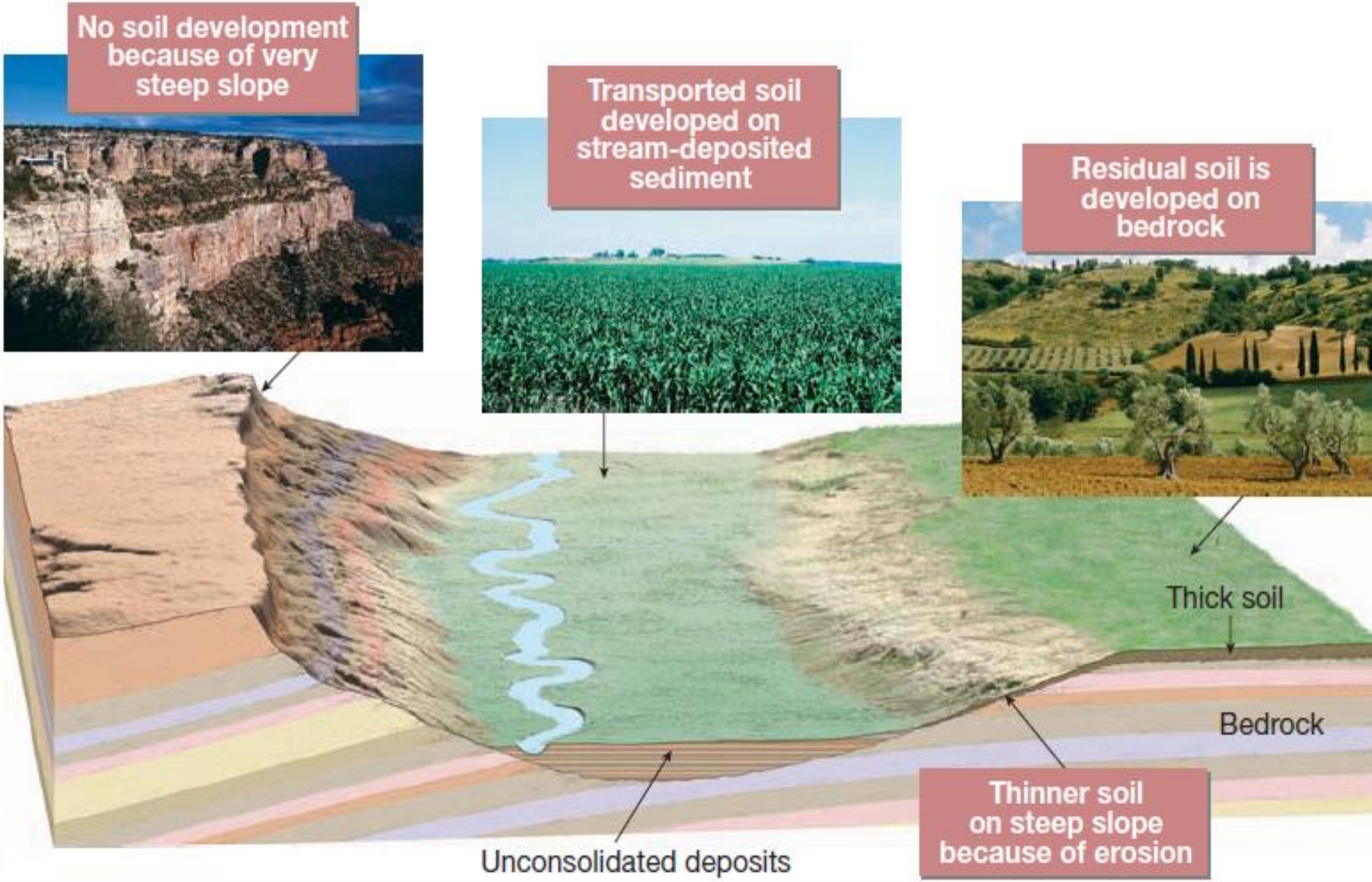
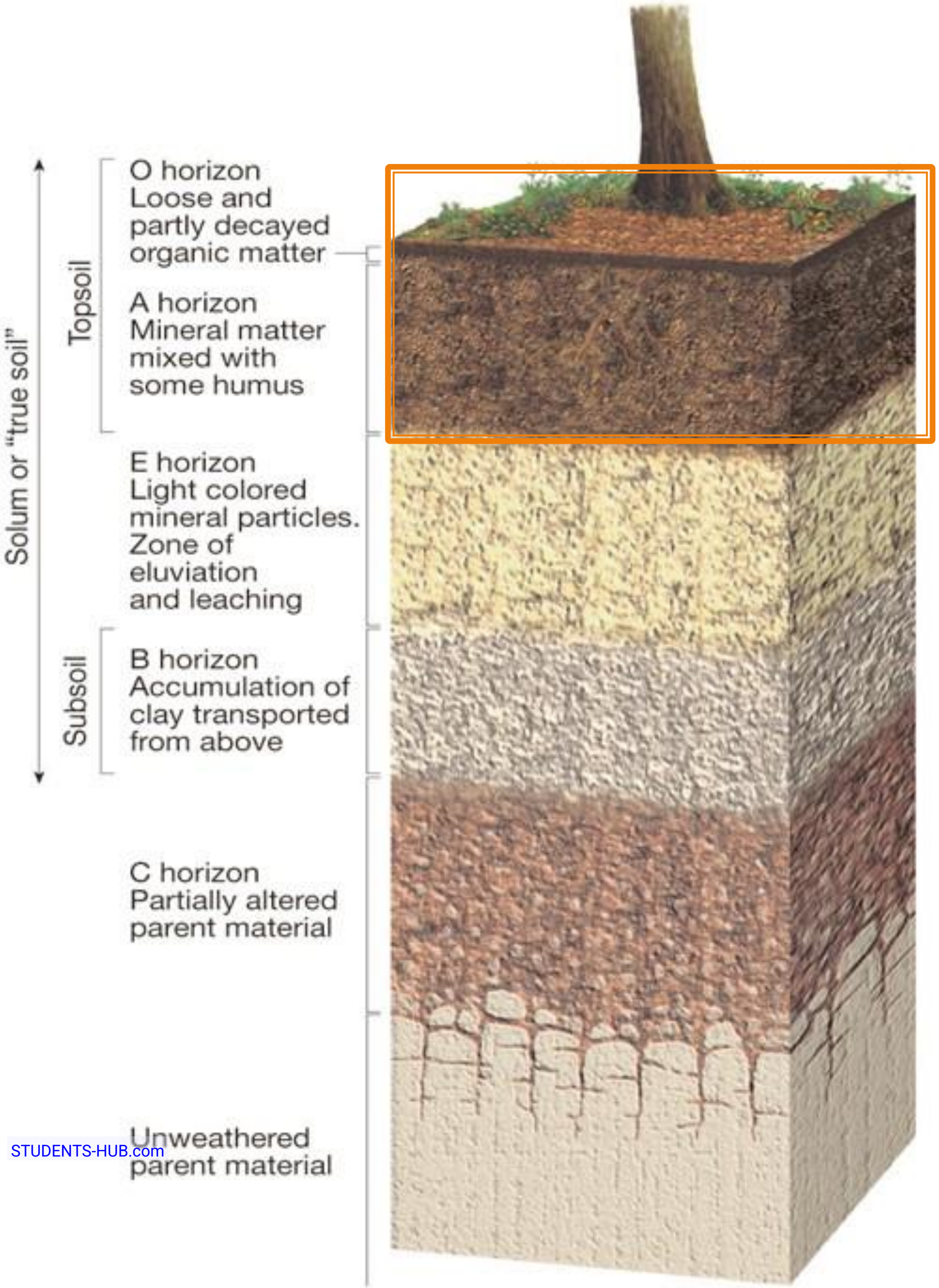


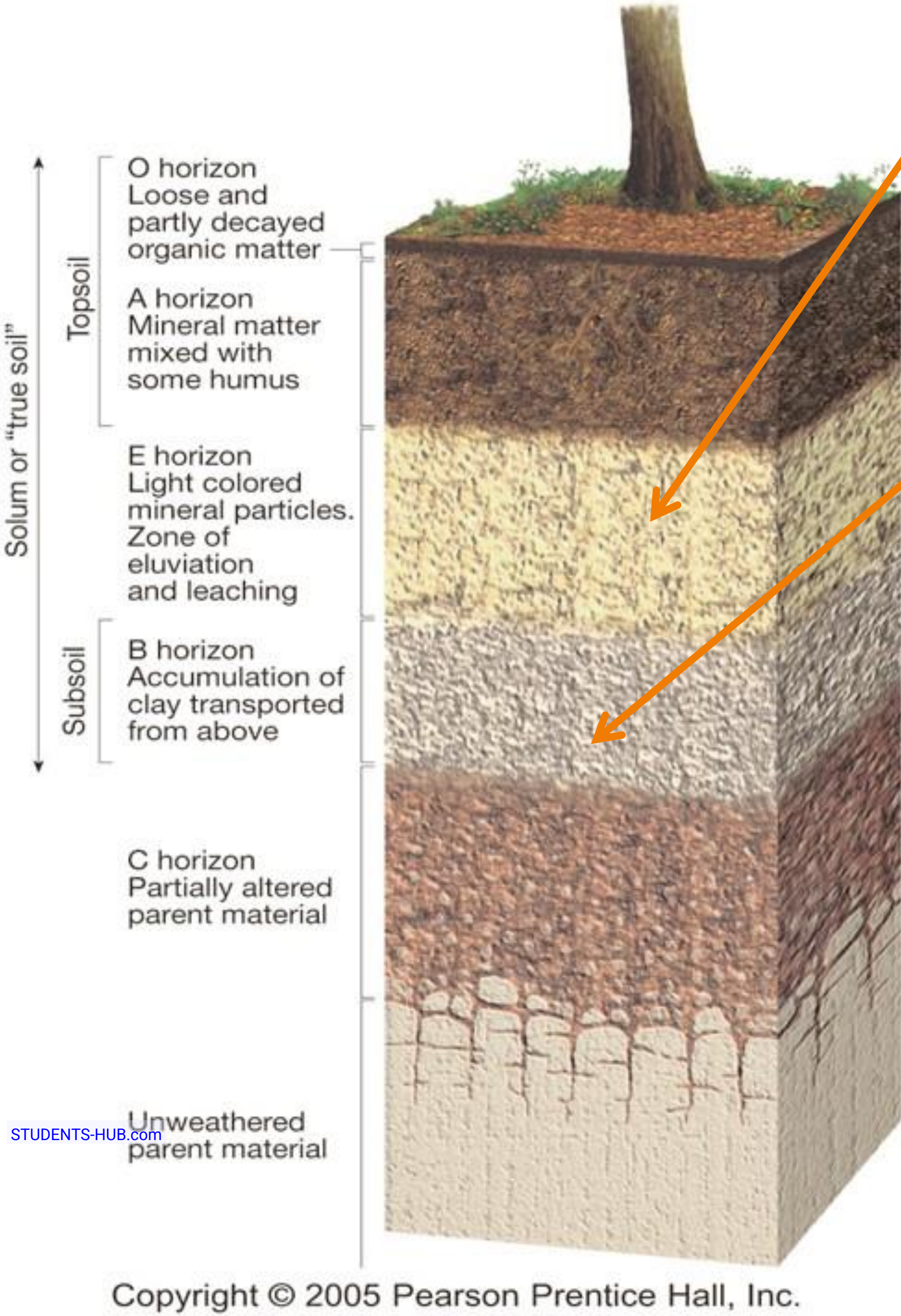
FIGURE 5.15 The parent material for residual soils is the underlying bedrock, whereas transported soils form on unconsolidated deposits. Also note that as slopes become steeper, soil becomes thinner. *(Left and center photos by E. J. Tarbuck; right photo by Grilly Bernard/Getty Images, Inc./Stone Allstock)*

The Soil Profile

- Because soil processes take place at the surface downwards, there are variations in composition, texture, structure, & color that develop with depth.
- With time, these differences become more pronounced & divide the soil into layers or zones known as **horizons**.
- When digging into soil, the vertical section through the horizons constitutes the **Soil Profile**.
- The profile of an idealized well-developed soil is **divided into 5 major horizons O, A, E, B & C**.



- **O Horizon:** consists largely of **organic matter** & filled with microorganisms. Its upper section is mainly tree leaves & other identifiable plant litter, while the its lower portion is mainly made up of decomposed organic material (humus).
- **A Horizon:** A zone largely composed of **mineral matter**, yet has high biological activity as humus constitutes up to 30% of its content.
- **Both O & A** Horizons make up what is commonly referred to as "**top soil**".



- **E Horizon:** Light- colored layer, little organic material, & is depleted by percolating water transporting fine soil particles (Eluviation) & dissolving inorganic soil components (leaching).
- **B Horizon (Subsoil)**: referred to as the **"zone of accumulation"** because it accumulates/ receives the fine material removed from the overlying horizon E through eluviation. If fine clay accumulates, it enhances water retention & in some extreme cases can form a compact impermeable layer called **"hardpan"**.
- ***Horizons O, A, E, & B*** *together constitute the* ***Solum*** or ***True Soil.*** It is the area where soil-forming processes take place & most roots, plants and animals reside.

- Finally, **Horizon C** is a layer of partially altered parent material (i.e. the bedrock below it). It

d

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steep slopes).

Soil Classification

- Soils have a vast and variable range types & compositions in different areas and time of processing. Hence, putting these types in groups or categories is necessary to better understand and simplify.
- **Many classification systems exist depending on the application.**
- For instance, The **Soil Taxonomy System** is suitable for agricultural & land-use purposes. It emphasizes the physical & chemical properties of a soil profile and on the basis of observable characteristics. In this system, soils are placed in 6 major categories from ***order*** (Qty. 12) [the broadest category] to **series** (Qty. 19,000).

Soil Erosion

- However, for engineering applications, this system is useless.
- Some of the most commonly used Classification Systems used by Engineering Geologists & Engineers are as follows:

1) **Unified Soil Classification System (USCS)**
2) **American Association of State Highway and Transportation Officials (AASHTO)**

- The Basis of these two classification systems is **Soil Particle Size**.

- **Gravel (G), Sand (S), Silt (M), & Clay (C).**

Soil Classification Systems

Soil Type	USCS	AASHTO
Boulders	> 12″ (300 mm)	> 3″ (75 mm)
Cobbles	3″ (75mm)- 12″ (300mm)	
Gravel	No.4 Sieve (4.75mm)- 3″	2.0- 75 mm (3″)
Sand	**No. 200- No. 4** Coarse: 2.0-4.76 mm Med.: 0.42 – 2.0 mm Fine: 0.42- 0.074 mm	0.074- 2 mm
Silt	**Fines < No.200** -If plastic→ Clay -If non-plastic→ Silt	0.005-0.074 mm
Clay		<0.005

- **Sieve Analysis is used.**

Examples: Sieve No. 4 (4.75mm), Sieve No. 10 (2.0mm), No. 200 (0.074mm), etc.

Soil Erosion

- Soil erosion is part of the Rock Cycle (i.e. the natural process of the recycling of earth materials).
- Once soil forms, erosional forces, especially water & wind, attach the soil & move it from one place to another.
- water flowing across the surface carries the soil particles in thin sheets in a process termed **sheet erosion**.
- This process also forms tiny channels called *rills* and if they become larger they are called *gullies*.
- Once soil is eroded in a channel, the soil particles can then be called ***sediment***.

Rates of Erosion

- Soil erosion is expected to occur to soil particles.
- However, it varies from place to place and to factors such as **soil characteristics, climate, topography, and amount & type of vegetation**.
- On a broad area, erosion caused by surface runoff can be estimated by determining the amount of sediment carried & deposited by a stream.
- Studies show that prior to (before) intense human activity, soil erosion was less:

- **Past**→ sediment transported by rivers to oceans, just over **9 billion tons/year**.
- **Present**→ **24 billion tons/year**.


Channel or stream carrying soil particles
Deposited Sediment

Affects of Excessive Soil Erosion

Effects:

- In many areas, soil erosion is faster than its formation. At present, more than 1/3 of the world's croplands affecting **agricultural productivity and quality of crops**.
- Excessive erosion & deposition of too many sediments, will **reduce the capacity of reservoirs** (affecting hydroelectric generation & flood control, etc.).
- Soils containing **Fertilizers & chemicals** may also affect the **water quality** of lakes, reservoirs, etc.
- Hence, soil preservation is necessary.

Weathering of Ore Deposits

- Weathering can also produce economically valuable deposits by depositing small scattered (مبعثر أو منتشر) metals into concentrated areas.
- This process is termed "**Secondary Enrichment**".
- This may occur either through **1)** chemical weathering of undesirable material and percolating water moving it downwards, concentrating desired elements in the **upper zone** or **2)** the reverse, the desirable material (in low concentrations) moved downward to **lower zones** where they are highly concentrated.

Weathering of Ore Deposits

- **Example:** **Bauxite,** an aluminum ore that forms (predominantly in rainy tropical climates) when intense & prolonged chemical weathering leaches elements such as Ca, K, & Na leaving concentrations of Bauxite (a hydrated aluminum oxide) on the top **due to its insolubility**.

ENCE 231: Engineering Geology
Fall Semester 2017/2018

Department of Civil Engineering-
Birzeit University, Palestine

Chapter 8: Mass Wasting

Instructor : Saheem Murshid
Dr. Khalil M. Qatu

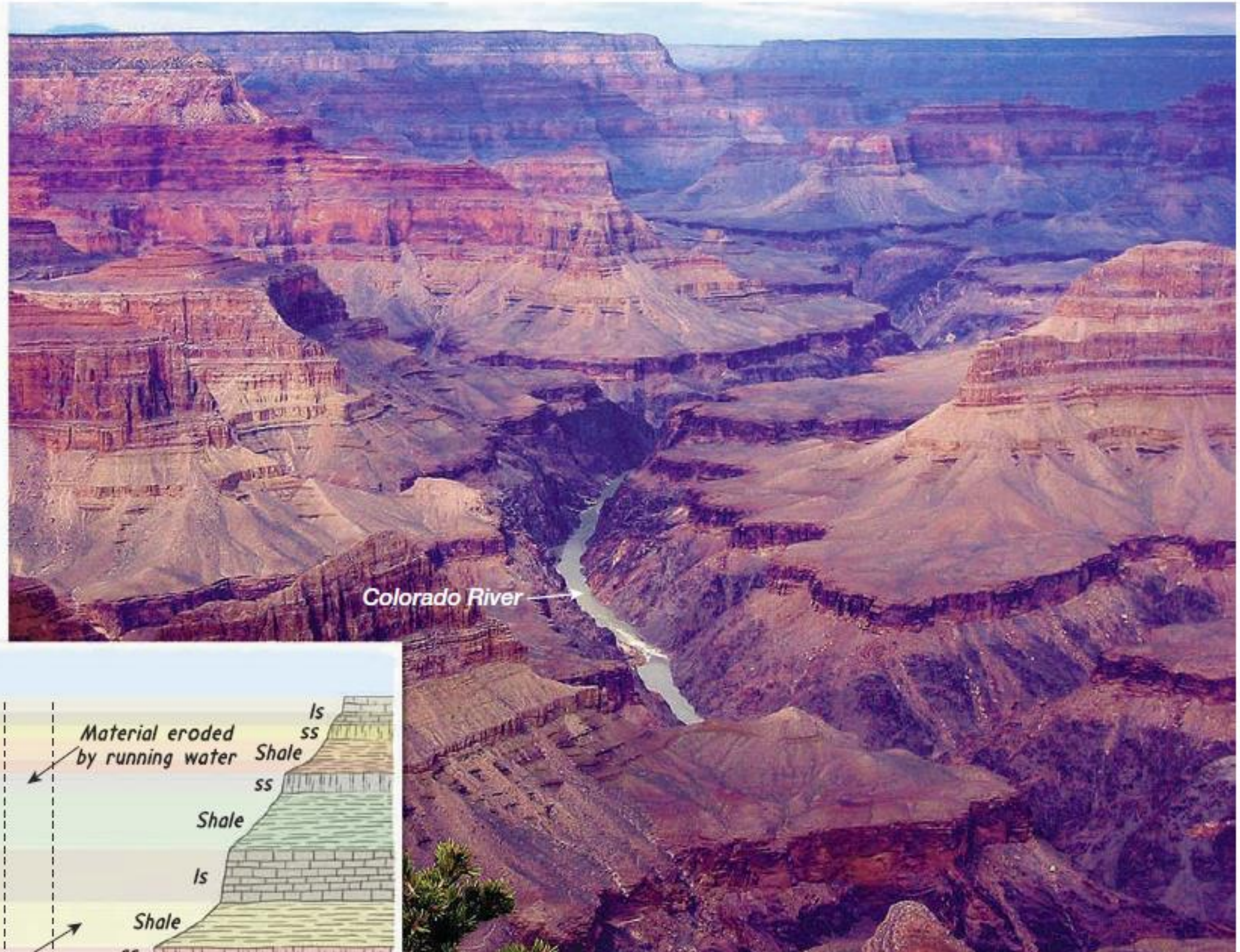
Mass Wasting: Definition

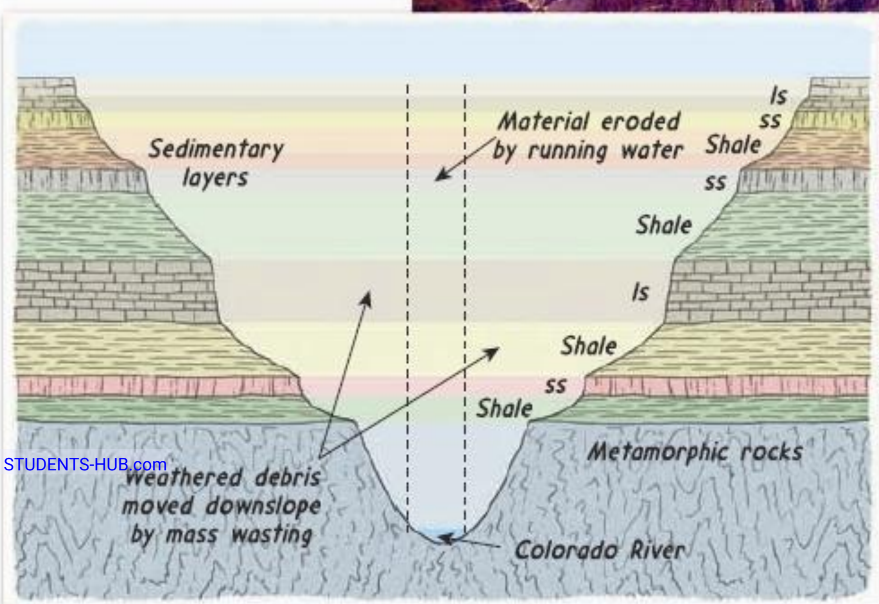
- **Mass Wasting:** The down-slope movement of rock, regolith and soil under the direct influence of gravity. It is distinct from erosional forces in that it does not require a transporting medium such water & wind.
- The movement may be gradual or sudden & violent.
- Landslides are a worldwide **natural hazard** when they cause damage to property & loss of life.

Mass Wasting

- **Weathering & Mass Wasting:** Once weathering breaks weakens & breaks rock apart, mass wasting transfers the debris down-slope.
- As mentioned in earlier chapters, **Mass wasting opposes the internal processes of mountain building and volcanic eruptions**. If the latter did not exist, earth would be flatter and mass wasting would slow or stop
- **Mass wasting supplies materials to streams**, which then carries it away (eventually to the sea). Mass wasting explains why river valleys are much wider than the channel filled with water.

FIGURE 8.2 The walls of the Grand Canyon extend far from the channel of the Colorado River. This results primarily from the transfer of weathered debris downslope to the river and its tributaries by mass-wasting processes. *(Photo by Bryan Brazil/Shutterstock)*





Geologist's Sketch

In the Grand Canyon, mass wasting makes the valleys much wider than the channel of the river.

Controls & Triggers of Mass Wasting

- Gravity is the controlling force, but other factors may play an important role in reaching instability in a slope. These factors are called ***"triggers"*** **(محفزات).** Some of the most common **natural triggers** are as follows:

- **Saturation of Materials from <u>Water.</u>**
- **Over-steepening of <u>Slopes</u>.**
- **Ground Vibrations from <u>Earthquakes</u>.**
- **Geologic structure / Bedding.**
- **Removal of anchoring Vegetation.**

The Role of Water

- Heavy rain or snowmelt may trigger mass wasting.
- In rock masses, we mentioned how water causes **frost wedging** through freeze-thaw cycles.
- Water may fill the pores of a sediment with water causing the particles' cohesion (التصاق او التحام) to be reduced or destroyed, allowing them to slide past one another (**reducing shear strength**).
- In the same way, saturation **reduces internal friction** between particles, allowing it to move by gravity.
- Water also **adds considerable weight** to a mass of material, which may cause it to slide or flow down-slope.

The Role of Water

Reduction of internal friction

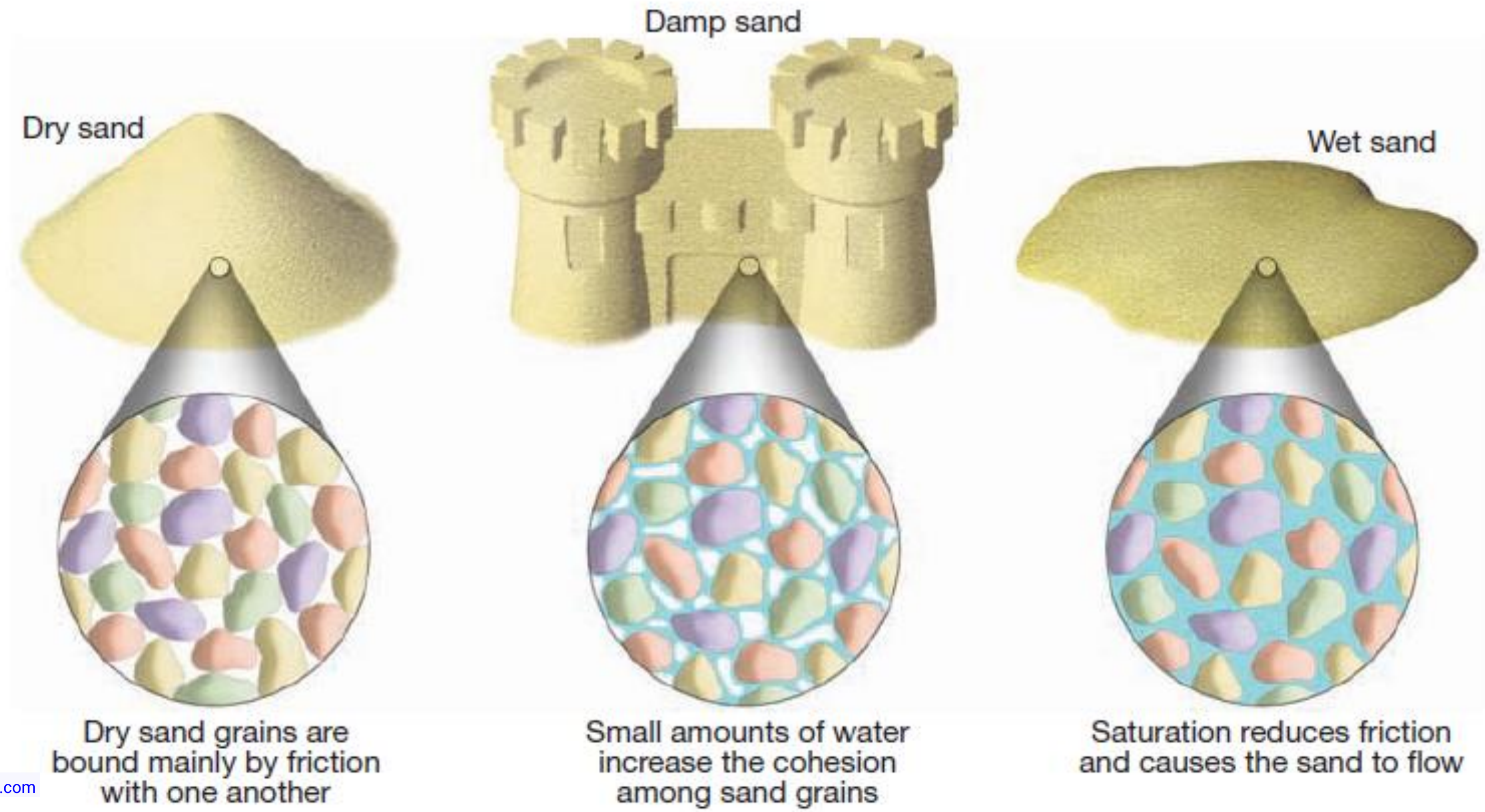
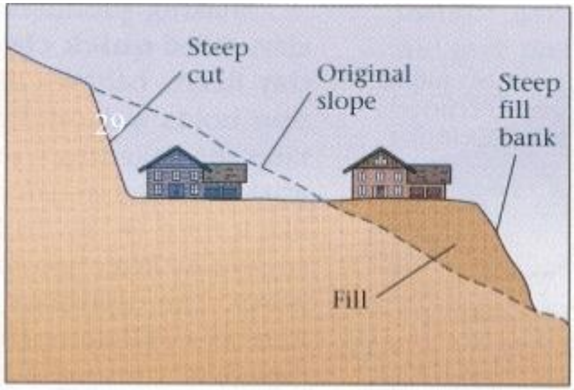
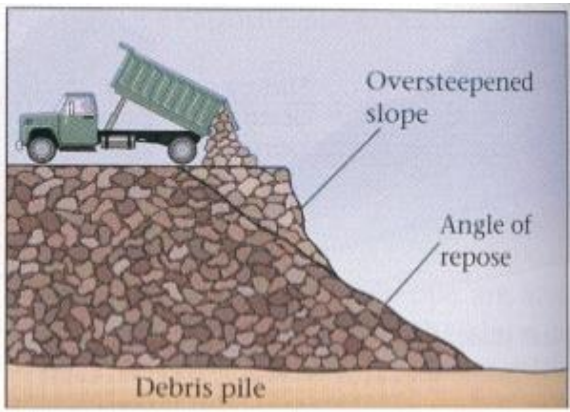


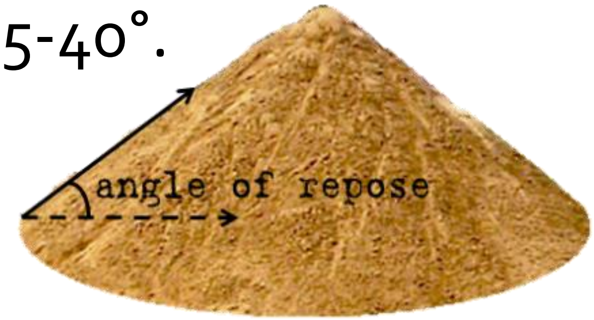
FIGURE 8.4 The effect of water on mass wasting can be great. When little or no water is present, friction among the closely packed soil particles on the slope holds them in place. When the soil is saturated, the grains are forced apart and friction is reduced, allowing the soil to move downslope.

Over-steepening of Slopes

- It is simply when slopes become steeper(شديدة الانحدار). May be caused by a stream undercutting a valley wall via human activity.
- The **Angle of Repose** is the steepest angle at which a slope is considered stable (on the verge of collapse) and it depends on the size & shape of the particles.
  In an unconsolidated mass of granular particles (sand-sized or larger) the angle of repose ranges from 25-40°.







Earthquakes

- Mass movement conditions may exist for a long time without movement. An earthquake can be a dramatic trigger.
- Earthquakes may trigger tens, hundreds or thousands of landslides in a susceptible area.
- **LIQUEFACTION.** Intense ground shaking during earthquakes can cause water saturated surface materials to lose their strength and behave as a liquid.

Quick Sand

A combination of Triggers is also common

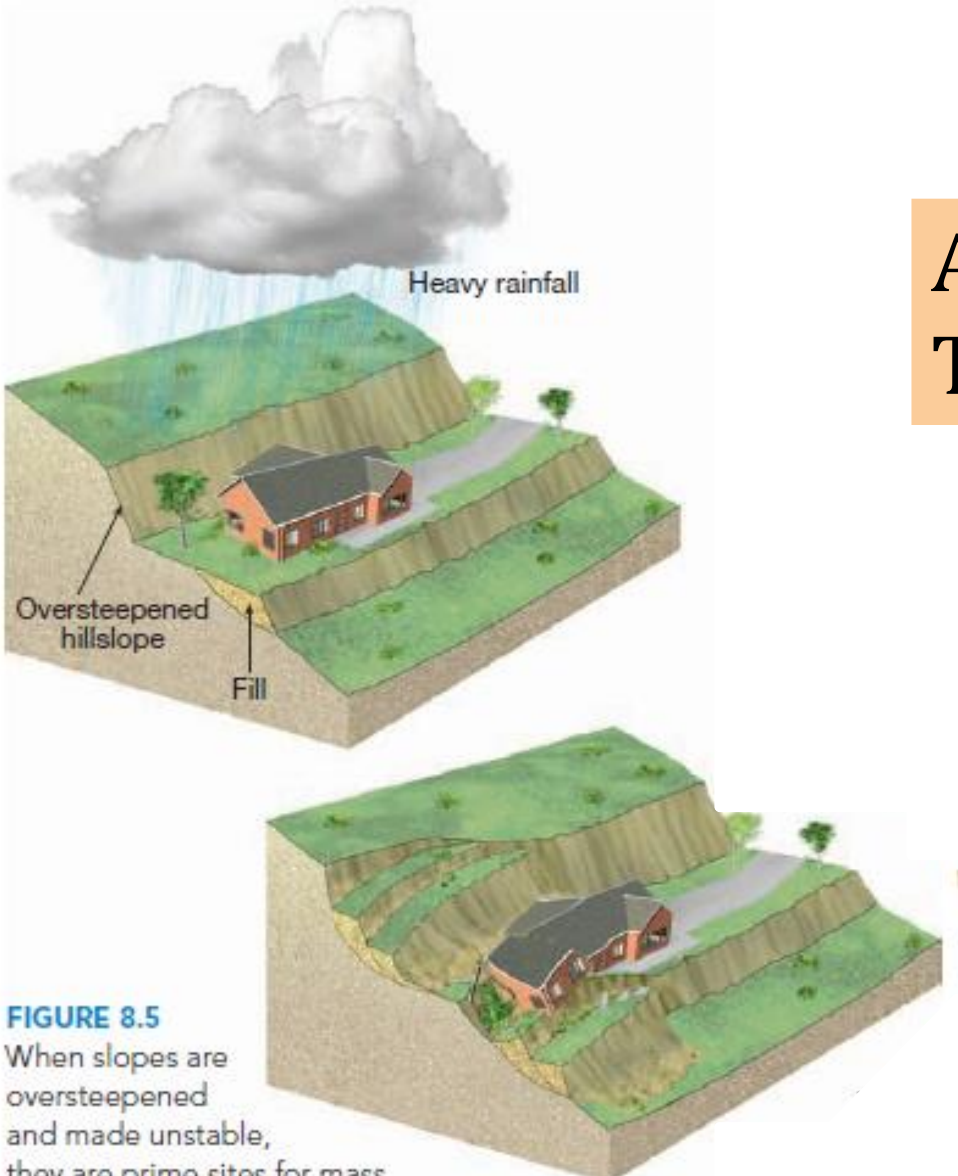
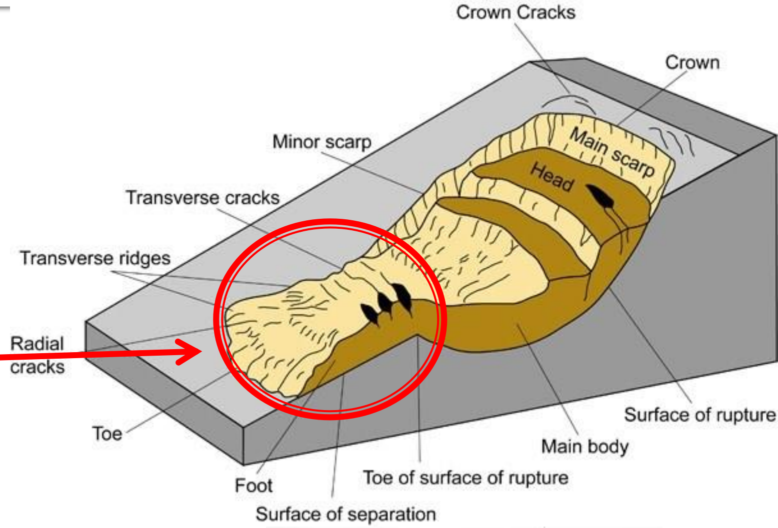


FIGURE 8.5
When slopes are oversteepened and made unstable, they are prime sites for mass wasting. Natural processes such as stream and wave erosion can oversteepen slopes. Changing the slope to accommodate a new house or road can also lead to instability and a destructive mass wasting event.

Class Question:
Can a landslide occur without an external trigger?

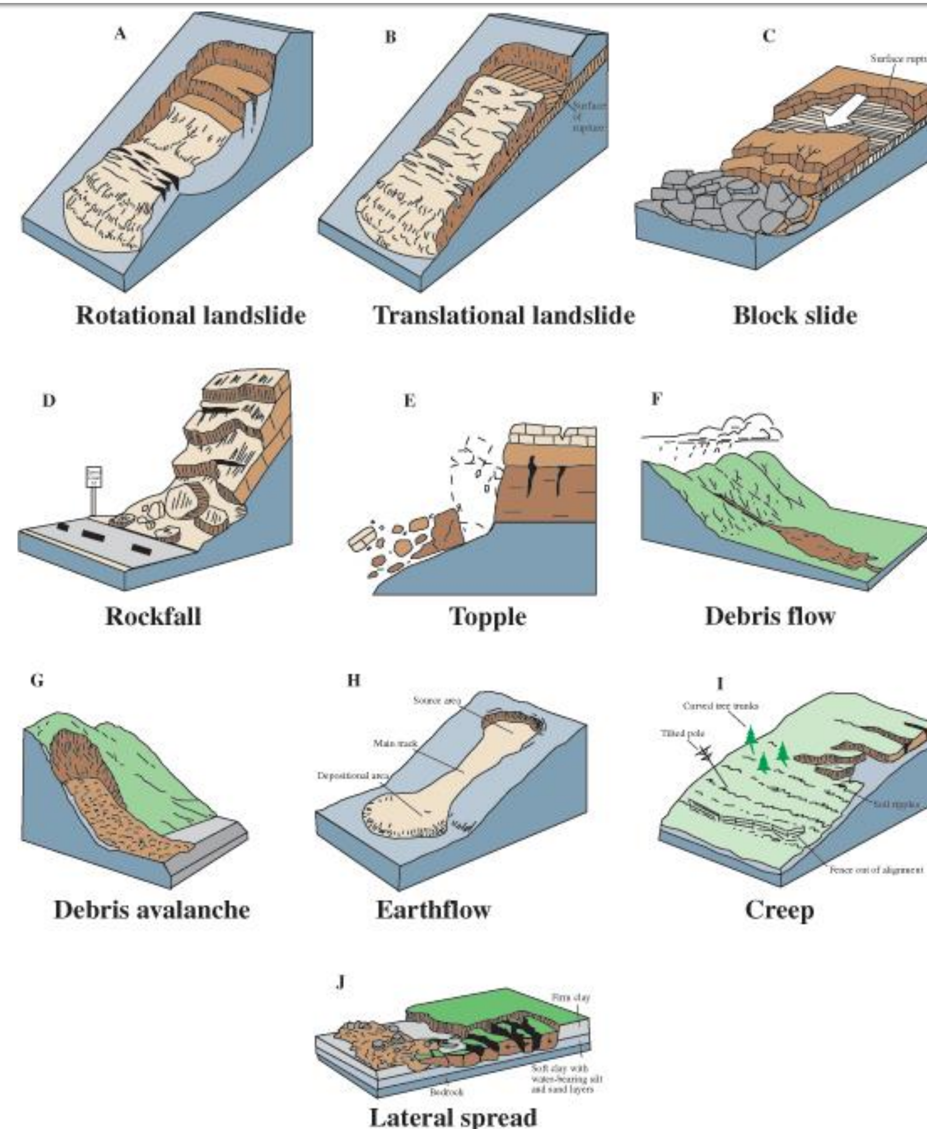
Other Factors (Mainly From Human Activity)

- Removal of Vegetation.
- Removal of the foot of a slope (considered the support of a slope).
- Vibrations (Ex: quarrying, construction, etc.)
- Loading at the top of a slope.
- Etc….



Classification of Mass Wasting Processes

- Classification of Mass Wasting events are generally classified based on the **type of material** involved, the **kind of motion** displayed, and the **velocity of the movement.**



Classification of Mass Wasting Processes: 1) Type of Material

- It depends on the **type of material** that the mass movement began from;
- Is **soil and regolith** dominate→ terms such as “mud”, “debris”, or “earth” are used.
- If mass of **bedrock** breaks loose → terms such as “rock” and “block” are used in the description.

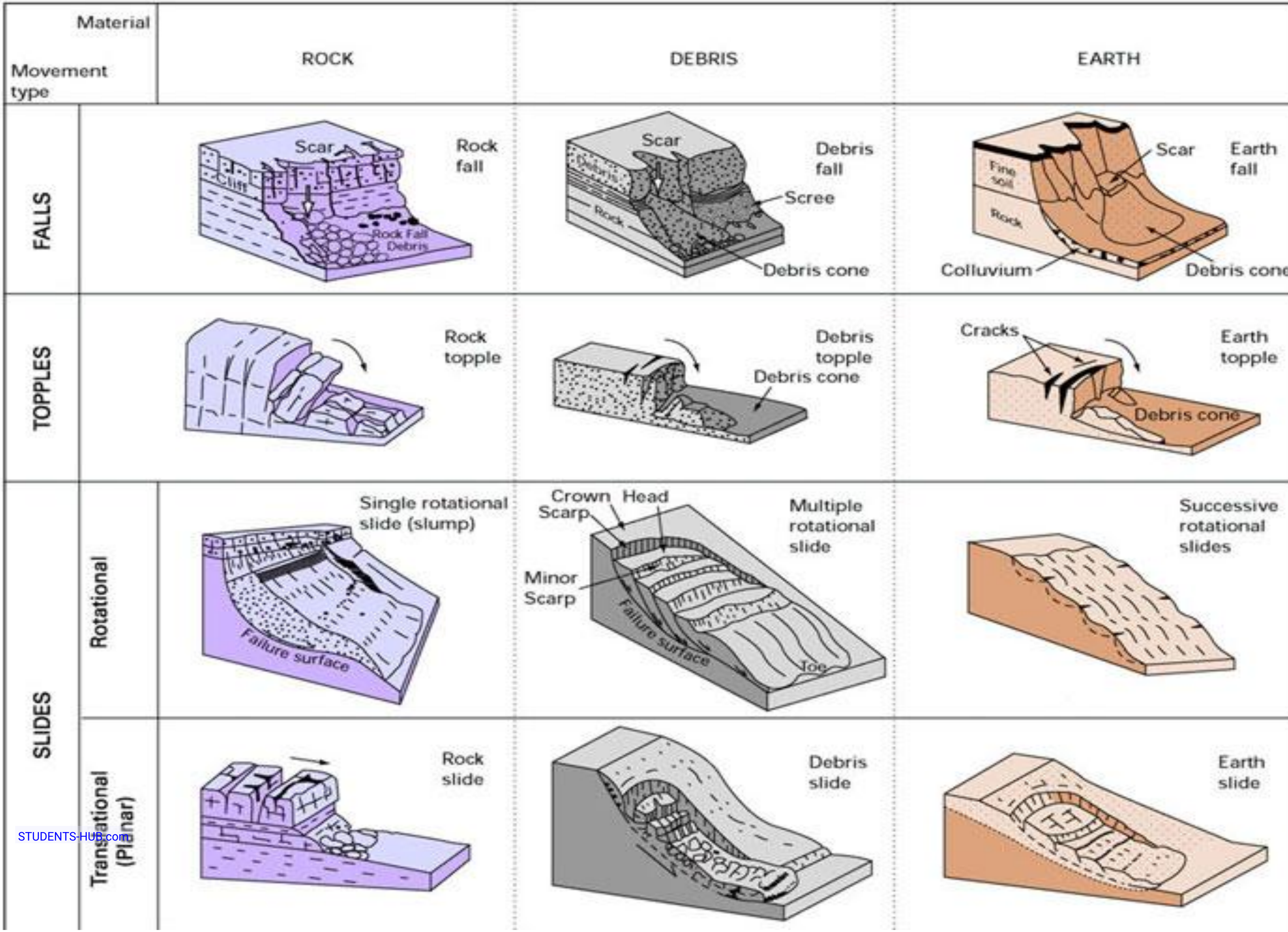
Classification of Mass Wasting Processes: 2) Type of Motion

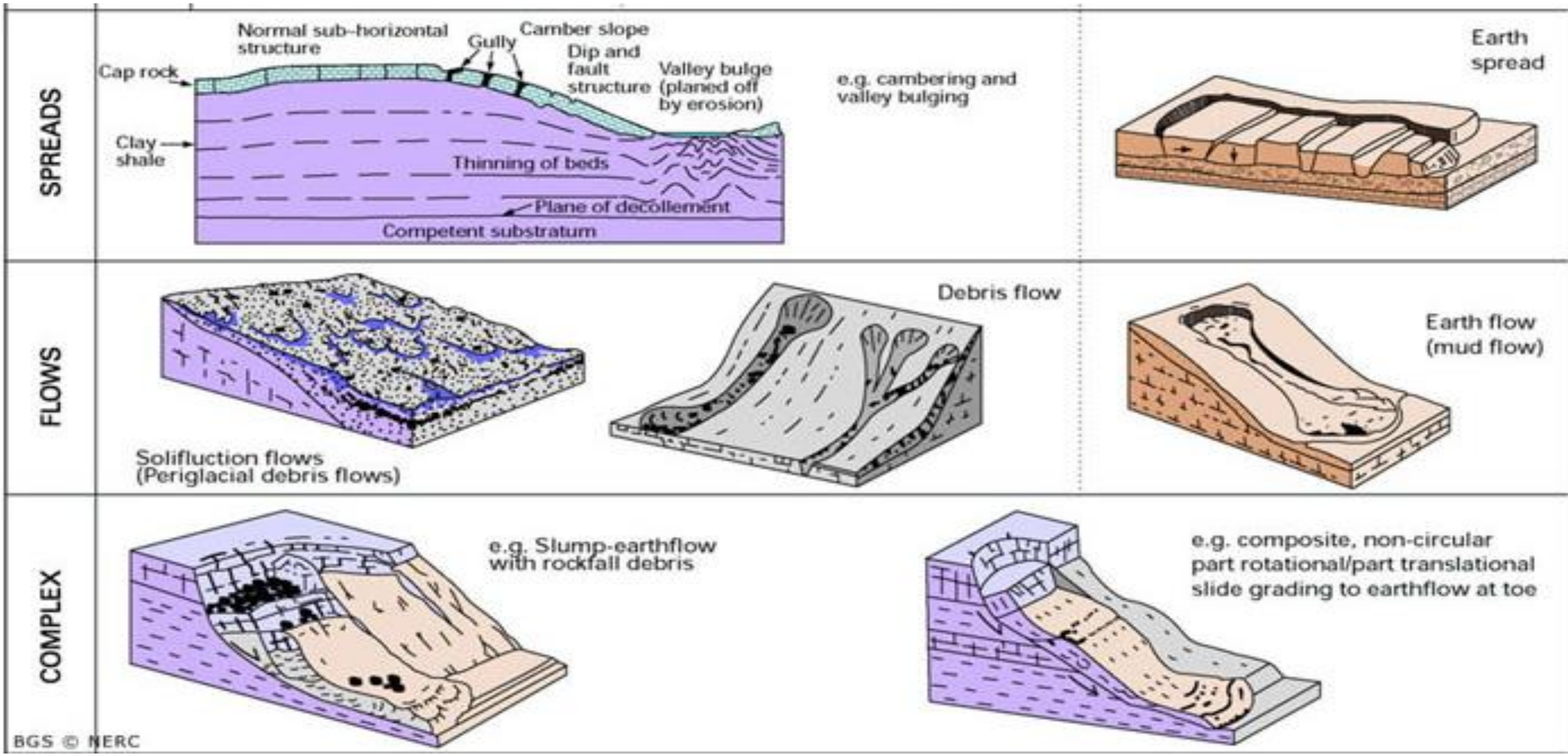
- The types of motion or how the mass moves are highly variable, but generally it is either described as **fall, slide, or flow**.
- **Fall:** describes a motion of freefall of detached pieces of any size. It is common in steep slopes when material cannot remain on the surface. This type of motion may cause other types.
- **Slide:** Occur when material remains fairly coherent until it moves along a well-defined surface. This surface may be a *joint, fault* or even a *bedding plane* nearly parallel to slope. When movement occurs along a curved surface, it is called **slump (rotational).**

Classification of Mass Wasting Processes: 2) Type of Motion

- **Flow:** Occurs when material moves down-slope as a viscous fluid. Most flows are saturated with water.

- Other possible types of motion:
- Spreads
- Topples
- And Complex


Material
Movement type
ROCK
DEBRIS
EARTH
FALLS
Scar
Cliff
Rock Fall Debris
Rock fall
Scar
Debris
Rock
Scree
Debris cone
Debris fall
Fine soil
Rock
Scar
Earth fall
Colluvium
Debris cone
TOPPLES
Rock topple
Debris topple
Debris cone
Cracks
Earth topple
Debris cone
SLIDES
Rotational
Single rotational slide (slump)
Failure surface
Crown Scarp
Head
Minor Scarp
Failure surface
Toe
Multiple rotational slide
Successive rotational slides
Translational (Planar)
Rock slide
Debris slide
Earth slide


SPREADS
Normal sub-horizontal structure
Camber slope
Gully
Dip and fault structure
Valley bulge (planed off by erosion)
Cap rock
Clay shale
Thinning of beds
Plane of decollement
Competent substratum
e.g. cambering and valley bulging
Earth spread
FLOWS
Solifluction flows (Periglacial debris flows)
Debris flow
Earth flow (mud flow)
COMPLEX
e.g. Slump-earthflow with rockfall debris
e.g. composite, non-circular part rotational/part translational slide grading to earthflow at toe
BGS © NERC

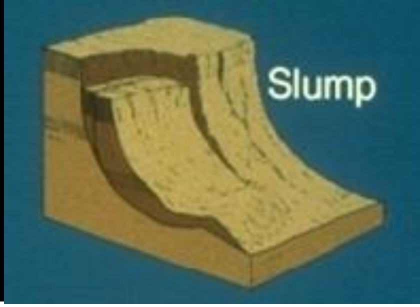
Classification of Mass Wasting Processes: 3) Rate of Movement

- Rates of movement can be very sudden or exceptionally gradual.
- When mass-wasting events make the news, it is most likely because a large quantity of material has moved rapidly down a steep slope and has had a disastrous effect upon people and property.

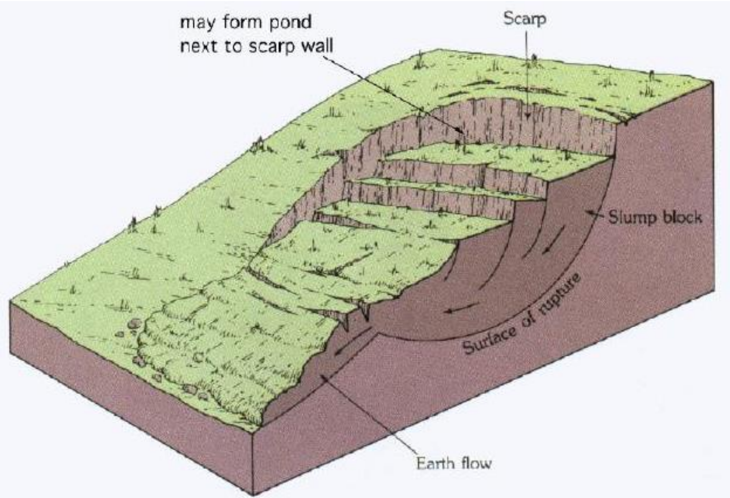
For instance, rock avalanches**, rock and debris can hurtle** down-slope at speeds exceeding 200 kilometers per hour.
In this case, high velocities result when air becomes trapped and compressed beneath the falling mass of debris, allowing it to move as a buoyant, flexible sheet across the surface.

However most mass movements is slow. One process that is extremely slow is **Creep**, *in which* movement is usually measured in millimeters or centimeters per year.

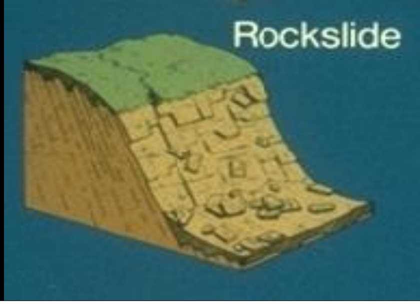
Slump (slow)



- Slump is a common type of mass movement and refers to the downward sliding of a mass of rock or unconsolidated material moving as a unit along a curved surface.
- Usually slumped material does not travel fast or to long distances.
- It is common in thick accumulations of cohesive material such as clay and the surface of rupture forms crescent-shaped (spoon).
- Commonly occurs due to over-steepened slopes by removing slope foot or overloading at the top. Water may also play a role when weak rock layer (clay-rich) underlies a more resistant rock (ex: sandstone).

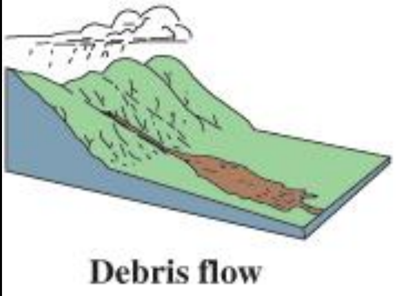


Rockslide (fast)



- Occurs when blocks of bedrock break loose and slide down-slope.
- If the material is largely unconsolidated the term *debris slide* is used.
- It occurs where either rock strata (bedding/ dip) or joints and fractures are inclined parallel the slope.

Debris Flow or Mudflow (fast)



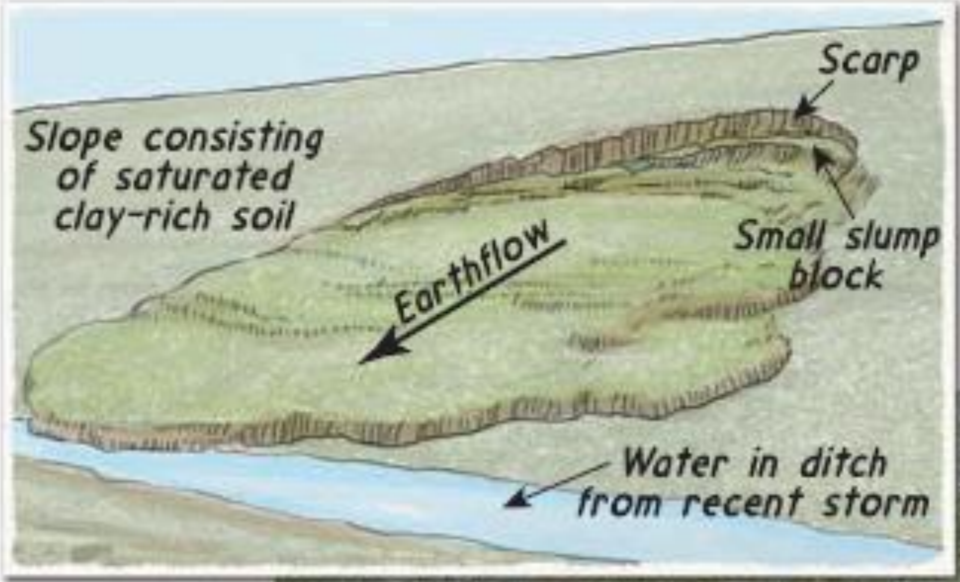
- It is a relatively rapid type of mass wasting that involves a flow of debris containing a large amount of water.
- It is characteristic of **semi-arid mountain regions** with infrequent but heavy rainfall.
- Mudflows occurring on slopes of volcanoes are termed "Lahars". They occur when a highly unstable layer of ash and debris become saturated with water and flow down-slope.

Earthflow (slow-med.)

Earthflow

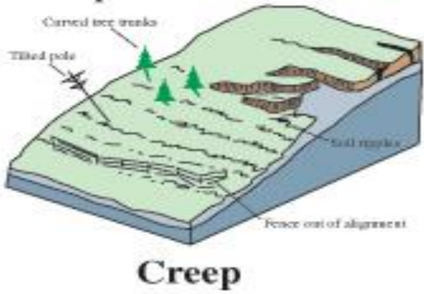
- Most often forms in **hillsides in humid areas** during heavy precipitation or snowmelt. Water saturates the soil and regolith, which then moves down-slope in the shape of a teardrop.
- It varies in size; from a few meters in width, length & depth to over a kilometer long, several hundred meters wide & more than 10 meters deep.
- The material involved is commonly rich in clay & silt, with small portion of sand & coarse particles.
- The material is more viscous than in mudflows, so it is typically slower and more consistent. It may move over a period of days to years depending on slope steepness, amount of rain, and consistency of material.

Earthflow



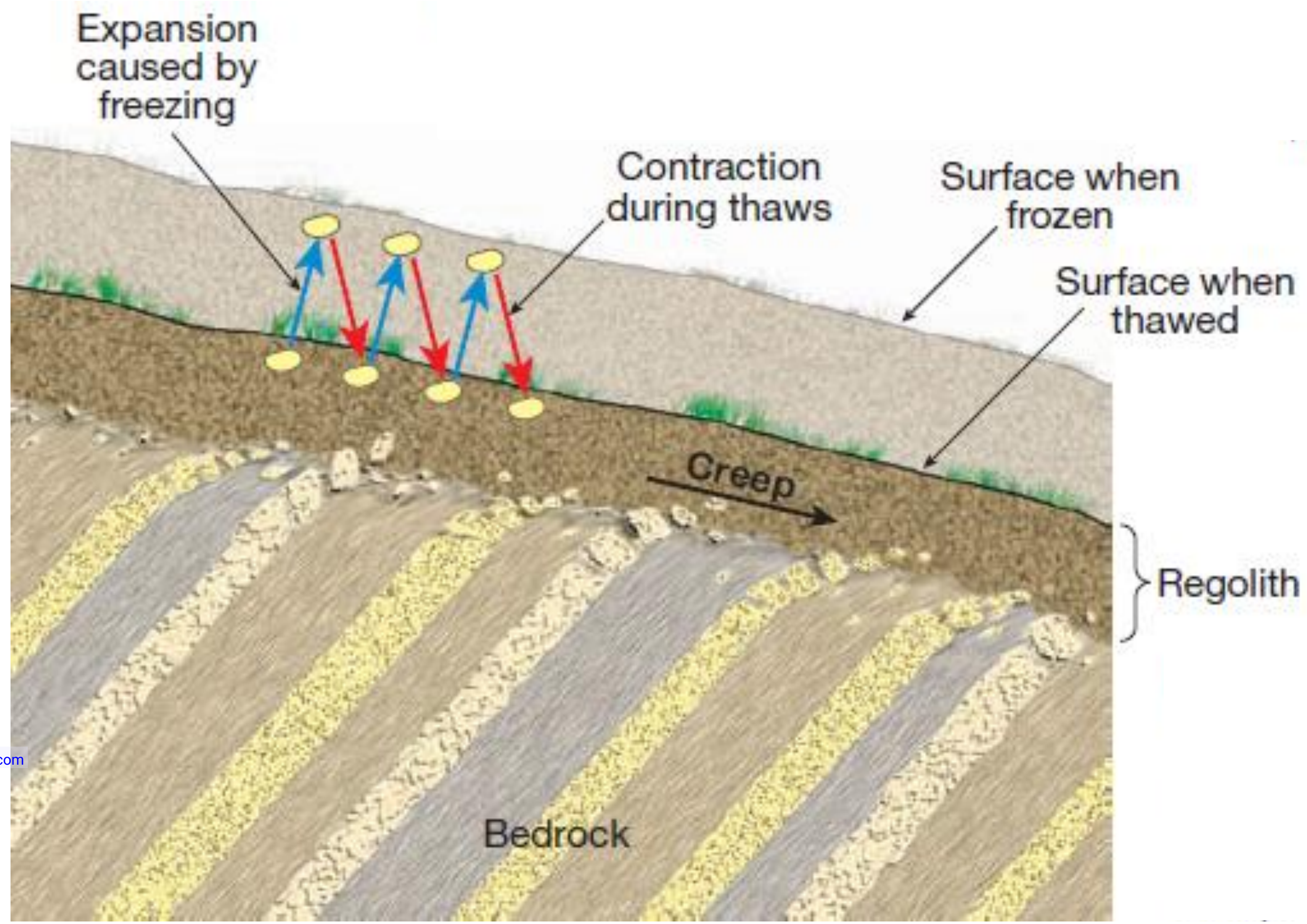
Geologist's Sketch

Creep (very slow)



- Very wide-spread as it occurs on both steep & gentle slopes. Despite this fact, it is characterized by very slow movement.
- By definition, Creep is the type of mass wasting that involves the gradual downhill movement of soil & regolith.
- One of the factors controlling creep is freezing & thawing cycles or wetting & drying cycles. Freezing or wetting lifts particles at right angles to the slope

Creep: Movement due to Freezing-Thawing or Wetting-Drying Cycles

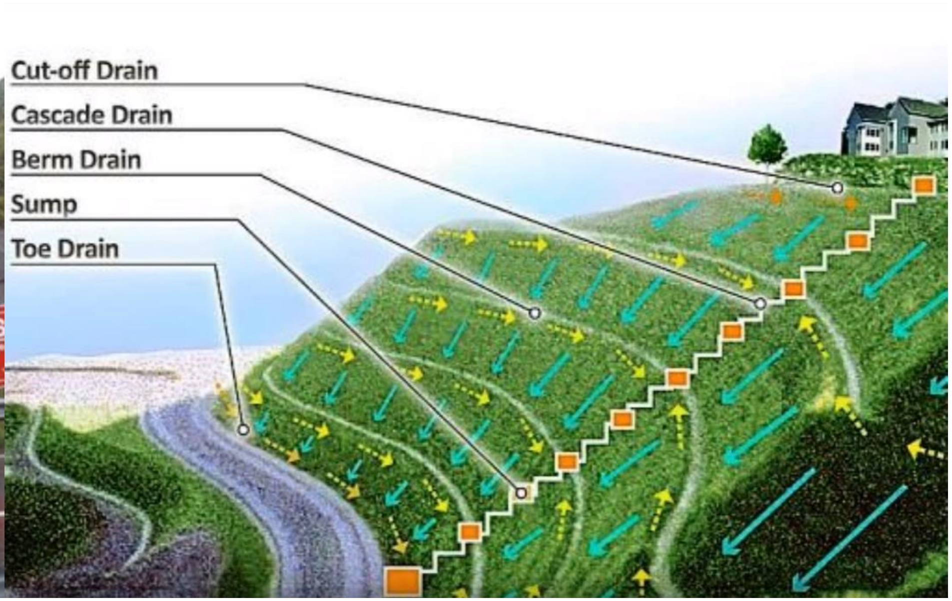


Solifluction

- When soil is saturated with water, the soggy mass may flow down-slope at a rate of a few millimeters or a few centimeters per day or per year. Such a process is called solifluction (literally, "soil flow").
- It is a type of mass wasting that is common wherever water cannot escape from the saturated surface layer by infiltrating to deeper levels. A dense clay hardpan in soil or an impermeable bedrock layer can promote solifluction.
- It is common in regions underlain by permafrost**. Permafrost refers to the permanently frozen ground.**
- Solifluction occurs in a zone above the permafrost called the *active layer, which thaws to a depth of about a meter during the brief* high-latitude summer and then refreezes in winter. During the summer season, water is unable to percolate into the impervious permafrost layer below. As a result, the active layer becomes saturated and slowly flows. The process can occur on slopes as gentle as 2 or 3 degrees.

Landslide Mitigation Techniques "Slope Protection"

1) **Drainage:** Both at surface & subsurface (ex: drainage pipes, drainage tunnels, soil filters or geotextile filters, and ditches & trenches also serve for drainage).



Landslide Mitigation Techniques “Slope Protection”

2) Retaining Structures: most common is retaining walls (typically concrete, but may also be pile wall, geotextile or other materials). Regardless of material, retaining structures need to have drainage to avoid water build-up “weepholes”.

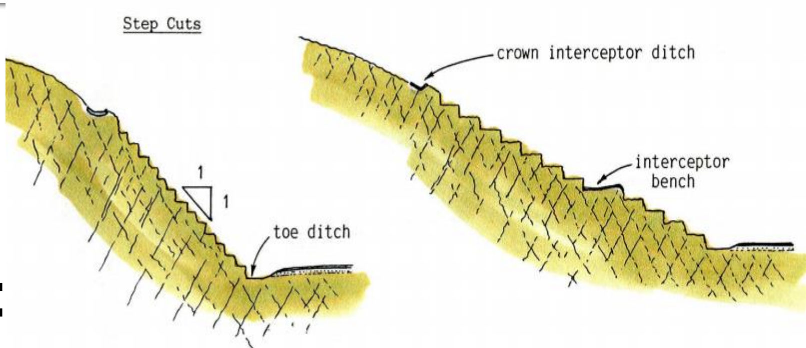
- **Gabions & Rip Rap** serve as both retaining structures (limited) and for drainage due to large gaps between rocks)

Landslide Mitigation Techniques "Slope Protection"

3) Slope Treatment:

Changing the risk factor in slopes with methods such as:

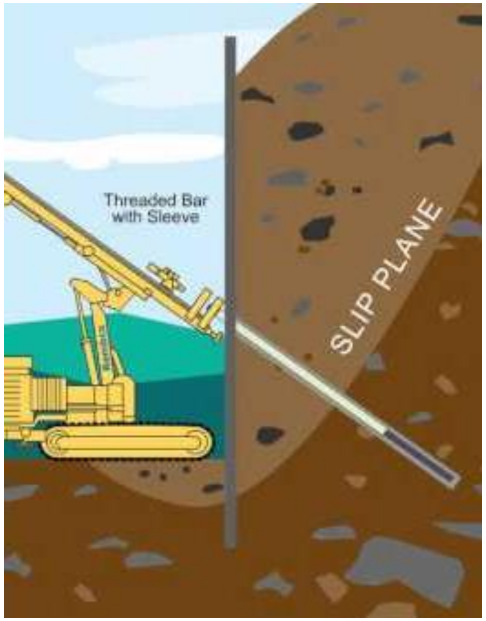
a. Slope Flattening (making it gentler)
b. Benching or Terracing
c. Scaling (removing unstable rocks)
d. Increasing Vegetation
e. Decreasing load on slope



Landslide Mitigation Techniques
"Slope Protection"

4) Other Techniques:

a. Safety Nets
b. Rock Anchoring
c. Ditches & Trenches
d. Shotcrete
e. Piles



ENCE 231: Engineering Geology
Fall Semester 2017/2018

Department of Civil Engineering-Birzeit University, Palestine

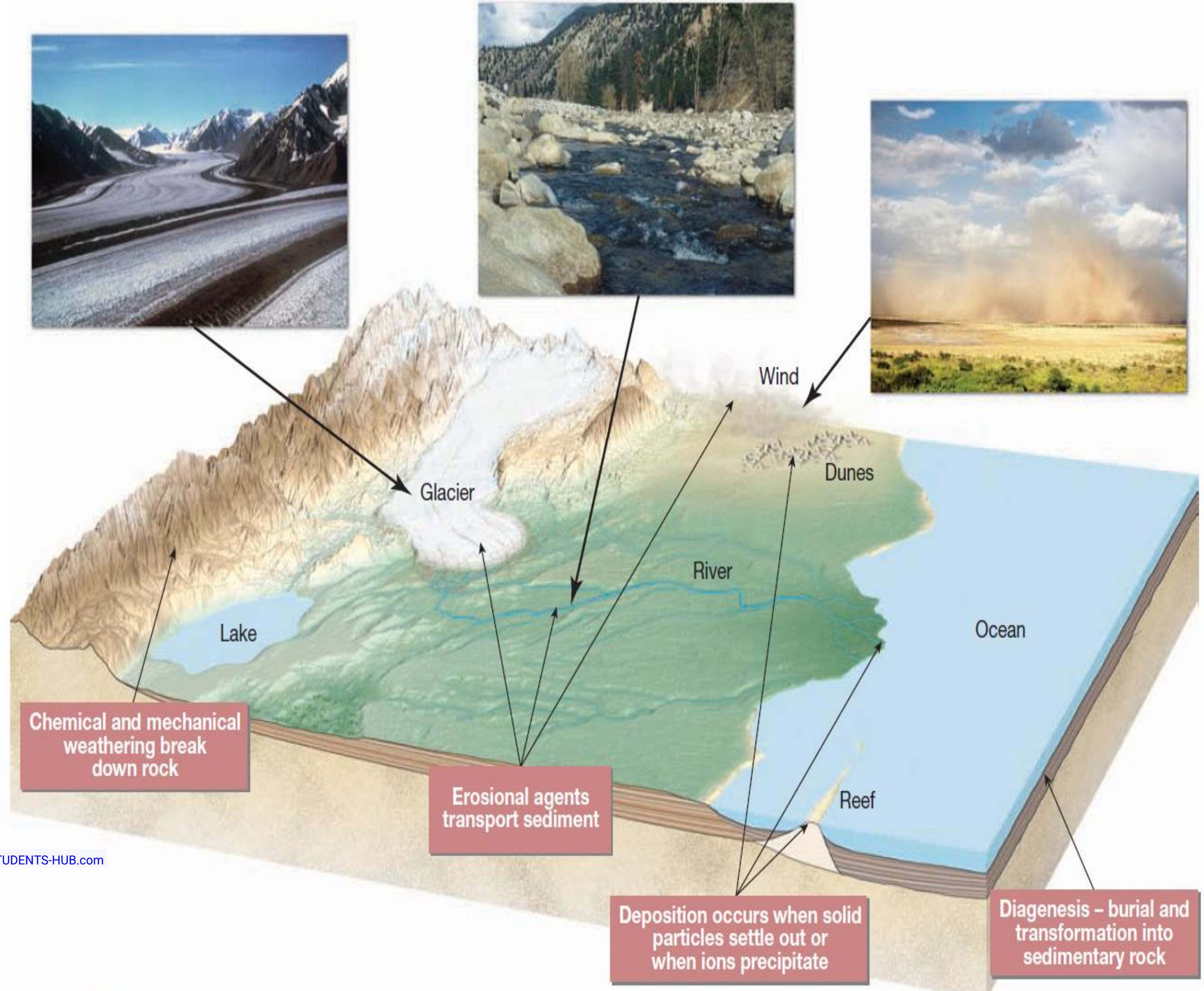
Chapter 6: Sedimentary Rocks

Instructor: Saheem Murshid
Dr. Khalil M. Qatu

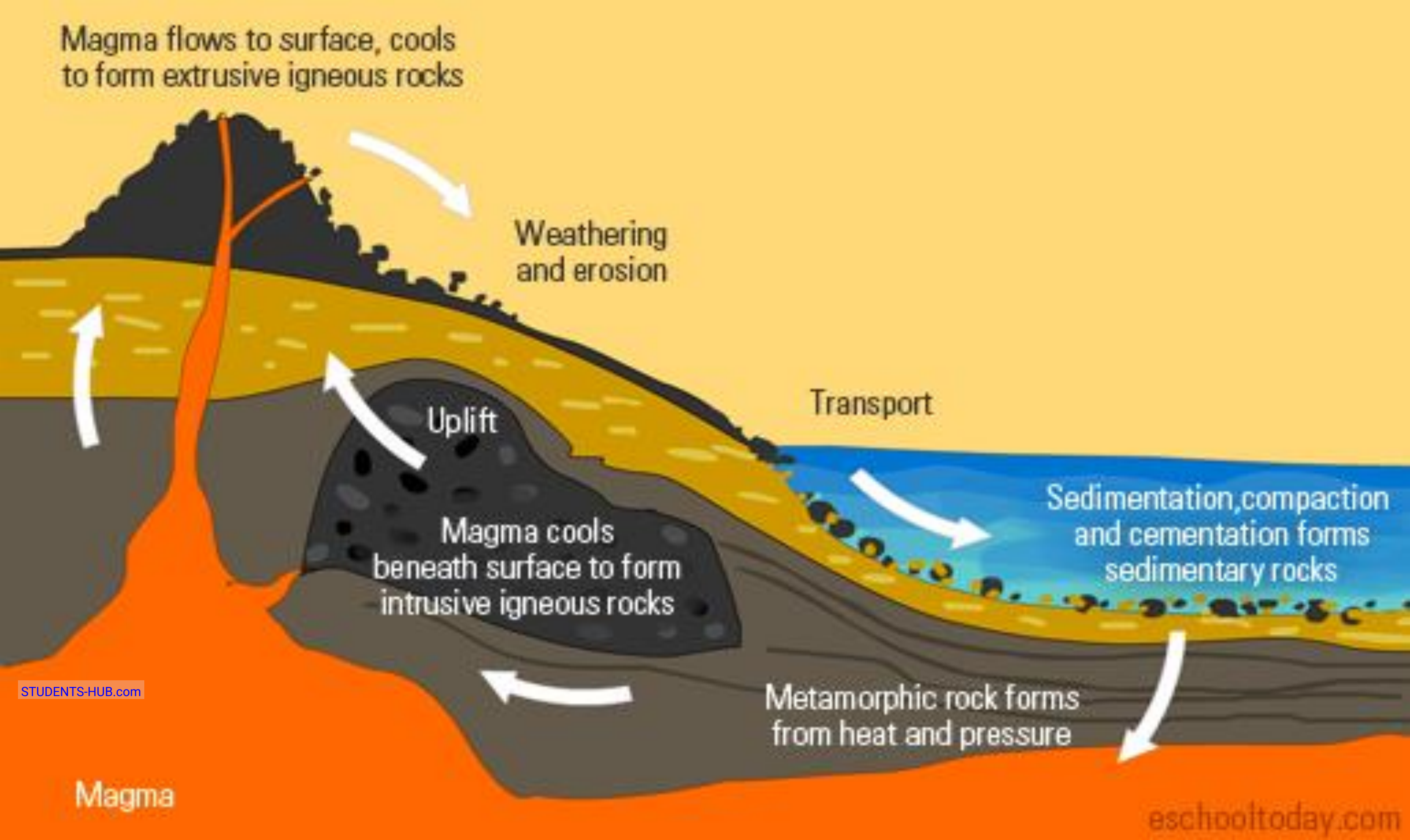
Formation of Sedimentary Rocks

- **The Process of Forming Sedimentary Rocks:**

1) **Weathering** of existing rocks on the surface.
2) **Transport** of weathered materials/fragments by mass movement (gravity) & erosional agents (running water, wind & ice).
3) **Deposition** of these materials in new locations [**Sedimentation**] such as lakes, river valleys, seas, etc. (they are broken even further during transport).
4) **Lithification** through compaction & cementation of this material (now called sediment) into solid Sedimentary Rock.


Wind
Glacier
Dunes
River
Lake
Ocean
Reef
Chemical and mechanical weathering break down rock
Erosional agents transport sediment
Deposition occurs when solid particles settle out or when ions precipitate
Diagenesis – burial and transformation into sedimentary rock

Formation of Sedimentary Rocks



What is Sedimentary Rock

- The primary raw material for sedimentary rocks is the product of mechanical & chemical weathering.
- **The origin of the word Sedimentary** comes from the latin word "*sedimentum*" meaning "*to settle*" (i.e. the material settling out of a fluid, although this is not always true).
- Because weathering, transport, & deposition are taking place on a constant basis, sediments are found almost everywhere and as they lithify they are continuously forming sedimentary rocks.

Importance of Sedimentary Rocks

- Although they make up only about 5% of the top 16kms of earth, we find sedimentary rocks everywhere on the surface (3/4 of it) because it is where they form.
- Because they form on the surface, they give us **evidences on past events & environments** at the surface. Containing **fossils**, they give us a historical record or at the least a tool to analyze the past.
- Furthermore, many sed. rocks are **important economically**; coal is a sed. rock…also petroleum & natural gas are typically associated with sed. rocks.

From Sediment to Sedimentary Rock: Diagenesis & Lithification

- Diagenesis: **A broad term for all the physical, chemical, and biological changes that occur during the conversion of sediment to sedimentary rock (i.e. all processes after deposition and during and after lithification).**
- All these changes takes place once sediments are buried and subjected to higher temperatures & pressures. However, diagenesis generally occurs at temperatures less then 150-200°C. Otherwise, we would start talking about Metamorphism.
- Lithification is not the only form of Diagenesis. For instance, the process of *Recrystallization* accounts for the development of more stable minerals from less stable ones. Example: Aragonite (from corals) to Calcite (L.S).

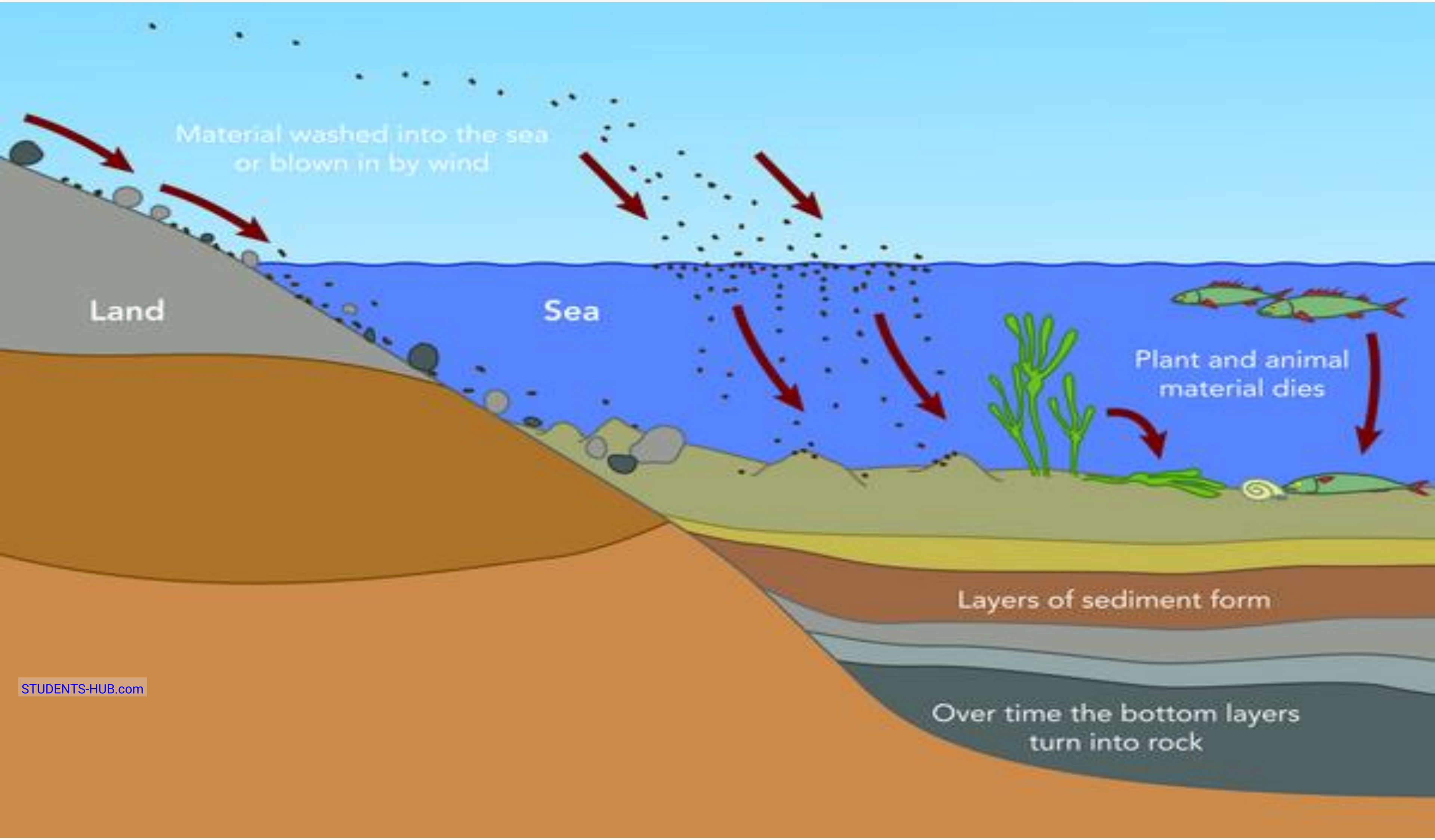
From Sediment to Sedimentary Rock: Diagenesis & Lithification

- **Lithification:** The process by which unconsolidated sediments are transformed into solid sedimentary rocks. It includes:

- **Compaction:** A common diagenetic change that occurs when deposited sediment accumulates & the weight of overlying material compresses it. How? Sediment grains are pressed closer & closer, reducing pore space between them.
- The deeper a sediment is buried → the more compacted & firmer it will become.
- fine- grained sediment compress more.

  Example: clay minerals under thousands of meters of material may loose up to 40% of the volume by compaction. [less in sand]

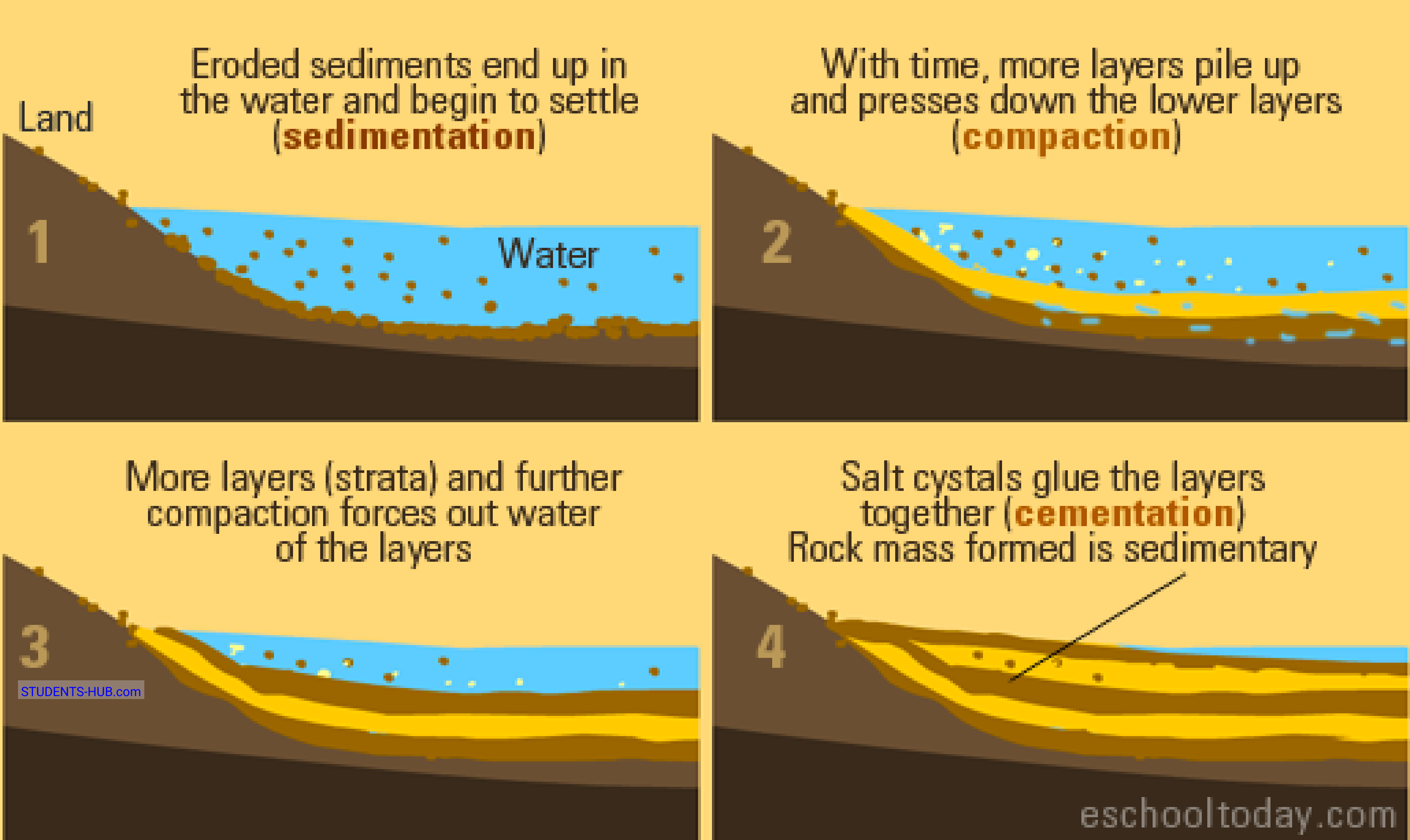
Formation of Sedimentary Rocks



From Sediment to Sedimentary Rock: Diagenesis & Lithification

- **Cementation:**
- A chemical diagenetic change that involves the precipitation of minerals (in solution) from water percolating through the pores between particles, which fill pores & joins the particles together.
- Compaction→ reduces the pore space.
- Cementation→ reduces the porosity.
- Examples of cement materials: **Calcite**, **silica** (strongest cement), and **iron oxide** (orange or dark red color). Note: type of cement α rock strength.

Lithification



Types of Sedimentary Rocks

1) Detrital Sedimentary Rocks (Clastic):
Sedimentary rocks that are formed from the deposition & accumulation of solid particles (detrital) [fragments produced by mechanical & chemical weathering].

2a) Chemical Inorganic Sedimentary Rocks:
Sedimentary rocks forming from the precipitation of material dissolved in water (chemical sediment).

2b) Chemical Organic or Biochemical Sedimentary Rock:
Sedimentary rocks forming from the accumulation of plant or animal debris. A primary example is coal; this black combustible rock consists of organic carbon from the remains of plants that died (undecayed) and accumulated on the floor of a swamp.

1) Detrital Sedimentary Rocks

- Detrital Sed. Rocks are made of a variety of mineral & rock fragments. Clay minerals & Quartz are the most common.

Explain Why….

Clay→ the most abundant product of chemical weathering of silicate minerals & stable at the surface

Quartz→ abundant because it is extremely durable & resistant to chemical weathering.

- Other common minerals: feldspar & micas when chemical weathering doesn't have time to break them down (i.e. rapid erosion & deposition).

1) Detrital Sedimentary Rocks

- **Classification of Detrital Sedimentary Rocks:**

Particle size is the primary basis for distinguishing among various detrital sedimentary rocks. Not only because it is an easy way, but because grain size provides evidence on the depositional environment. **The more energy the erosional force has→ the larger the particles it will transport.**

Examples:

- ***Gravel (large):*** moved by swiftly flowing rivers as well as by landslides and glaciers. *[High Energy]*
- ***Sand (medium):*** windblown dunes and some river deposits and beaches. [Medium Energy]
- ***Clay (small or fine):*** associated with the quiet waters of a lake, lagoon, swamp, or certain marine environments. [Low Energy]

Common detrital sedimentary rocks, in order of increasing particle size, are **shale**, **sandstone**, and **conglomerate or breccia**.

Size Range (millimeters)	Particle Name	Common Name	Detrital Rock
>256	Boulder	Gravel	Conglomerate 
64–256	Cobble		or
4–64	Pebble		Breccia 
2–4	Granule		
1/16–2	Sand	Sand	Sandstone 
1/256–1/16	Silt	Mud	Shale, Mudstone or Siltstone 
<1/256	Clay		

0 10 20 30 40 50 60 70 mm

1) Detrital Sedimentary Rocks Shale

- **General:** Shale is a sedimentary rock consisting of silt- and clay-size particles. These fine-grained detrital rocks **account for over 50% of all sedimentary rocks.**
- **Depositional Environment:** The small particles indicate that deposition occurred in a low energy environment (low turbulence current) with gradual settling. Examples: lakes, river floodplains, lagoons & deep-ocean basins.

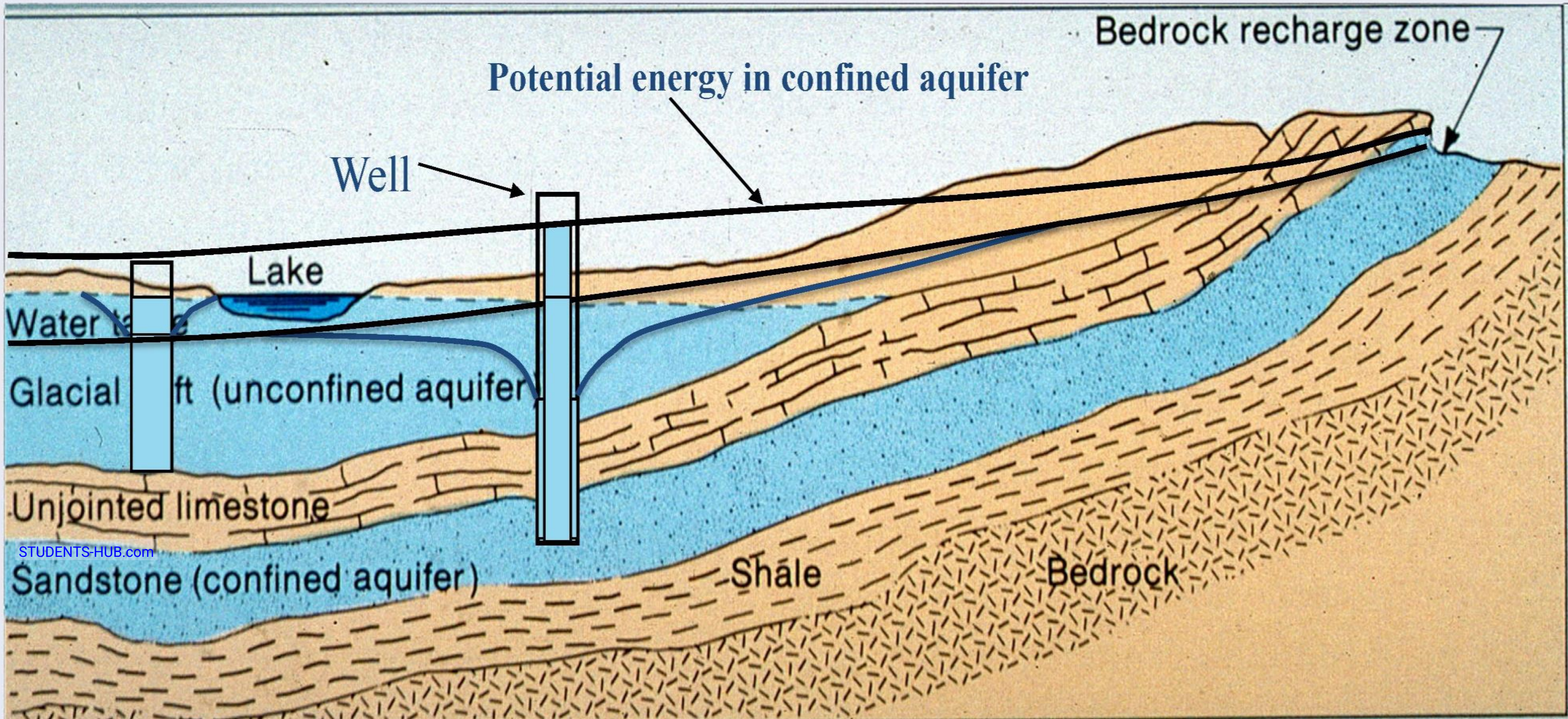
Black shales due to organic matter (carbon)→ indicate an oxygen poor environment such as a swamp (مستنقع) where organic matter doesn't decay or oxidize.

Shale

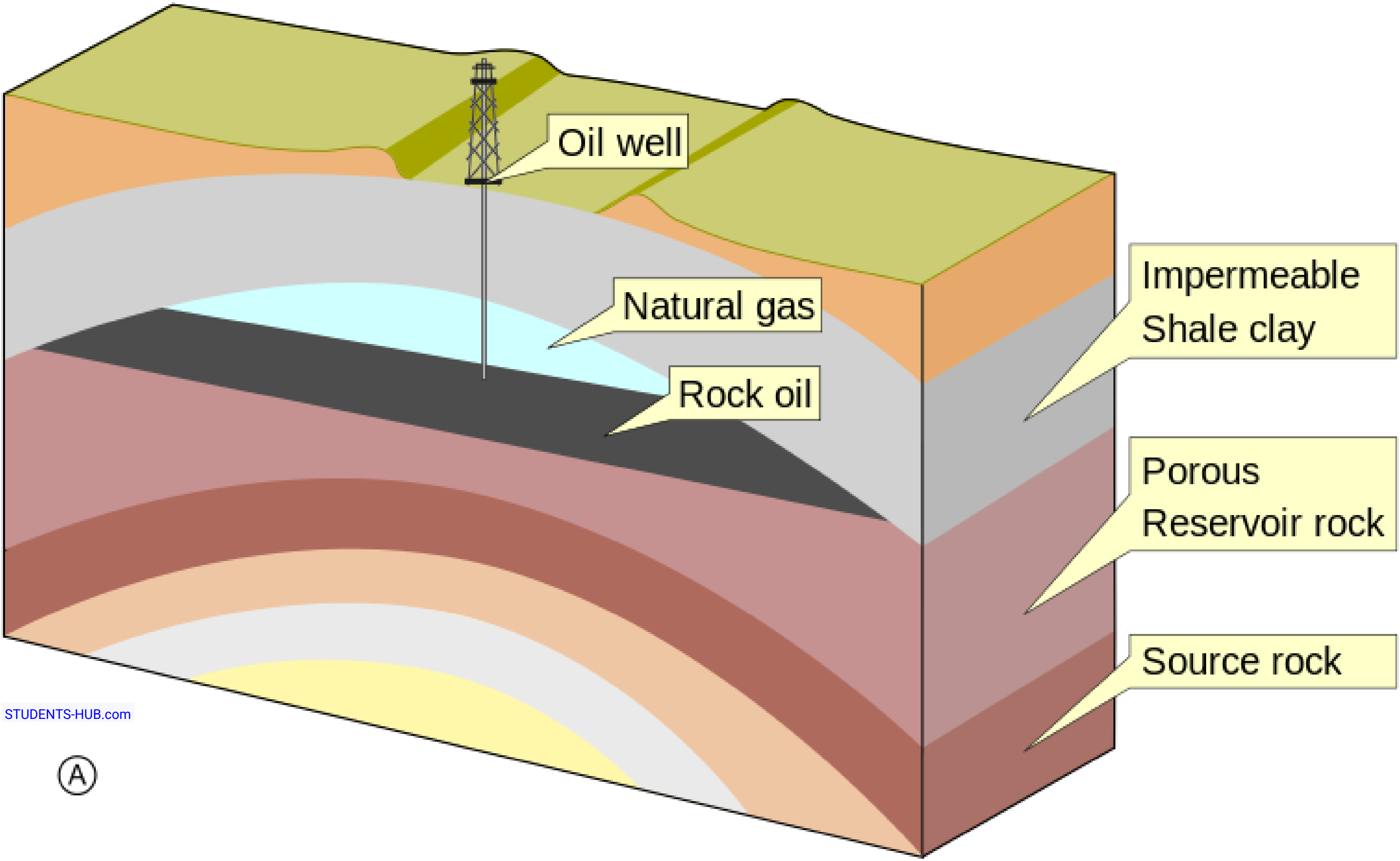
- **Shales are known to be weak rocks….why?**
  As silt & clay accumulate (when deposited), they form thin layers called ***"laminae"***. At first the particles are randomly oriented & have a lot of pore space.
  After compaction→ they become more parallel & the pore space is greatly reduced forcing out much of the water. It also become so tight that it doesn't allow solutions containing cementing materials to enter & cement the particles, therefore they are weak rocks because they are poorly cemented→ not well lithified.
- This property makes shale layers **impermeable** (a barrier) to subsurface fluids such as water and petroleum, which results in groundwater aquifers (أحواض المياه الجوفية)& oil traps that we benefit from…

Shale the confining impermeable layer→ Groundwater Aquifer

Confined Aquifer Schematic (from Driscoll, 1986)



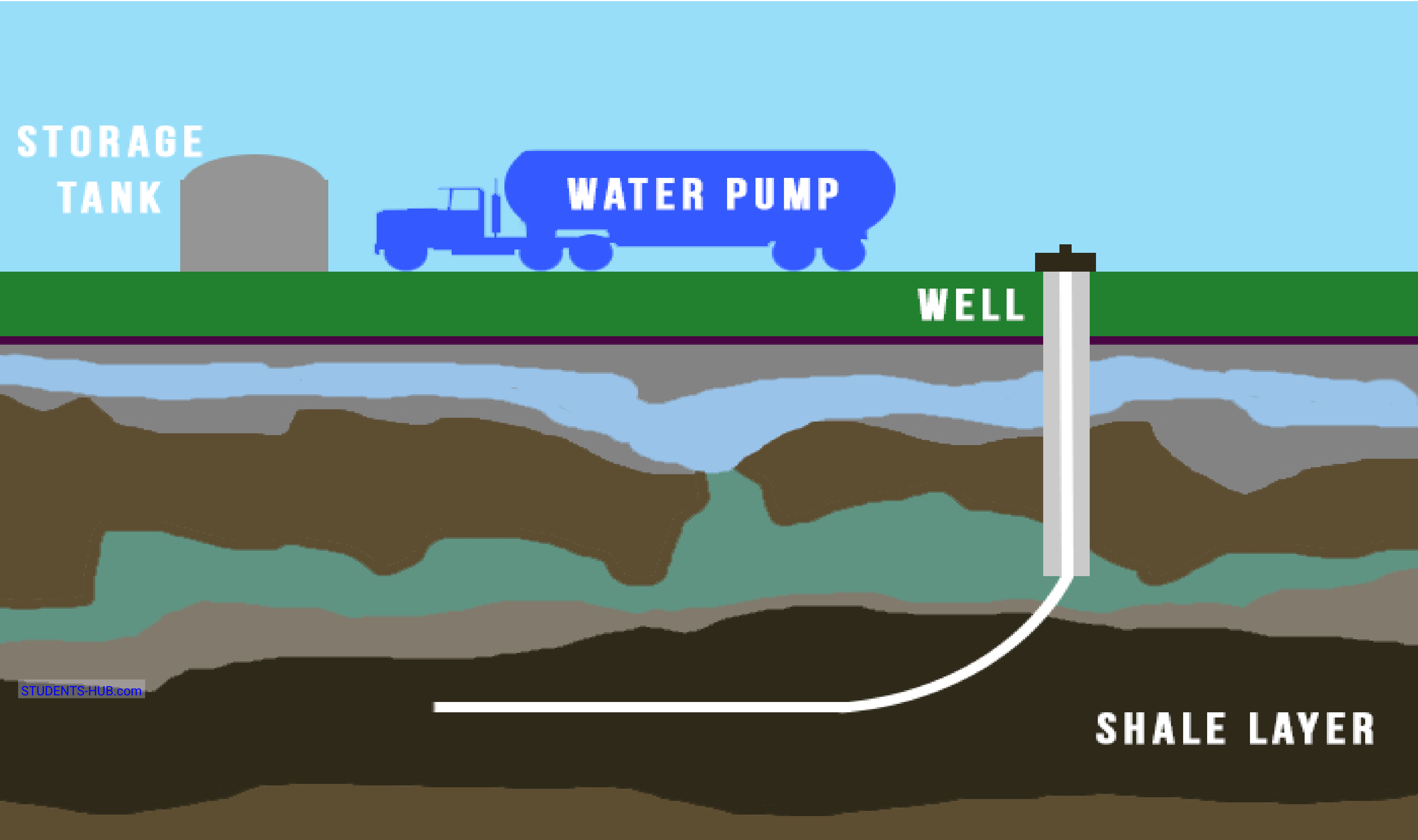
Shale "Anticline Trap"



Shale

- Shale exhibits splitting into **thin layers** along well-developed planes, a property referred to as ***fissility***. It is how we distinguish it from other similar rocks; **Mudstone** breaks into chuncks or blocks; **Siltstone** lacks fissility & is composed predominantly from silt.
- Due to its weakness, shale forms gentler slopes and crumbles often hiding underlying unweathered layers.
- Certain shales are also mined for raw material for pottery, brick, tile, & cement.

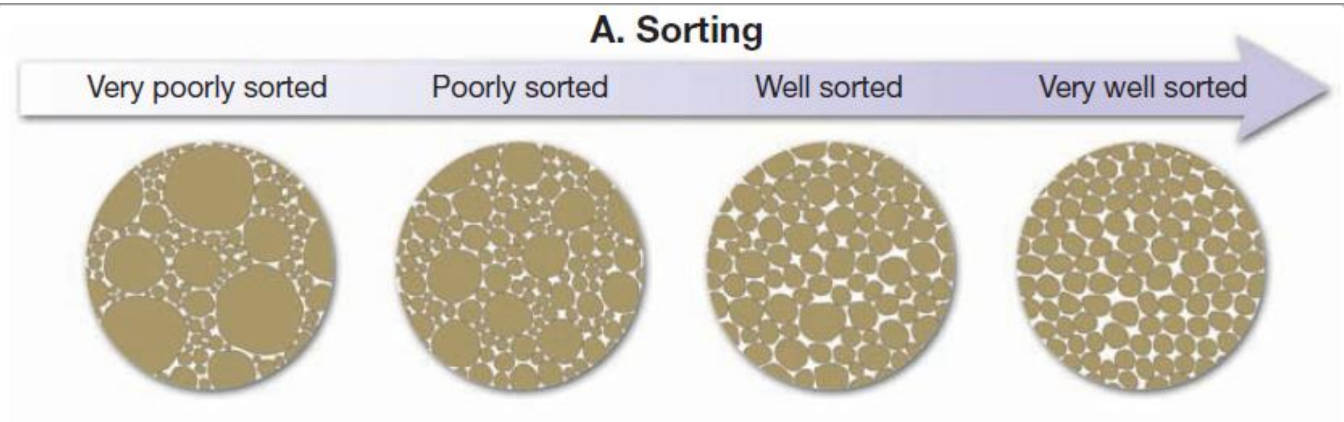
Shale Gas (Horizontal drilling or Hydraulic Fracturing "Fracking")



1) Detrital Sedimentary Rocks Sandstone

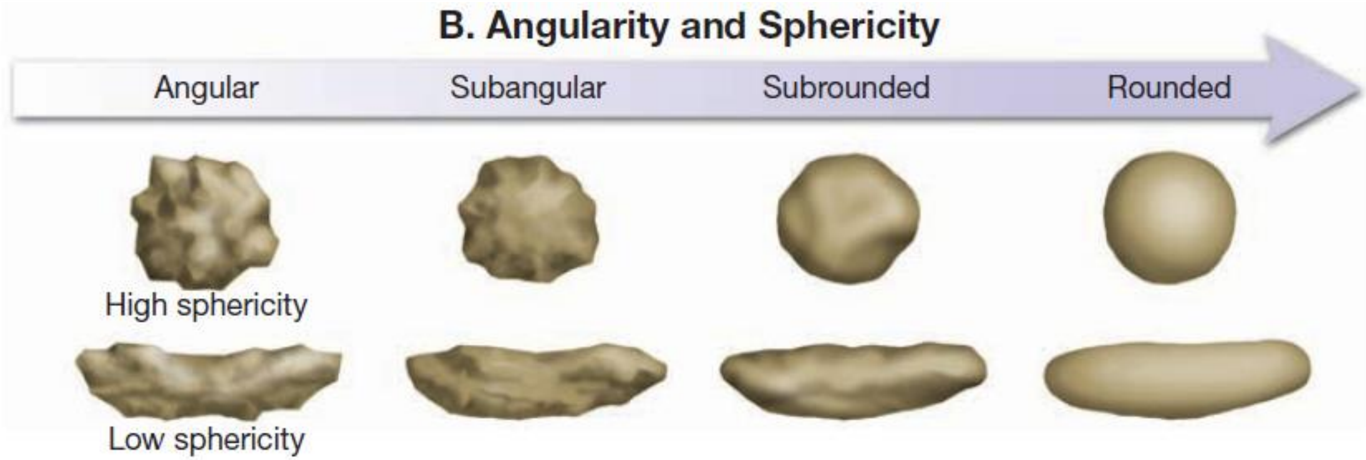
- Sandstone is the name given rocks in which sand-sized grains predominate. After shale, sandstone is the most abundant sedimentary rock, accounting for approximately 20% of the entire group.
- Sandstones form in a variety of environments and often contain significant clues about their origin, including **sorting**, **particle shape (angularity)**, and **composition**.

1) Sorting



- **Sorting:** the degree of similarity in particle size in a sedimentary rock.
- **Well Sorted→** sand grains are about the size.
- **Poorly Sorted→** rock contains mixed large & small particles.
- Degree of sorting indicates depositional environment: deposits of windblown sand are better sorted than those from wave activity, which in turn are better sorted than stream deposits (transported for short time & deposited rapidly).

2) Particle Shape or “Angularity”



- When streams, winds or waves move sedimentary particles, the grains lose their sharp edges and corners, becoming more rounded as they collide with other particles (abrasion) during transport.
- Thus, angularity indicates the distance or time of transport…

3) Mineral Composition

- Erosional forces not only influence sorting & degree of rounding, but also the mineral composition.
- **How?** Long transport & substantial weathering gradually destroy weaker & less stable minerals such as feldspar and ferromagnesian (dark) minerals. On the contrary, quartz is highly durable and survives turbulent air & water currents.
- Quartz Sandstone: quartz is the predominant mineral.
- Arkose: A sandstone containing appreciable quantities of feldspar (25%). Also contains quartz & mica.
  Envirn: granitic source rock, poor sorting & angularity → short-distance transport, little chemical weathering in dry climate, and rapid deposition.
- Graywacke: A dark colored sandstone that contains over 15% silt and clay as matrix (groundmass) around quartz & feldspar.

1) Detrital Sedimentary Rocks CONGLOMERATE & BRECCIA

- **Conglomerate consists largely of rounded gravels & the gaps are filled with sand & mud (matrix)**, so they can safely be considered poorly-sorted.
- The Gravel is large enough to be identified as a distinctive rock type; so they can indicate the **source areas of sediments.**
- **Depositional Environ:** Gravel usually indicates steep slopes or very turbulent current such as the action of energetic mountain streams or strong wave activity along a rapidly eroding coast . Some glacial and landslide deposits also contain plentiful gravel.

1) Detrital Sedimentary Rocks CONGLOMERATE & BRECCIA

- **Breccia: Same as a conglomerate but the large particles are angular rather than rounded.**
- Angular gravel particles indicate less abrasion, less travel time & distance.

Conclusion

- **Particle Sizes→** indicate the strength of the currents that transported them.
- **The Degree of Rounding→** indicate how far the particles traveled.
- **The Fragments→** identify the source rocks that supplied them.

2) Chemical Sedimentary Rocks

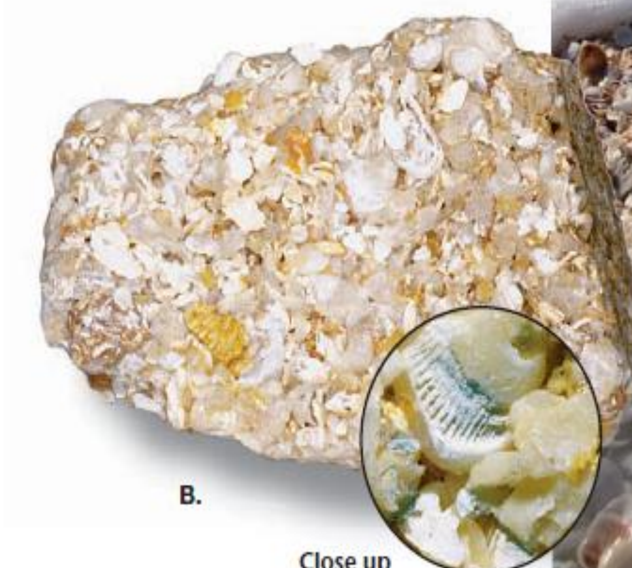
- **Sedimentary rocks formed from sediments derived from ions that are carried *in solution to lakes and seas, which precipitate out of the water to form sedimentary rocks such as* limestone, chert, and rock salt.**
- This precipitation of material occurs in two ways:
  1) ***Inorganic processes*** *such as evaporation [ex: salt]* and chemical activity can produce chemical sediments.
  2) ***Organic (life) processes*** *of water dwelling* organisms also form chemical sediments, said to be of biochemical origin.

Inorganic vs. Organic Chemical Sed. Rocks

FIGURE 6.8 Because many cave deposits are

FIGURE 6.9 **A.** This Florida beach consists primarily of shells and shell fragments—biochemical sediment. *(Photo by Donald R. Frazier Photolibrary, Inc./Plany)* **B.** This rock, a variety of limestone called coquina, consists of shell fragments. *(Photo by E.J. Tarbuck)*

A.



B.

Close up

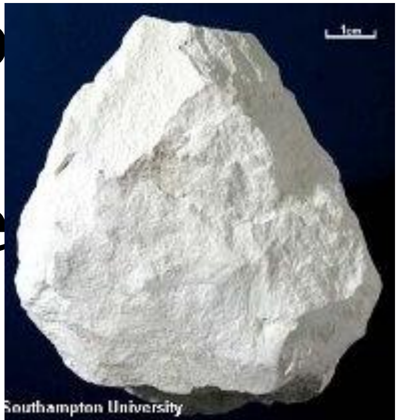
2) Chemical Sedimentary Rocks LIMESTONE الحجر الجيري

- Accounts for ~10% of the total volume of all sedimentary rocks.
- *limestone is* the most abundant chemical sedimentary rock.
- It is composed chiefly of the mineral calcite [Calcium Carbonate ($CaCO_3$)] and forms either by inorganic or biochemical processes.
- Limestones form under a variety of conditions producing many types, however, the composition of all limestones is similar. Those having a marine biochemical origin are by far the most common.

2) Chemical Sedimentary Rocks LIMESTONE

- **<u>Organic Limestone:</u>**

- *Corals (Carbonate Reefs)*
- ***Coquina:***
  a coarse rock composed of poorly cemented shells and shell fragments.
- ***Chalk:***
  a soft, porous rock made up almost entirely of the hard parts of microscopic marine organisms

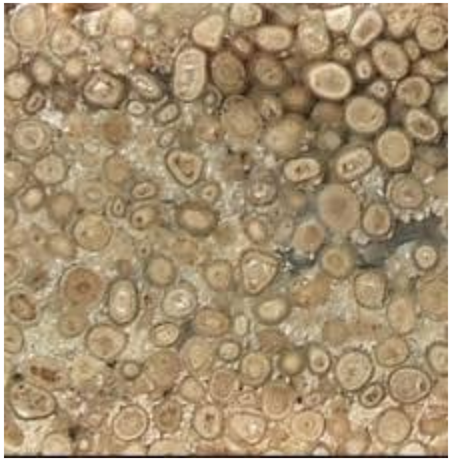


2) Chemical Sedimentary Rocks LIMESTONE

- **Inorganic Limestone:**

  Form when chemical changes or high water temperatures increase the concentration of calcium carbonate to the point that it precipitates.

- ***Travertine:*** deposited in caves, groundwater precipitates $CaCo_3$.
- ***Oolitic limestone:*** It is a rock composed of small spherical grains called *ooids* which form in shallow marine waters.



2) Chemical Sedimentary Rocks DOLOSTONE

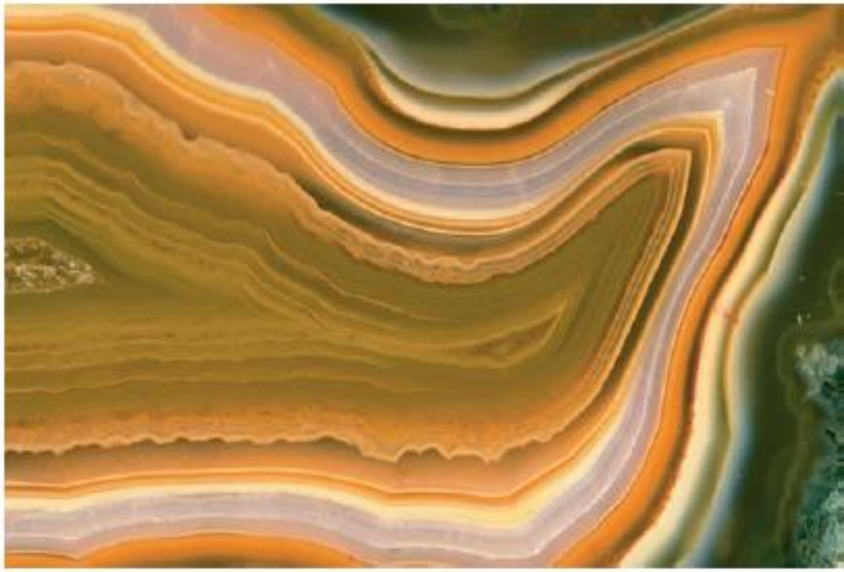
- *It is composed of* **calcium-magnesium carbonate** mineral dolomite [$CaMg(CO_3)_2$].
- Dolostone is a rock closely related to limestone & sometimes look alike, so we can distinguish using **dilute hydrochloric acid**; limestone reacts strongly (fizzes), while it is less in dolostone.
- **The origin of dolostone** is still debated among geologists, but it can occur as follows:

1) Chemical precipitation of dolomite from seawater. (less common & in unusual water chemistry in certain near-shore sites).
2) **Dolostone produced when magnesium-rich waters circulate through limestone and convert calcite to dolomite** by the replacement of some calcium ions with magnesium ions (*dolomitization).*

Note: However, other dolostones lack evidence that they formed by such a process, and their origin remains uncertain.

2) Chemical Sedimentary Rocks CHERT الصوان

- *Chert is a name used for a number of very* compact and hard rocks made of microcrystalline quartz (SiO_2).
- ***Flint:*** dark colored from the organic matter it contains.
- ***Jasper***: red bright colored from the iron-oxide it contains.
- ***Agate:*** a banded form of chert. One well-known form is *flint, whose dark color results from the*



A. Agate

B. Flint C. Jasper D. Arrowhead

2) Chemical Sedimentary Rocks
CHERT الصوان

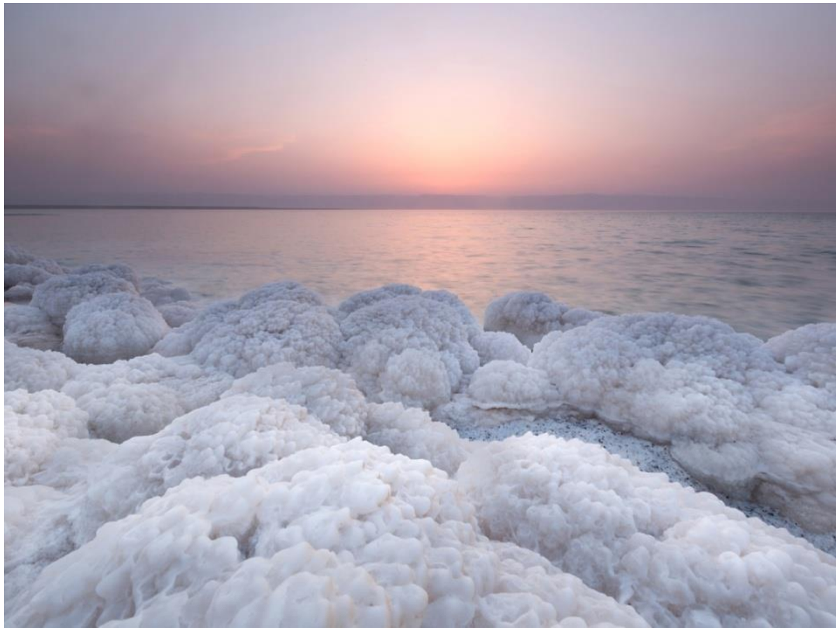
- Chert deposits are commonly found in one of two situations:

1) ***Bedded Chert:*** when tiny water-dwelling organisms are able to extract silica even though seawater contains only tiny quantities of the dissolved material. It is from their remains that most bedded cherts are believed to originate. Some bedded cherts occur in association with lava flows and layers of volcanic ash.
2) ***Chert nodules*** are sometimes referred to as *secondary or replacement cherts and most often occur within beds of limestone. They* form when silica originally deposited in one place dissolves, migrates, and then chemically precipitates elsewhere, replacing older material.

EVAPORITES

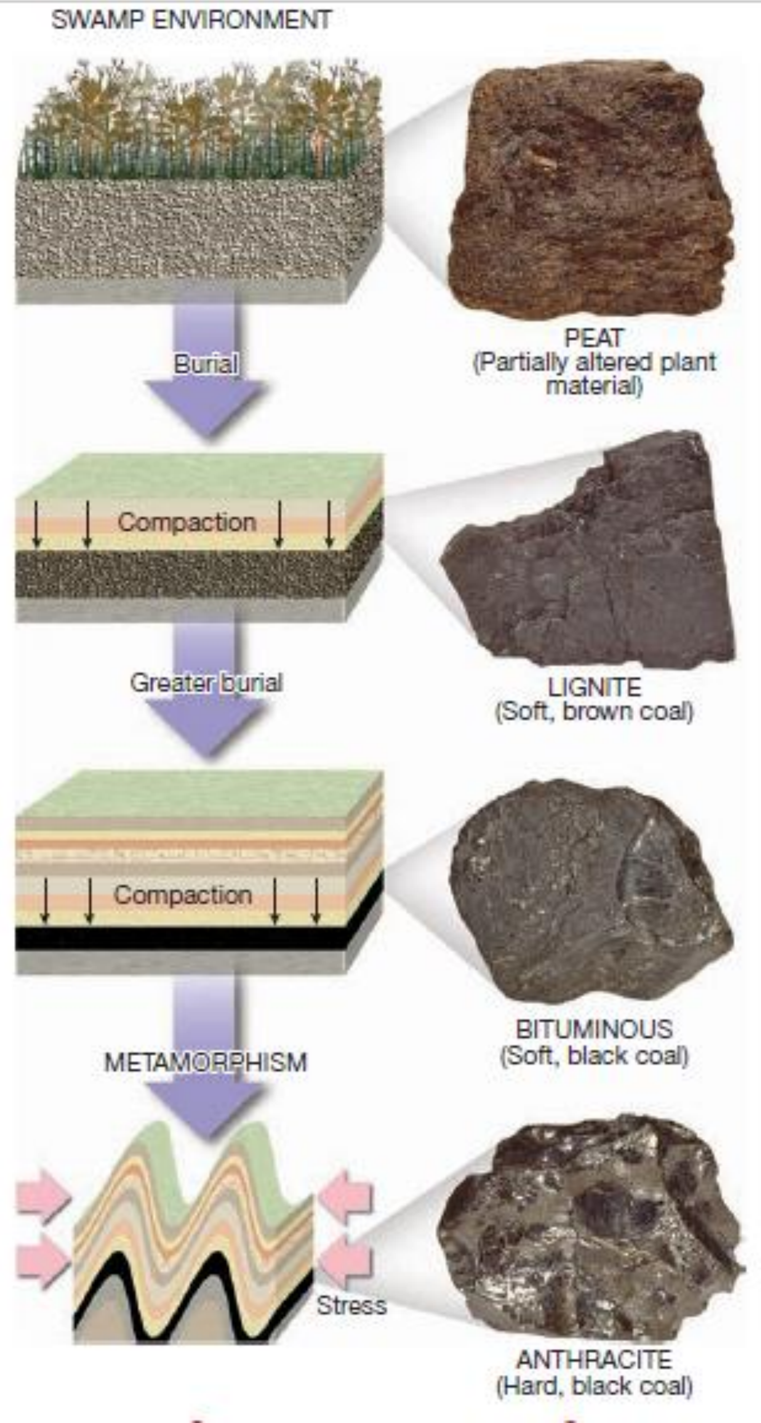
- A form of inorganic chemical sedimentary rocks resulting from the evaporation of water and precipitation of minerals such as halite (sodium chloride, NaCl), the chief component of *rock salt*, and gypsum (hydrous calcium sulfate, $CaSO_4\ 2H_2O$), the main ingredient of *rock gypsum*.

- **Uses of these evaporates:**
  Halite → *kitchen* salt, melting ice on roads, etc.
  Gypsum → is the basic ingredient of plaster of Paris. This material is used as wall board and interior plaster.



COAL (الفحم)

- *Coal* is quite different from other sedimentary rocks. Unlike limestone and chert, which are calcite or silica rich, coal is made mostly of organic matter. coal is in fact the end product of large amounts of plant material buried for millions of years [organic chemical sedimentary rock].



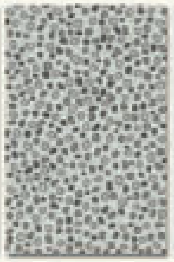
Classification of Sedimentary Rocks

- Sedimentary rocks are divided into two major groups:

1) **Detrital:** The main criterion for subdividing the **detrital rocks** is particle size.
2) **Chemical:** the primary basis for distinguishing among different rocks in the **chemical group** is their mineral composition & Texture.

- **Texture:** Similar to Igneous rocks texture is a part of sedimentary rock classification. Two major textures are used in the classification:
  1) **Clastic:** from Greek meaning "broken", so consisting of fragments & particles that are cemented and compacted together. [Ex: Coquina, fossiliferous L.S., chalk]
  2) **Nonclastic:** or crystalline texture in which the minerals form a pattern of interlocking crystals. [ex: travertine, rock salt, rock gypsum, bituminous coal, etc.]

Detrital Sedimentary Rocks

Clastic Texture (particle size)		Sediment Name	Rock Name
Coarse (over 2 mm)		Gravel (Rounded particles)	**Conglomerate**
		Gravel (Angular particles)	**Breccia**
Medium (1/16 to 2 mm)		Sand (If abundant feldspar is present the rock is called **Arkose**)	**Sandstone**
Fine (1/16 to 1/256 mm)		Mud	**Siltstone**
Very fine (less than 1/256 mm)		Mud	**Shale or Mudstone**

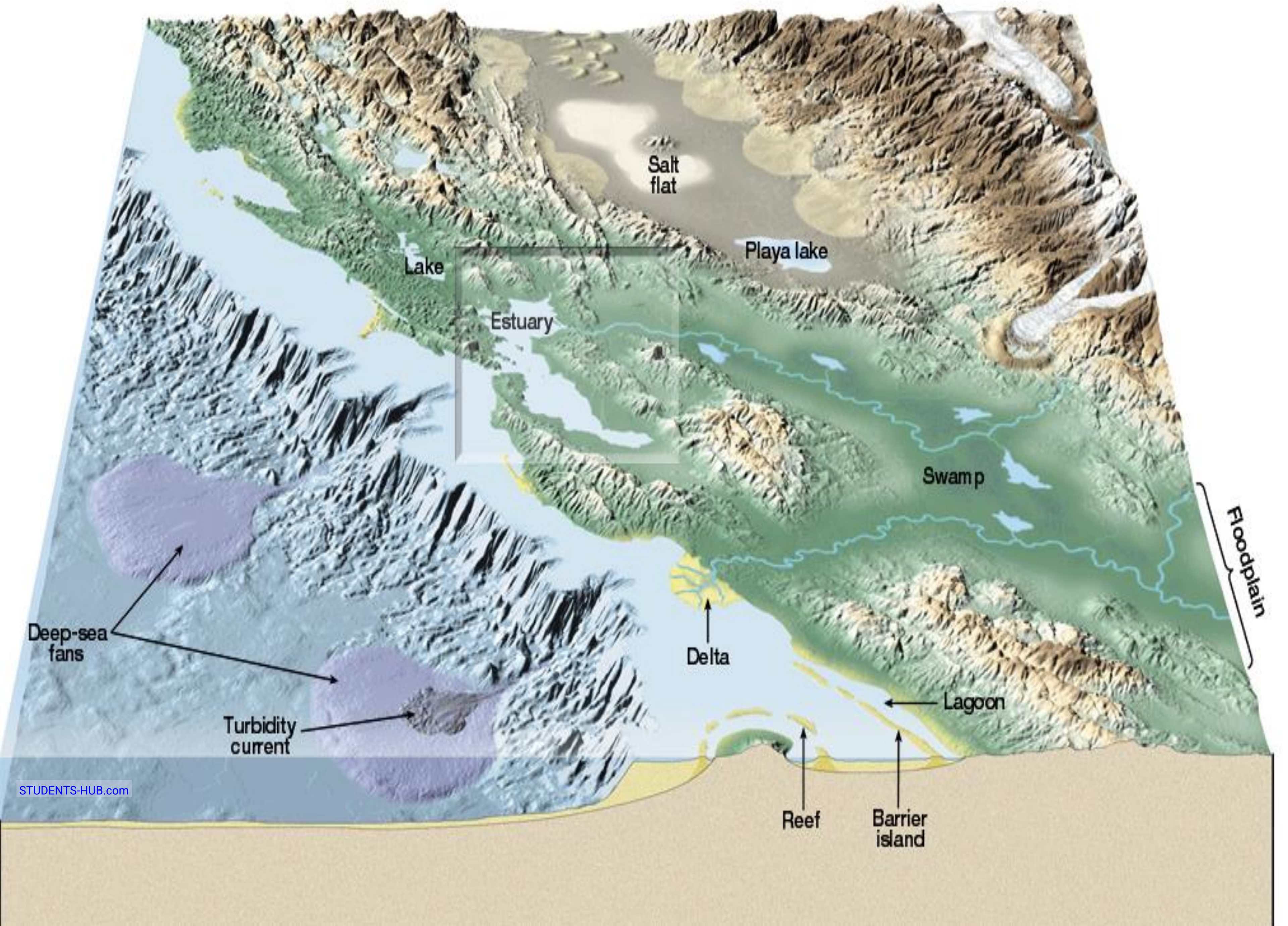
Chemical and Organic Sedimentary Rocks

Composition	Texture	Rock Name	
Calcite, $CaCO_3$	Nonclastic: Fine to coarse crystalline	**Crystalline Limestone**	
		Travertine	
	Clastic: Visible shells and shell fragments loosely cemented	**Coquina**	**Biochemical Limestone**
	Clastic: Various size shells and shell fragments cemented with calcite cement	**Fossiliferous Limestone**	
	Clastic: Microscopic shells and clay	**Chalk**	
Quartz, SiO_2	Nonclastic: Very fine crystalline	**Chert (light colored)** **Flint (dark colored)**	
Gypsum $CaSO_4 \cdot 2H_2O$	Nonclastic: Fine to coarse crystalline	**Rock Gypsum**	
Halite, NaCl	Nonclastic: Fine to coarse crystalline	**Rock Salt**	
Altered plant fragments	Nonclastic: Fine-grained organic matter	**Bituminous Coal**	

FIGURE 6.16 Identification of sedimentary rocks. Sedimentary rocks are divided into three groups—detrital, chemical, and organic. The main criterion for naming detrital sedimentary rocks is particle size, whereas the primary basis for distinguishing among chemical sedimentary rocks is their mineral composition.

Sedimentary Rocks & Structures Represent Past Environments….

- By analyzing a sedimentary rock, geologists can often reconstruct the history of a rock; including the **origin of its component** particles, the method of sediment **transport**, and the **depositional environment** or sedimentary environment (associated with a type of topography).
- Conclusions about the past can be also supported by observing/ studying present-day depositional environments **[Law of Uniformitarianism: "the present is the key to the past"]**
- Sedimentary environments are commonly placed into one of three categories: *continental, marine, or transitional (shoreline).* Each category having many specific subenvironments.



Salt flat
Playa lake
Lake
Estuary
Swamp
Floodplain
Deep-sea fans
Turbidity current
Delta
Lagoon
Reef
Barrier island

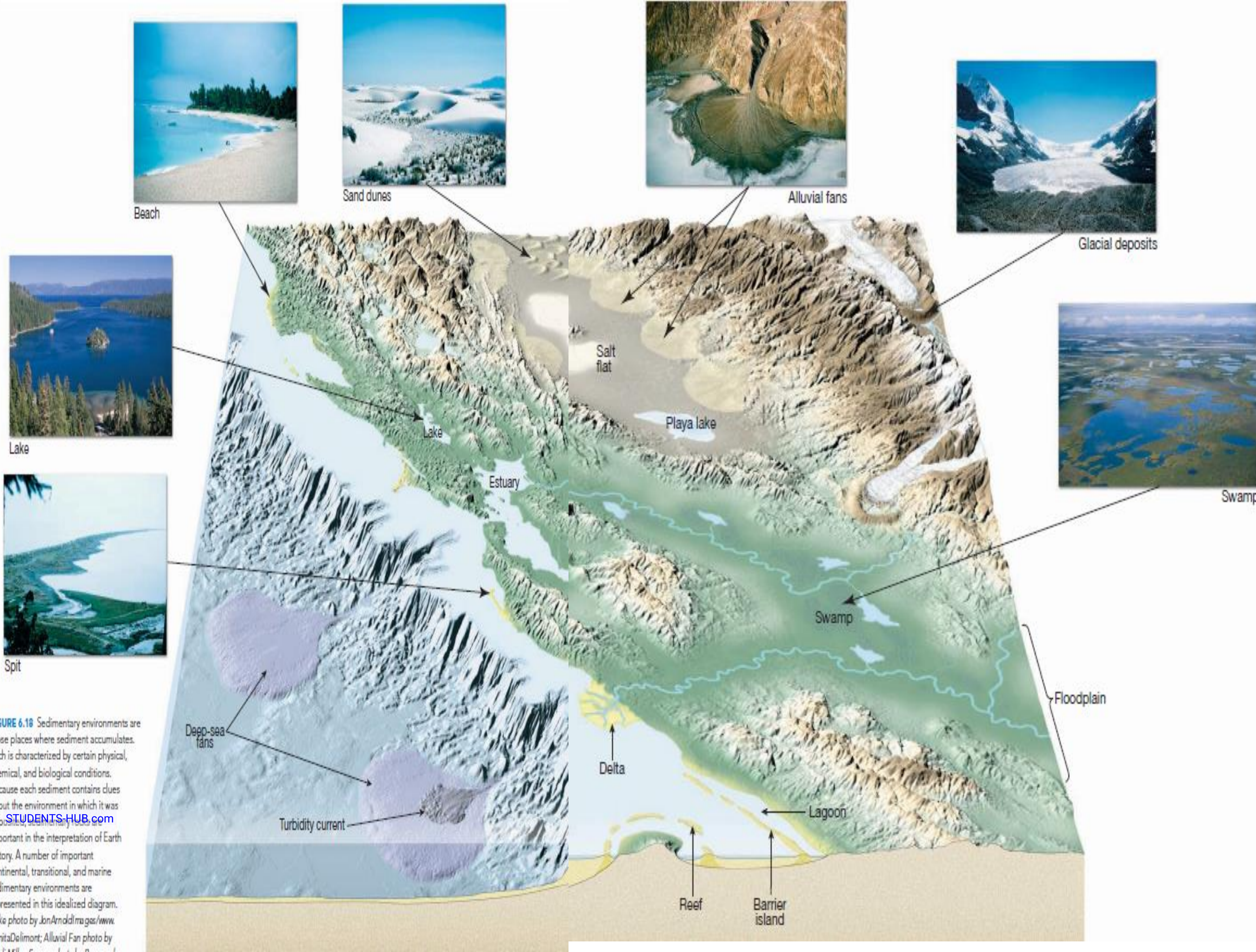


FIGURE 6.18 Sedimentary environments are those places where sediment accumulates. Each is characterized by certain physical, chemical, and biological conditions. Because each sediment contains clues about the environment in which it was deposited, sedimentary rocks are important in the interpretation of Earth history. A number of important continental, transitional, and marine sedimentary environments are represented in this idealized diagram. (Lake photo by JonArnoldImages/www.DanitaDelimont; Alluvial Fan photo by

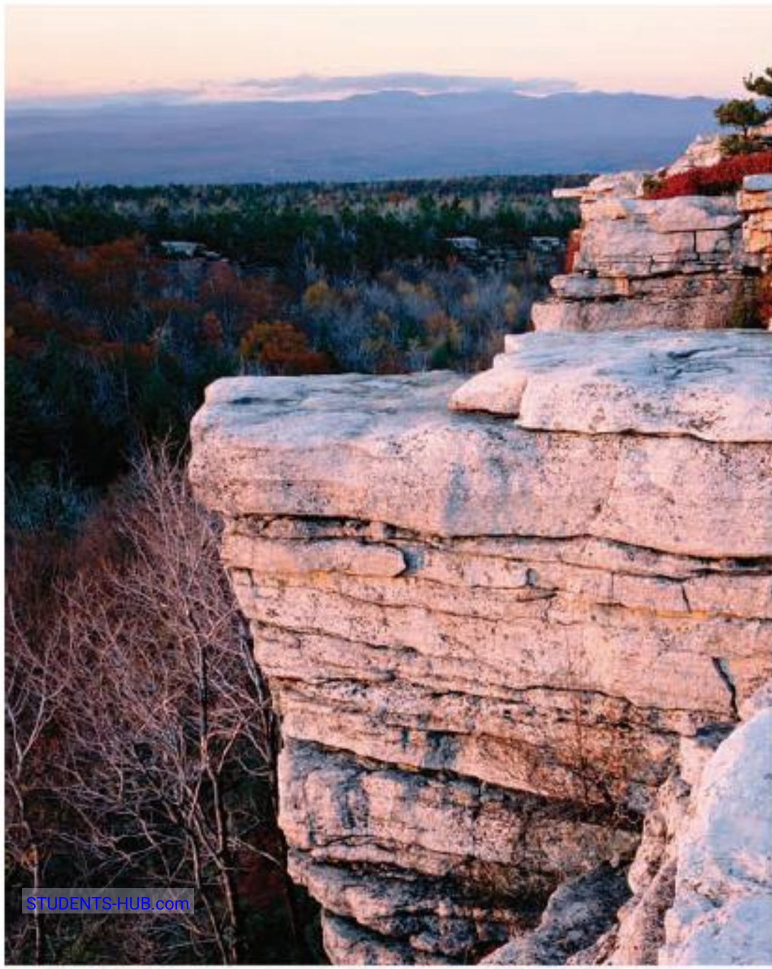
Sedimentary Structures

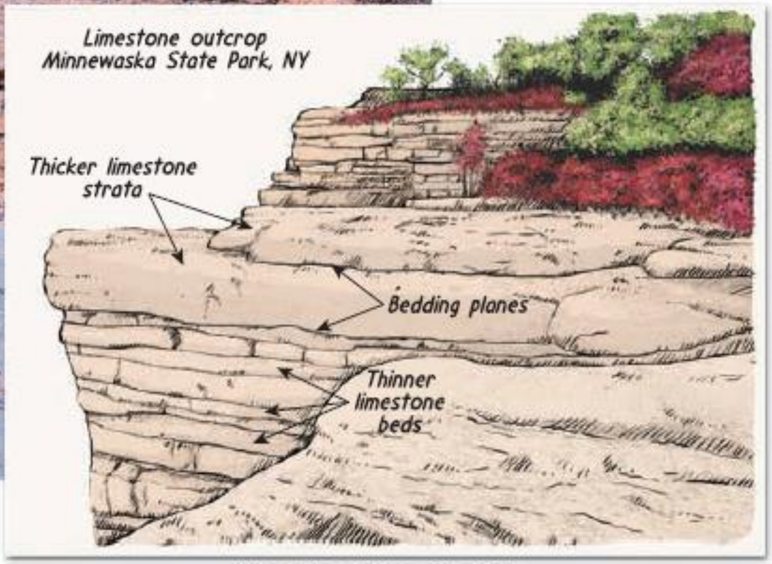
- In addition to variations in grain size, mineral composition, and texture, sediments exhibit a variety of structures.
- Sedimentary rocks form as layer upon layer of sediment accumulates in various depositional environments. **These layers, called strata or beds,** are probably *the single most common and characteristic feature of sedimentary rocks.*
- *Each stratum/ layer is unique with its own* texture, composition, and thickness reflecting the different conditions under which each layer was deposited.

Sedimentary Structures

- The thickness of beds ranges from microscopically thin to tens of meters thick.
- Separating the strata are **bedding planes, flat surfaces along which rocks tend to separate or break.**
- **These bedding planes are created when there is a change** in the grain size or in the composition of the deposited sediment, or even pauses in deposition.
- Generally, each bedding plane marks the end of one episode of sedimentation and the beginning of another.

Sedimentary Structures: Bedding & Bedding Planes



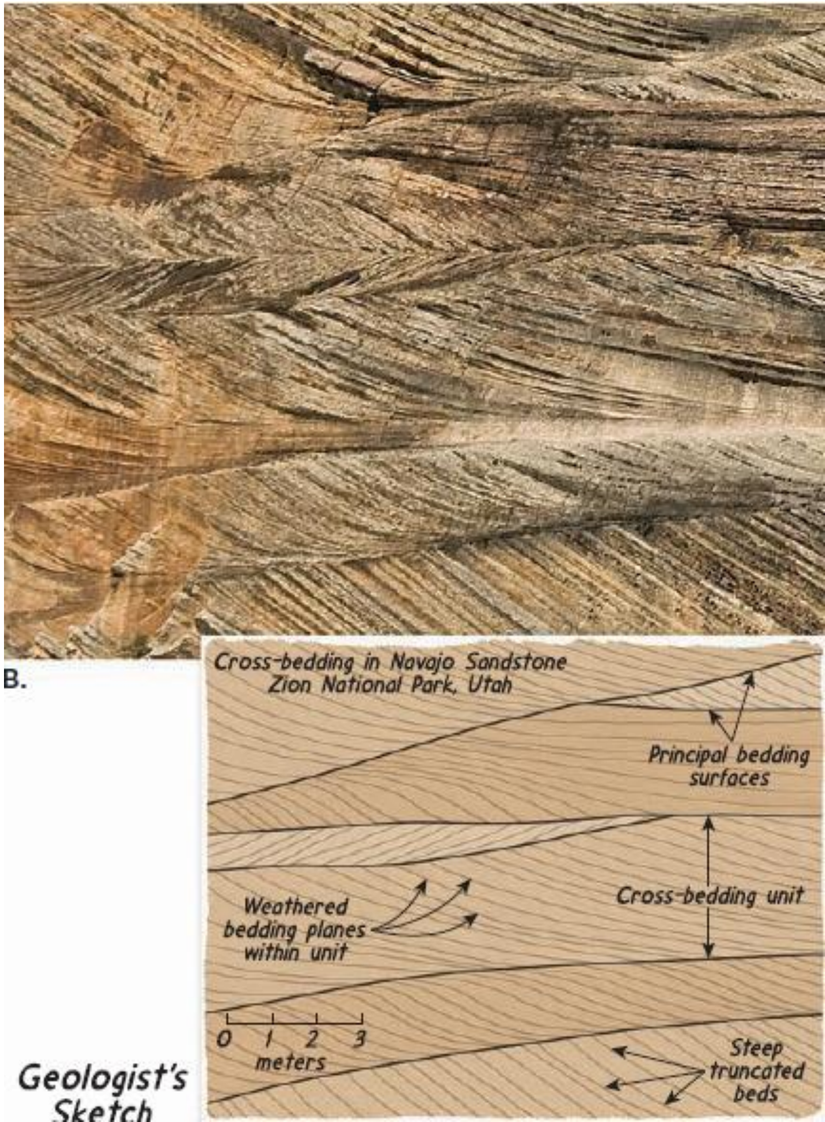


Geologist's Sketch

FIGURE 6.19 This outcrop of sedimentary strata illustrates the characteristic layering of this group of rocks. Minnewaska State Park, New York. *(Photo by Carr Clifton/National Geographic Stock)*

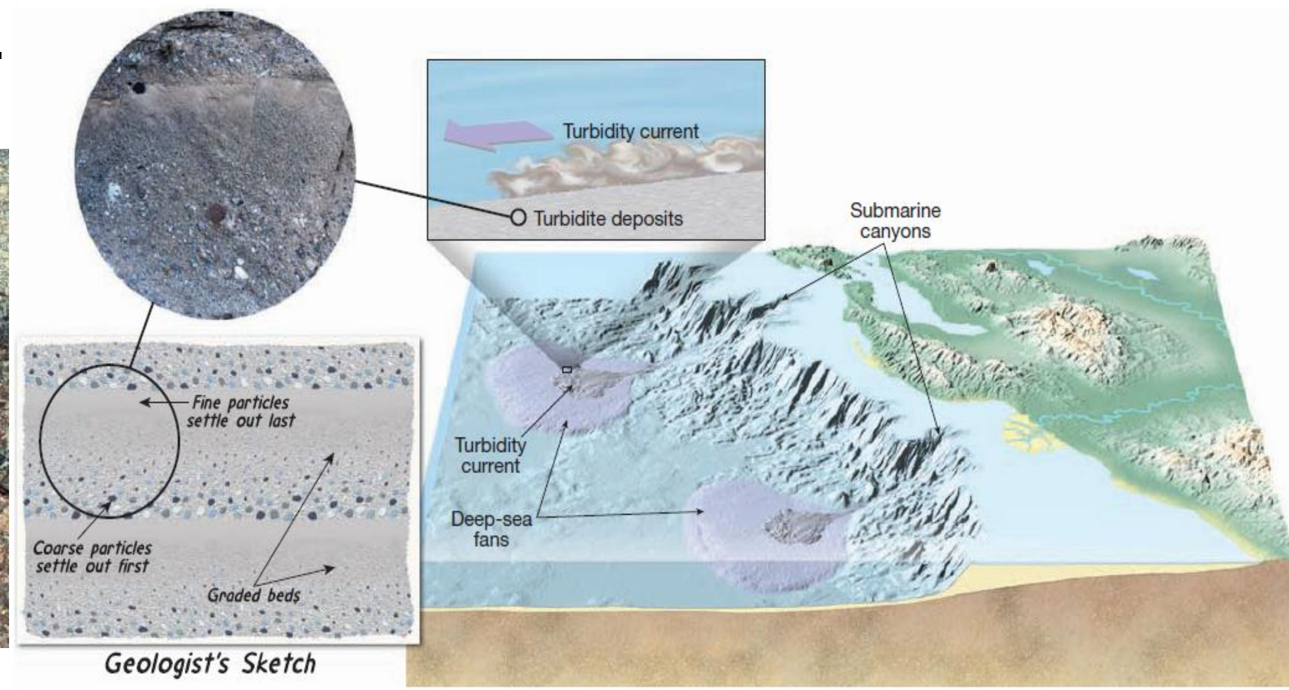
Sedimentary Structures: Cross Bedding

- Typically sediments are deposited in horizontal layers/ beds.
- However, in some circumstances, they do not form horizontal beds. In this case it is called **cross-bedding** and is most characteristic of sand dunes, river deltas, and some stream channels.



Sedimentary Structures: Graded Bedding

- **Graded bedding: The particles in a single layer gradually change from coarse at the bottom to fine at the top.**
- **How this occurs:** When a current experiences a rapid energy loss, the largest particles settle first, followed by successively smaller grains.
- **Depositional Environment:** Most often associated with a turbidity currents.



Sedimentary Structures: More Features: Ripple Marks & Mud Cracks

- **Ripple Marks** are small waves of sand that develop on the surface of a sediment layer by the action of moving water or air (usually at right angle to flow direction).

- **Mud Cracks** Mud cracks indicate that the sediment in which they were formed was alternately wet and dry. Wet mud dries out and shrinks, producing cracks.

Sedimentary Structures: Fossils

- **Fossils, the remains or traces of prehistoric life**, are important features sedimentary rocks. They are important tools for interpreting the geologic past. We also use them to correlate rocks of the similar age but from different places.

Nonmetallic Mineral Resources from Sedimentary Rocks

- Earth materials that are not used as fuels or processed for the metals they contain are referred to as nonmetallic mineral resources.
- **Nonmetallic mineral resources** are commonly divided into two broad groups: 1) ***building materials*** *and* ***2) industrial minerals.***
- Some fall under both categories. Ex: **Limestone** (most widely used rock) used as a **building material**: crushed rock and building stone, & in making cement. Also as **industrial mineral** as an ingredient in the manufacture of steel and in agriculture to neutralize acidic soils.
- **Other important building materials** include cut stone, aggregate (sand, gravel, and crushed rock), gypsum for plaster and wallboard, clay for tile and bricks, and cement (limestone & shale) is essential to construction.
- **Other important industrial minerals:** Limestone & fluorite in steel production, halite as table salt, etc.

Energy Resources from Sedimentary Rocks

- **Coal**, **petroleum**, and **natural gas** (**Fossil fuels**) are the primary fuels of our modern industrial economy.
- Despite exploration efforts, earth's petroleum reserved, cannot keep up with continuously increasing consumption.

- Two fossil fuels have potential for the future; oil sands & oil shale, however sooner or later we will have to shift to other sources such as **nuclear or renewable energy such as wind, solar, tidal, hydroelectric, etc.**

Energy Resources from Sedimentary Rocks: Coal

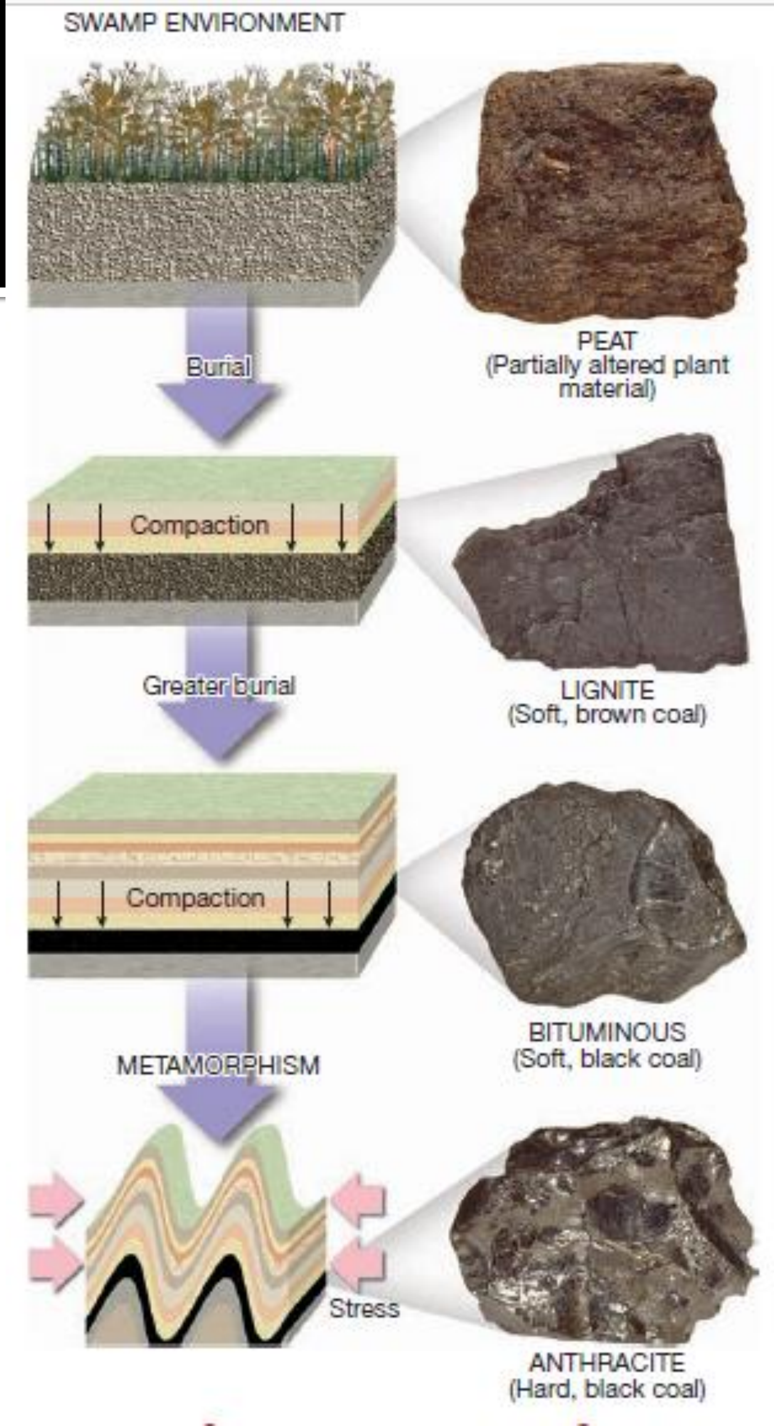
- **Coal** is one of the important fossil fuels that powered the industrial revolution 20th century.
- **Fossil Fuel:** when energy from the sun was stored by plants or organisms many million years ago. When we burn coal, we are burning a fossil.
- Problems: surface mining damages lands, underground mining causes stability problems, & pollution (التلوث) from its burning.

Energy Resources from Sedimentary Rocks: Coal

Coal Formation:

1) Accumulation of large quantities of plant remains in a swampy environment.
2) Partial decomposition by bacteria & release of oxygen & hydrogen (carbon increase)→ *Peat*
3) Shallow burial→ peat slowly changes to *lignite, a soft brown coal.*
4) Further burial→ rise in temperature causing chemical reactions yielding water and organic gases (volatiles).
Load increases from more sediment on top → water and volatiles are pressed out and increasing *fixed carbon* (solid combustible material) & making it more compact→ black rock called ***bituminous coal*** (1/10 the thickness of peat)

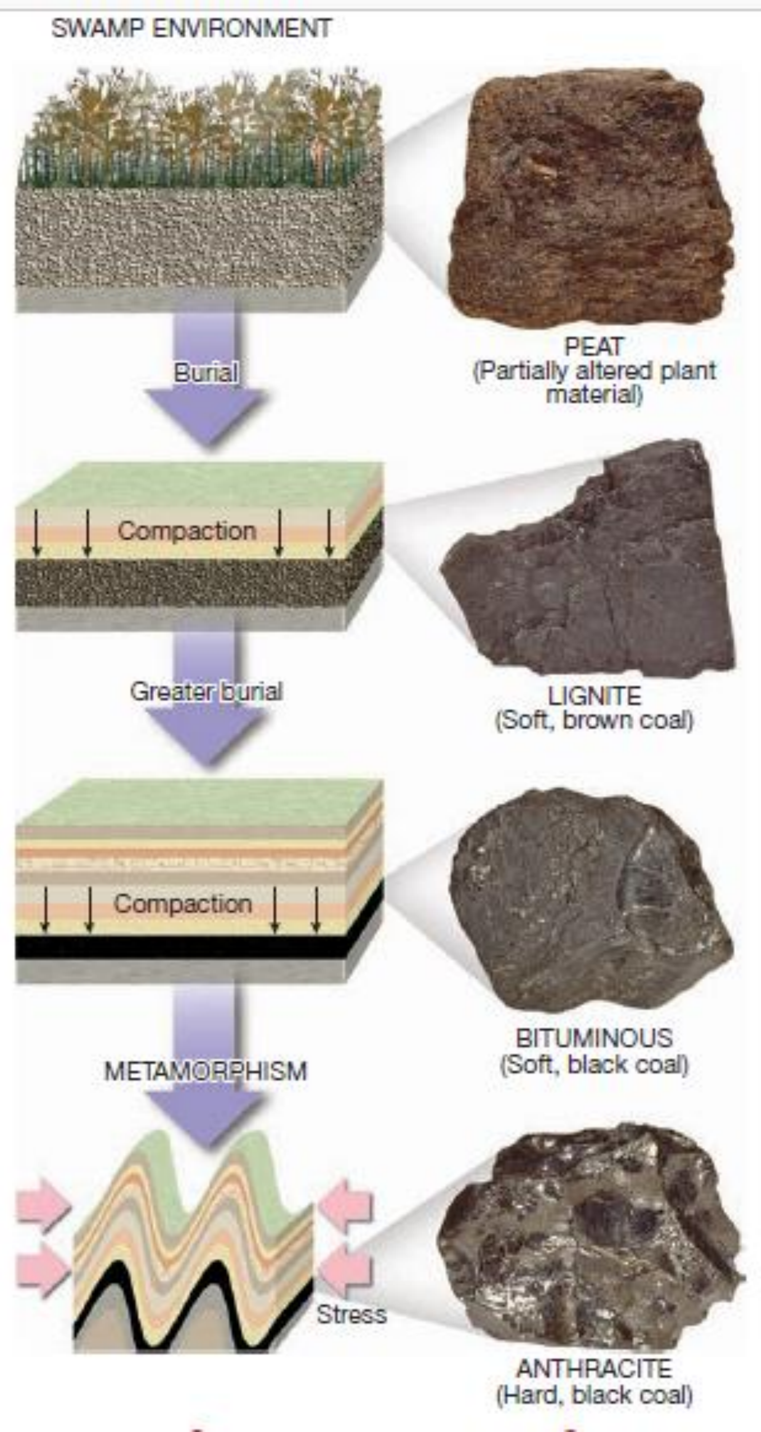
Note: The greater the carbon content, the greater the coal's energy ranking as a fuel.



Energy Resources from Sedimentary Rocks: Coal

Coal Formation:

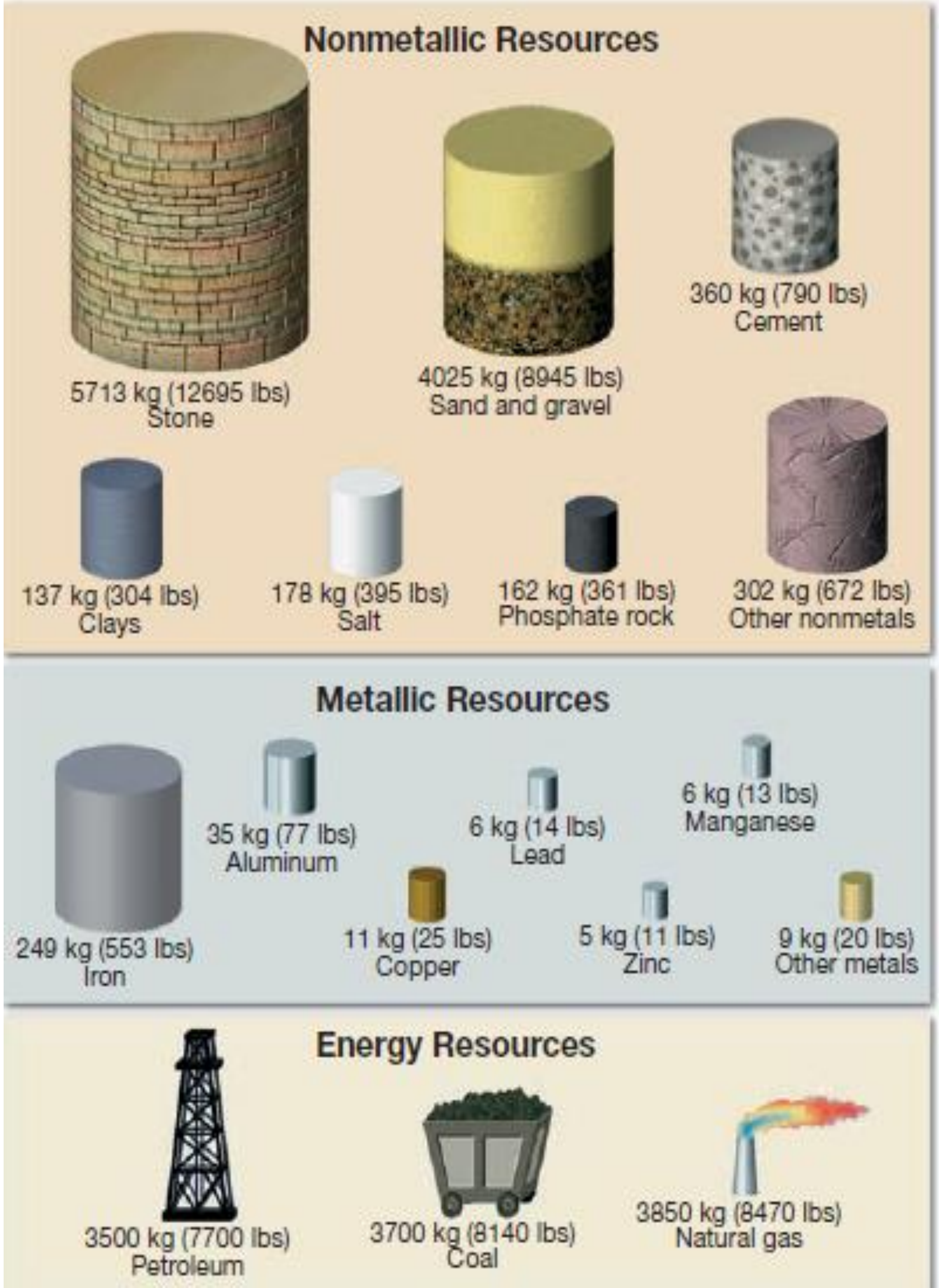
4) when sedimentary layers are subjected to the folding and deformation associated with metamorphism, the heat and pressure cause a further loss of volatiles and water, thus increasing the concentration of fixed carbon. This metamorphoses bituminous coal into ***anthracite***, *a* very hard, shiny, black *metamorphic* rock.



Energy from Sed. Rocks: Oil & Natural Gas

- Not a sed. rock, but associated with them.
- Consist of hydrocarbon compounds, the biological products of marine plant & animal remains.
- Formation of Petroleum:

- accumulation of sediment in ocean areas
- Biological activity & decay of organic matter before they are buried.
- Large quantities of organic matter buried and protected from oxidation.
- Burial over millions of years turning it into liquid and gas.



Nonmetallic Resources
5713 kg (12695 lbs)
Stone
4025 kg (8945 lbs)
Sand and gravel
360 kg (790 lbs)
Cement
137 kg (304 lbs)
Clays
178 kg (395 lbs)
Salt
162 kg (361 lbs)
Phosphate rock
302 kg (672 lbs)
Other nonmetals
Metallic Resources
249 kg (553 lbs)
Iron
35 kg (77 lbs)
Aluminum
11 kg (25 lbs)
Copper
6 kg (14 lbs)
Lead
5 kg (11 lbs)
Zinc
6 kg (13 lbs)
Manganese
9 kg (20 lbs)
Other metals
Energy Resources
3500 kg (7700 lbs)
Petroleum
3700 kg (8140 lbs)
Coal
3850 kg (8470 lbs)
Natural gas

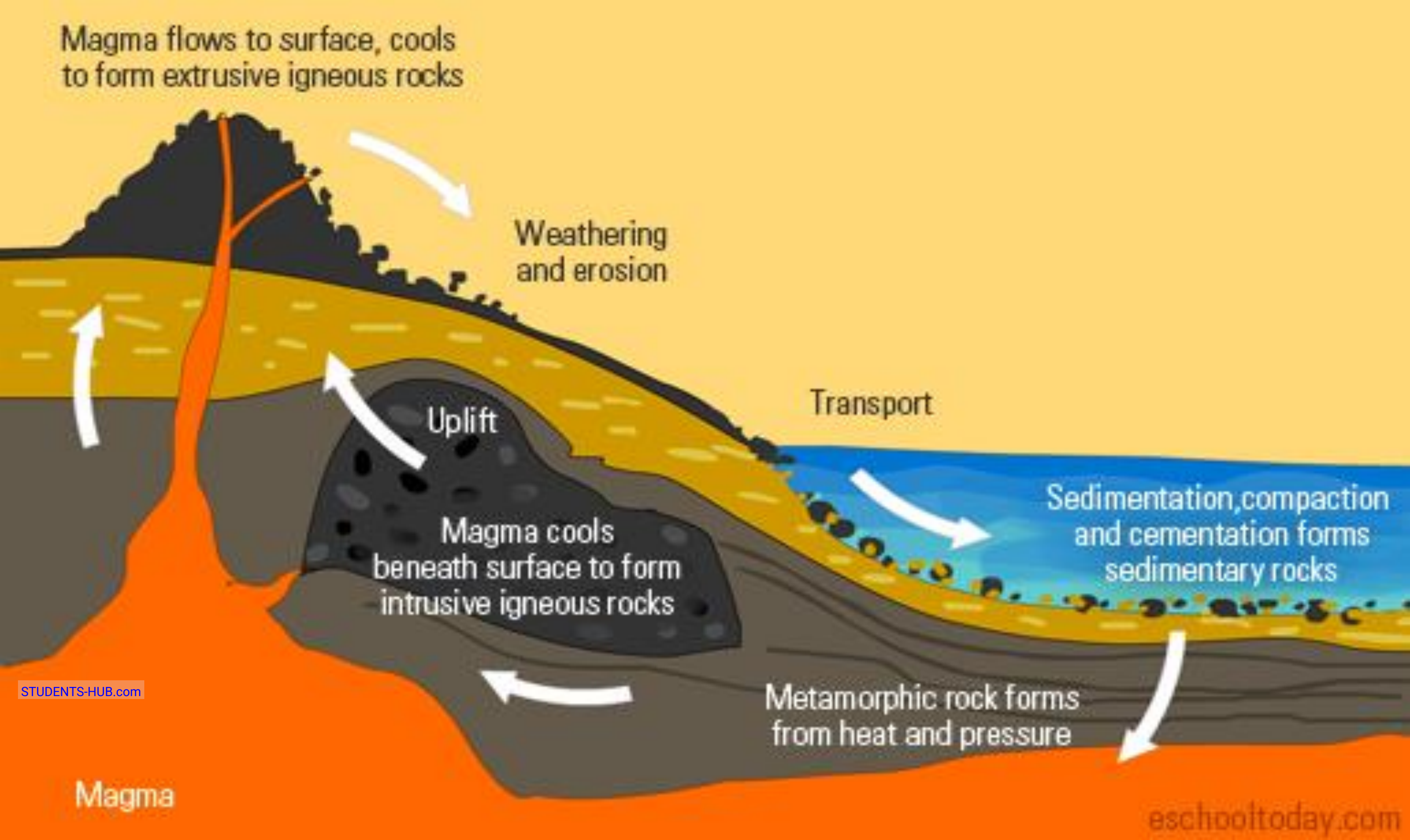
ENCE 231: Engineering Geology Fall Semester 2017/2018

Department of Civil Engineering- Birzeit University, Palestine

Chapter 7: Metamorphic Rocks

Course Instructors: Saheem Murshid
Dr. Khalil M. Qatu

Metamorphism Part of the Rock Cycle



Metamorphism: The basics

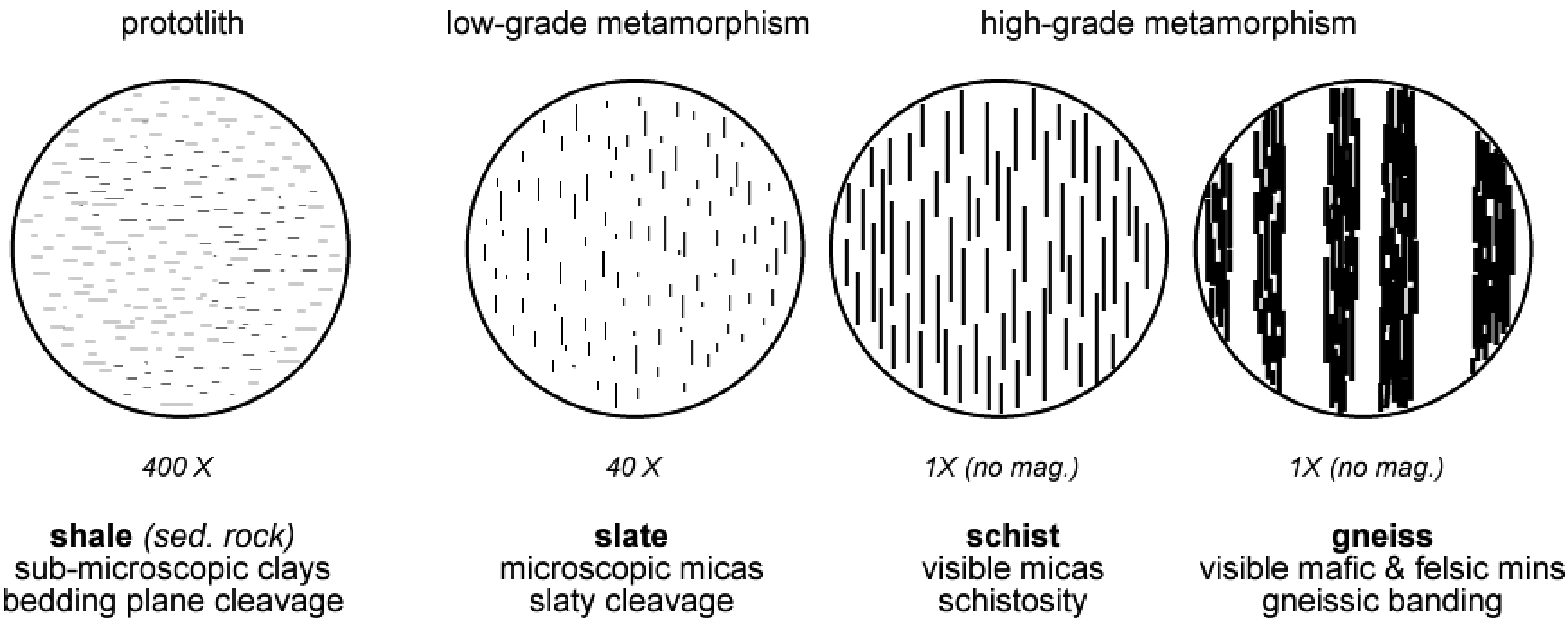
- **Metamorphism is the transformation of one rock type into another.** Metamorphic rocks are produced from preexisting igneous, sedimentary, or even other metamorphic rocks. Thus, every metamorphic rock has a parent rock—the rock from which it was formed.
- Metamorphism, which means to "change form," is a process that leads to **changes in the mineral content, texture, and sometimes the chemical composition of rocks.** Metamorphism takes place where preexisting rock is subjected to new conditions such as heat, pressures, and chemically active fluids.

Intensities/Grades of Metamorphism

1) **Low-grade Metamorphism:** Lower intensity. Ex: *Shale→Slate*

2) **High-grade Metamorphism:** more extreme environments. Causes a transformation so complete that the identity of the parent rock cannot be determined. Features such as bedding planes, fossils, and vesicles that existed in the parent rock are destroyed.

- Further, when rocks deep in the crust (where temperatures are high) are subjected to directed pressure, the entire mass may deform, producing large-scale structures such as **folds**.


prototlith
low-grade metamorphism
high-grade metamorphism
400 X
40 X
1X (no mag.)
1X (no mag.)
shale (sed. rock)
sub-microscopic clays
bedding plane cleavage
slate
microscopic micas
slaty cleavage
schist
visible micas
schistosity
gneiss
visible mafic & felsic mins
gneissic banding

Agents of Metamorphism:
1) Heat 2) Pressure 3) Fluids

- The agents of metamorphism include *heat, pressure (stress), and chemically active fluids.* During metamorphism, rocks are usually subjected to all three metamorphic agents simultaneously. However, the degree of metamorphism and the contribution of each agent vary greatly from one environment to another.

Agents of Metamorphism:

1) Heat 2) Pressure 3) Fluids

- Heat is the most important agent of metamorphism. **Temperature (T) ranges between 200°C and 850°C. Temperatures increase with depth.**
- It provides the energy for chemical reactions that result in the following:

1) **Recystallization of existing minerals**.
Clays & other fine particles join together to form larger minerals of the same mineralogy (Muscovite & Chlorite).

2) **The creation of new minerals.**
with increase in temperature some minerals become unstable, so new more stable minerals form (having an overall composition mostly similar to the previous ones).

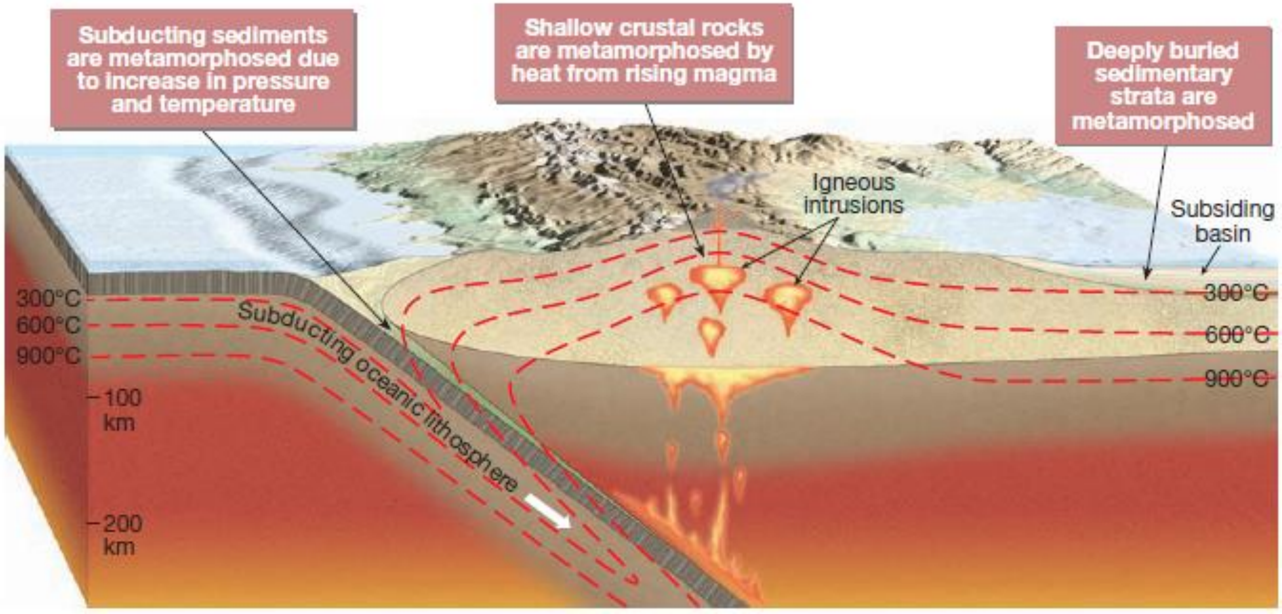
Agents of Metamorphism:

1) Heat 2) Pressure 3) Fluids

- Sources of Heat:

Radioactive Decay and thermal energy in the earth.

1) Geothermal Gradient.
2) Magmatic Intrusions.
3) Compression.

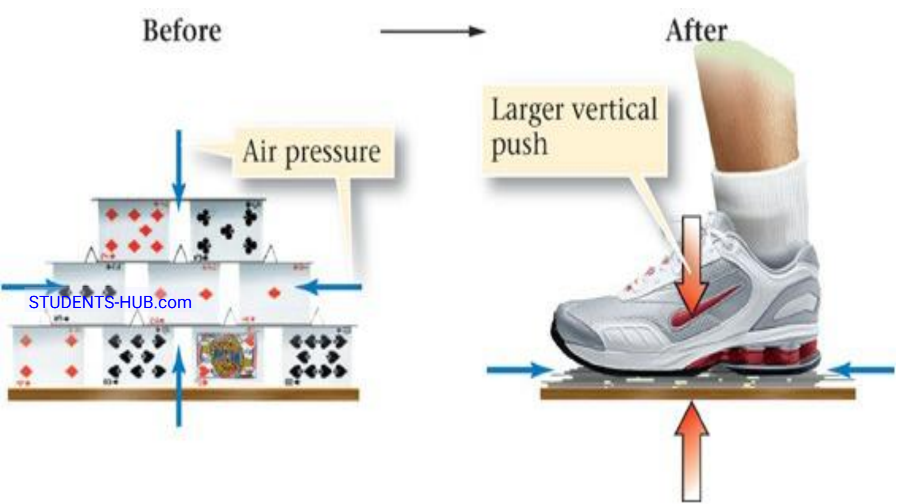


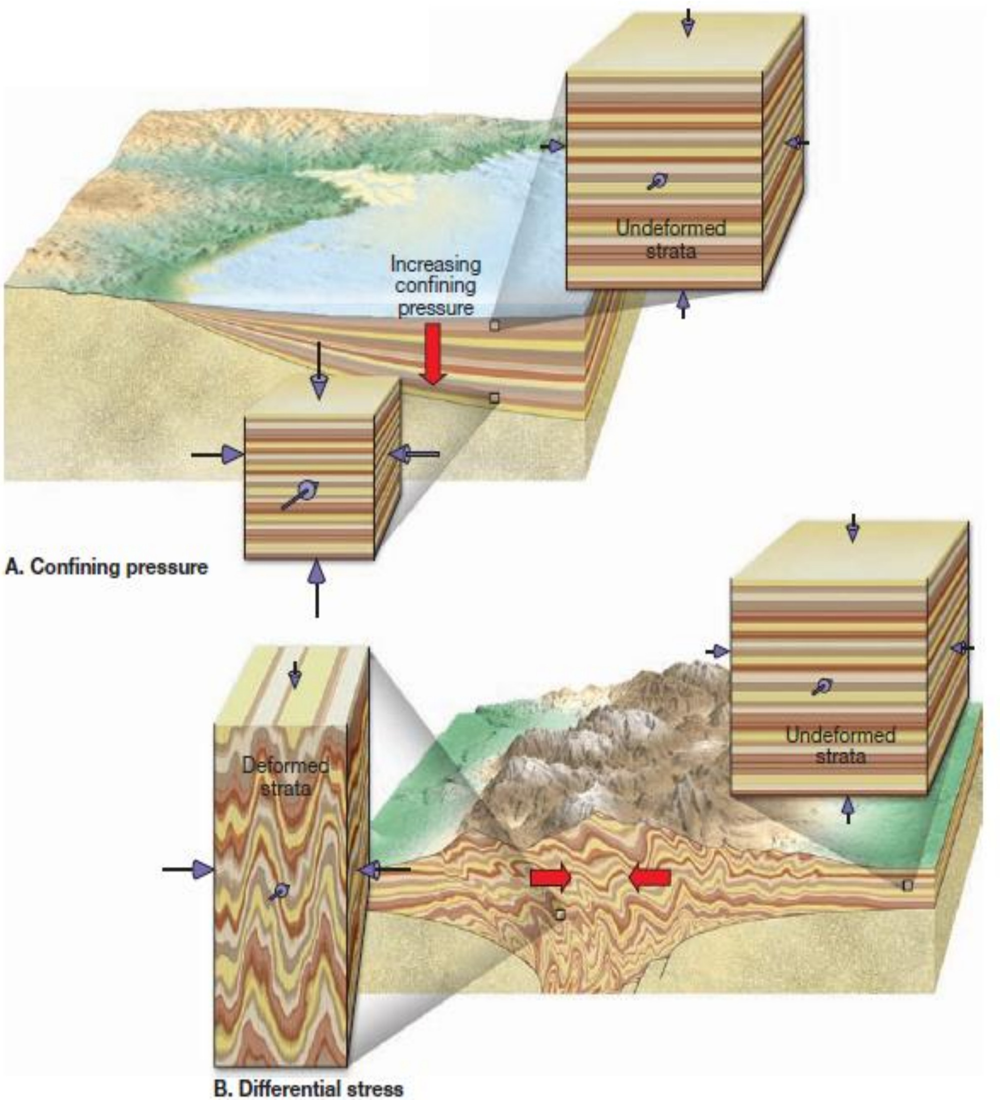
Agents of Metamorphism:

1) Heat 2) Pressure 3) Fluids

- **Pressure**, like temperature, increases with depth and comes in two forms:

1) **Confining Pressure**
2) **Differential Pressure**



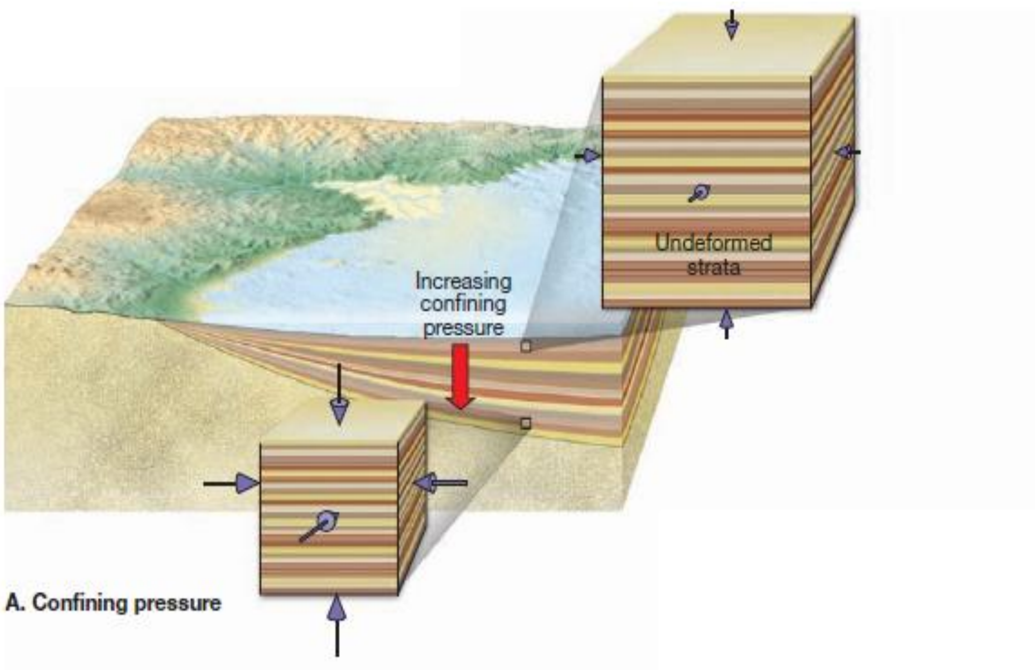


Agents of Metamorphism:

1) Heat 2) Pressure 3) Fluids

1) Confining Pressure:

Stresses or forces are equal in all directions. It "squeezes" rock & causes the spaces between mineral grains to close resulting in a more compact rock with greater density.

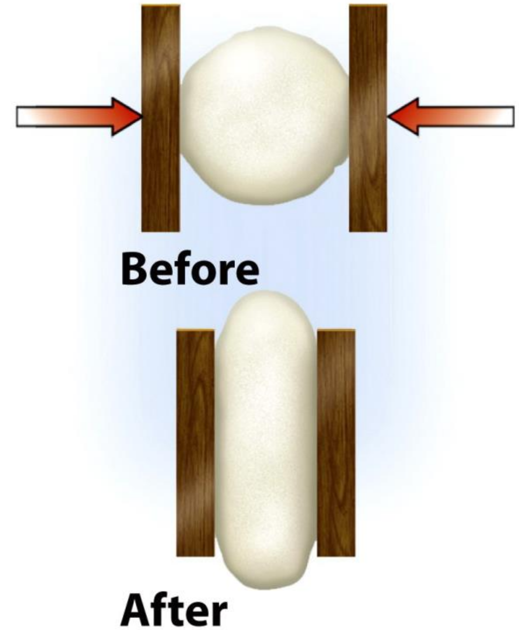


Agents of Metamorphism:
1) Heat 2) Pressure 3) Fluids

2) Differential Pressure

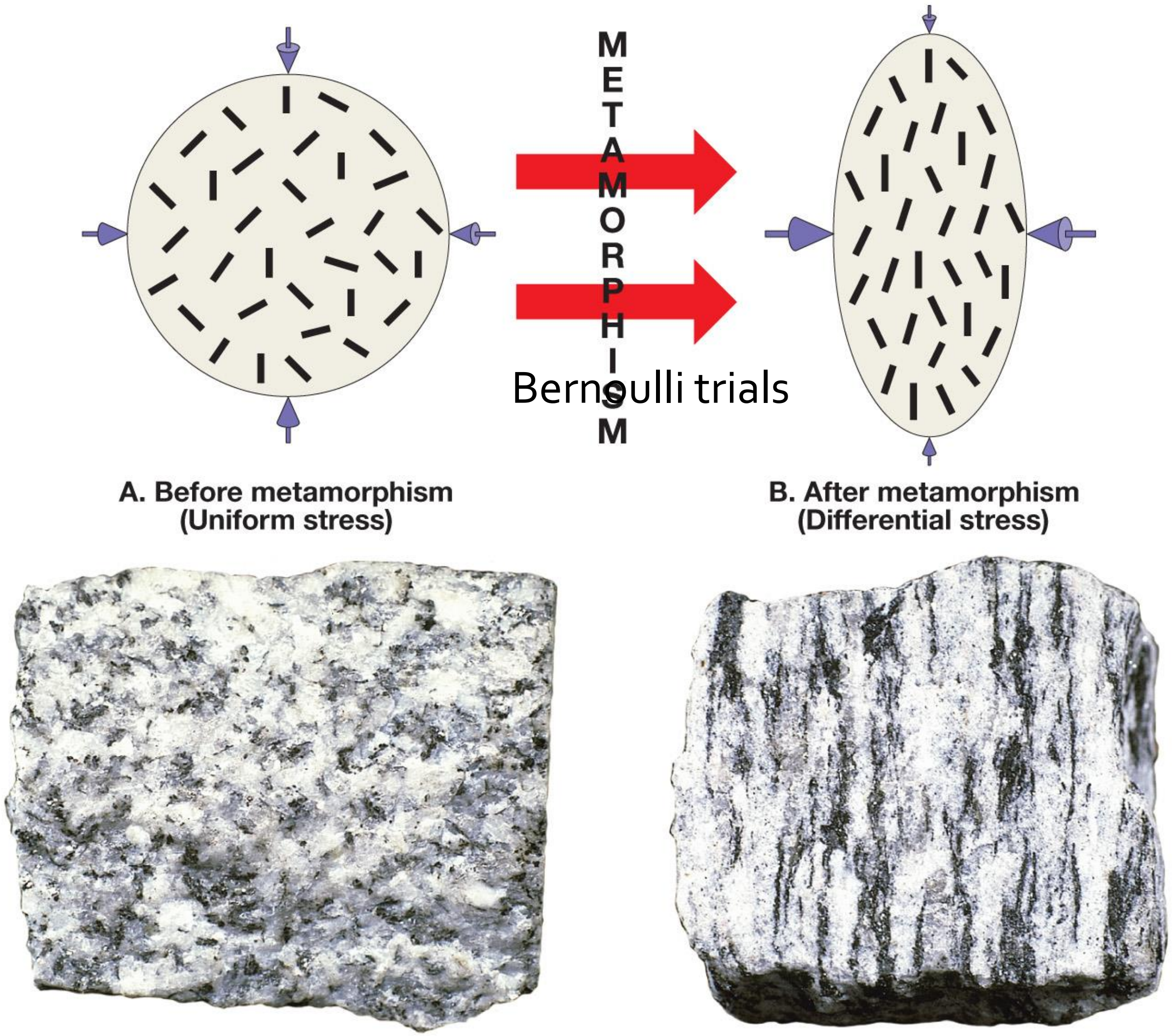
- Different stresses in different directions.
- Common in convergent boundaries (when two tectonic plates collide directly).
- Rocks are shortened in the direction of greater stress and elongated perpendicular to it. As a result, rocks are *folded* or *flattened*.
- Shallow/ low temp. envirn.→ rocks are *brittle* & fracture due to diff. stress.

  Deep/ high temp. envirn. → rocks are *ductile* & tend to fold with diff. stress (mineral grains flatten & elongate)



Metaconglomerate (previously a conglomerate)

Foliation; A common feature caused by Differential Pressure



Agents of Metamorphism:

1) Heat 2) Pressure <u>3) Fluids</u>

- **Chemically Active Fluids:**
- Composed mainly of water and other volatiles such as carbon dioxide.
- Ion-rich fluids within rocks become active with high temperatures, especially those at the surface of minerals where contact with other minerals occurs (high stress).
- The ions in the fluid migrate and are deposited & recrystallize. These resulting minerals are longer perpendicular to compressional stresses.
- When hot fluids circulate freely through several different rock layers or come into contact with the hot fluids from a pluton, ionic exchange takes place.
  The fluids escaping the pluton change the composition of surrounding rocks. This process is referred to as **Metasomatism**.

Metasomatism

hydrothermal alteration—metamorphism as a result of exposure to hot fluids passing through permeable rocks

hotsprings in Yellowstone

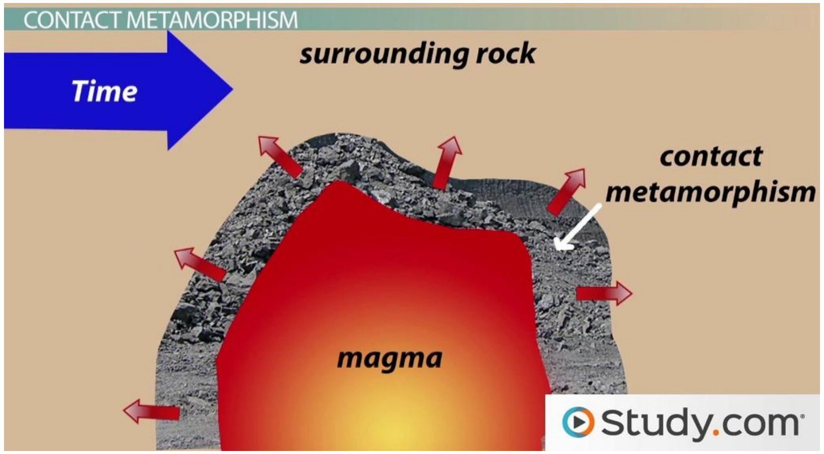
hydrothermally altered rocks

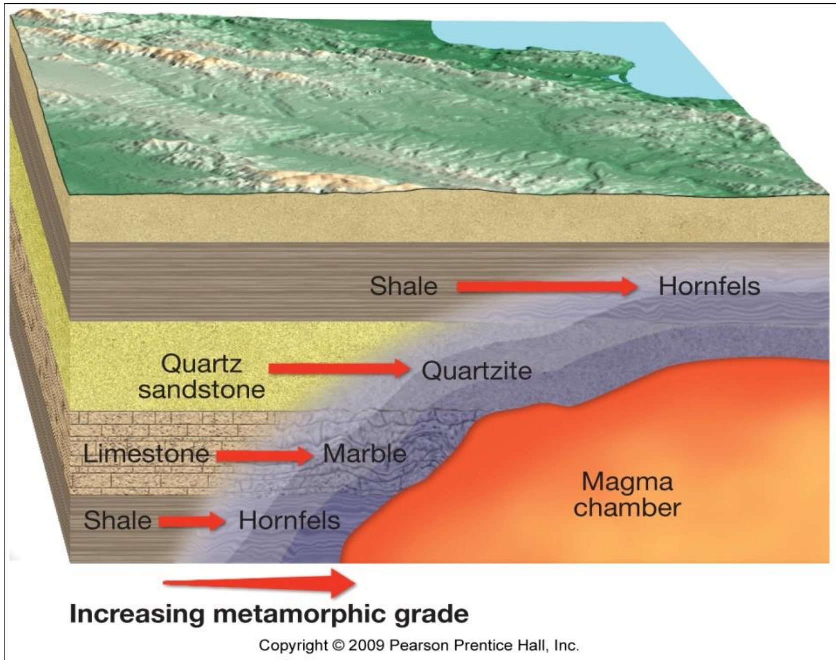
Metamorphic Settings/ Environments

1) Contact or Thermal Metamorphism:

- When rock comes into contact with magma, so the change is driven by rise in temperature.
- The altered rocks occur in a zone called a metamorphic aureole.
- The figure here shows the metamorphic rocks resulting from common sedimentary rocks due to contact metamorphism.

Note: Even though high temperatures occur, in metamorphism the rock must remain solid or we would be talking about igneous rocks once again

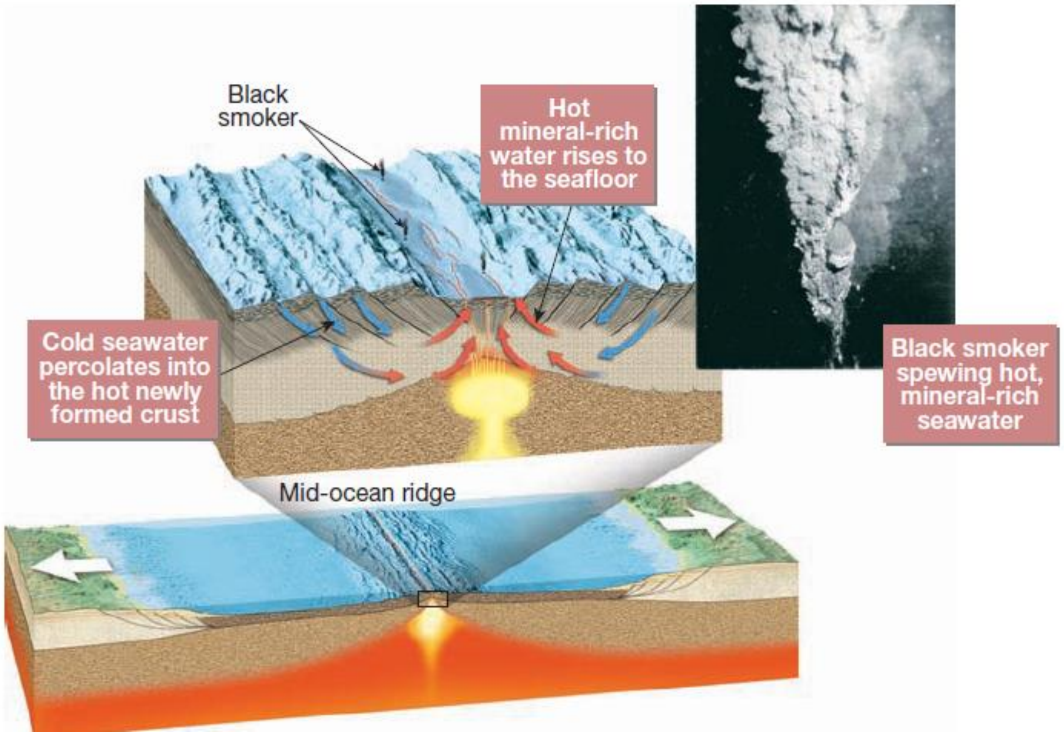




Metamorphic Settings/ Environments

2) Hydrothermal Metamorphism:

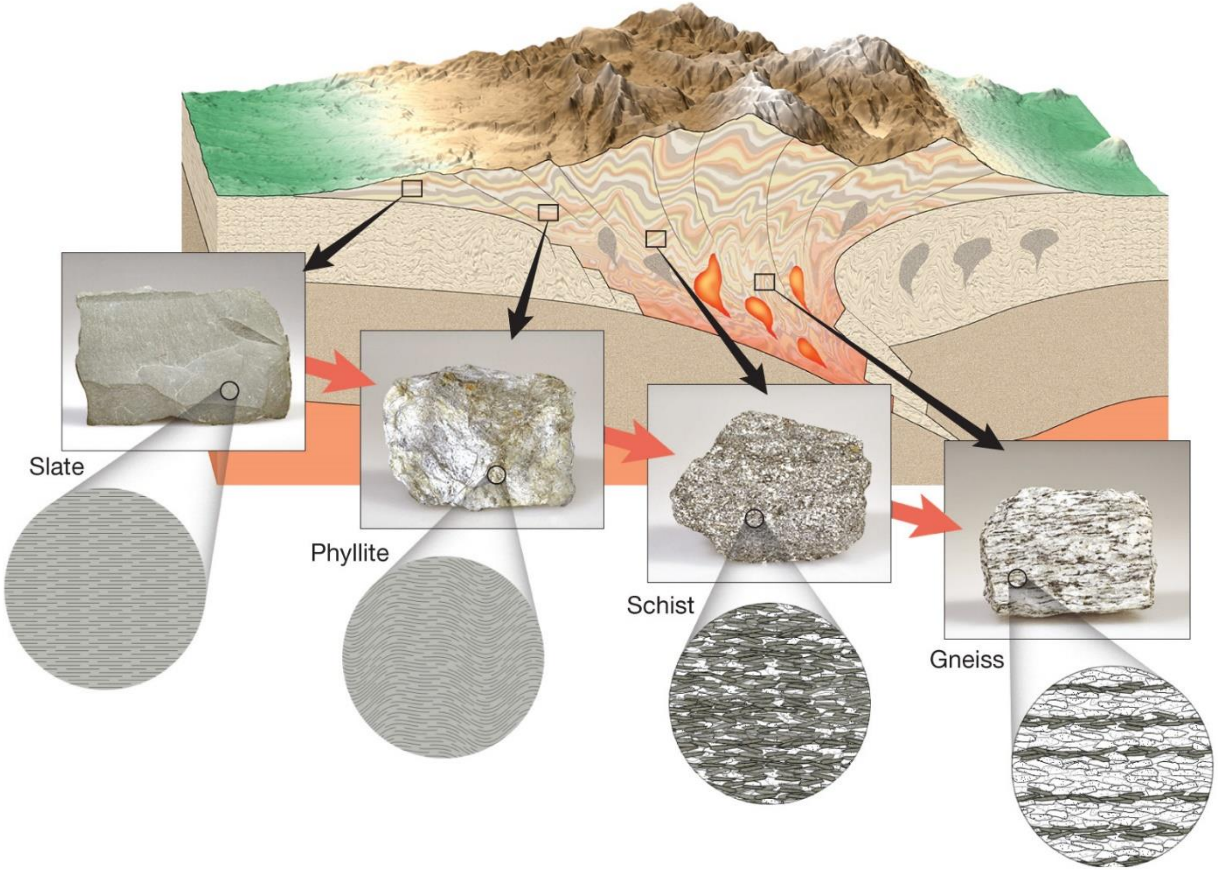
Involves chemical alteration that occur as hot ion-rich water circulates through fractures in rock. This type is also typically associated with igneous activity.



Metamorphic Settings/ Environments

3) Regional Metamorphism:

Most metamorphic rock is produced by regional metamorphism, which occurs where rocks are squeezed between two converging lithospheric plates during mountain building.



Other Metamorphic Environments

- **Burial and Subduction Zone Metamorphism**

- *Burial metamorphism* tends to occur where massive amounts of sedimentary or volcanic material accumulates in a subsiding basin.

- *Subduction Zone where* Rocks and sediments can also be carried to great depths along convergent boundaries where oceanic lithosphere is being subducted.

- **Metamorphism along fault lines**
- **Impact (or shock) metamorphism:** due to meteorites' (النيازك) impact

Examples of Metamorphic Rocks

Gneiss

Slate

Quartzite

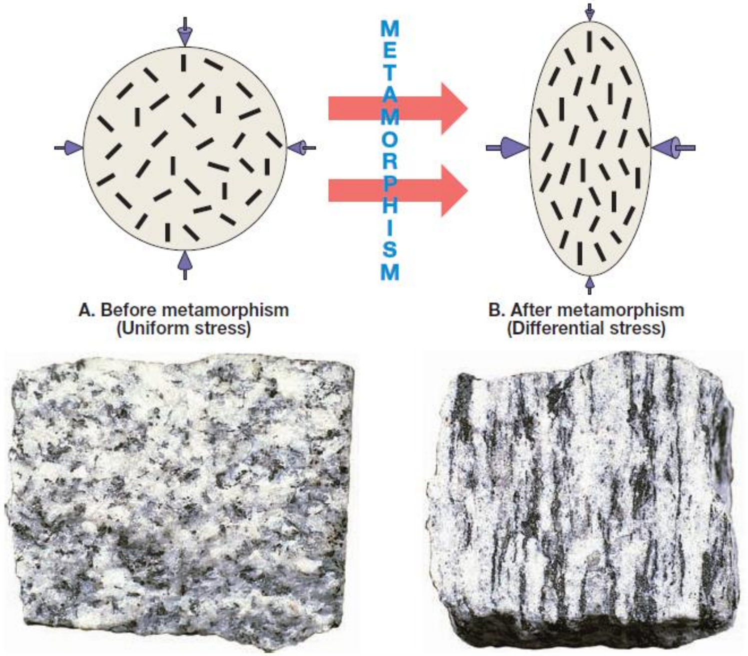
Schist

Marble

Phyllite

Metamorphic Textures

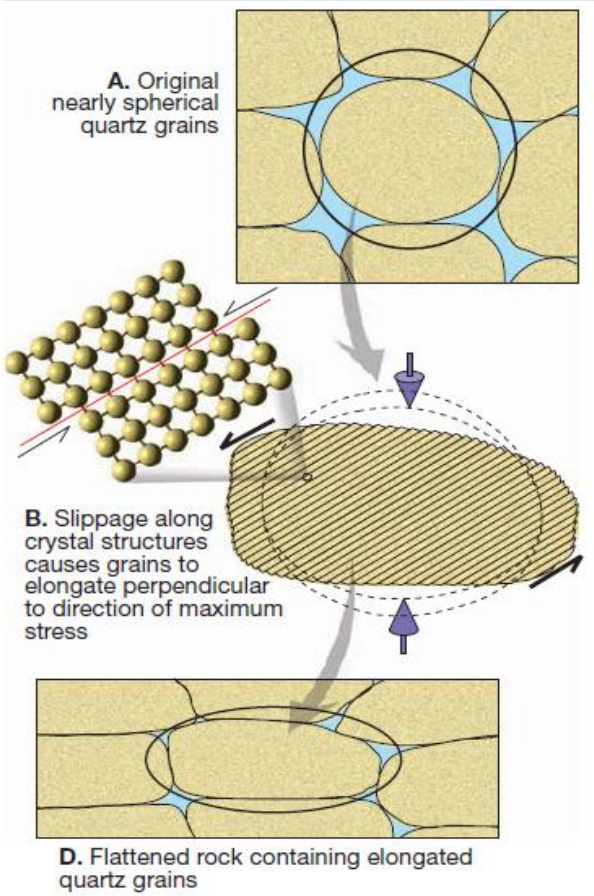
- You already know that texture describes the **size, shape & arrangement of minerals/grains** within a rock.
- Unlike many Sedimentary and Igneous textures, which contain grains in random orientation, Metamorphic textures typically display a kind of *preferred orientation* whereby the minerals exhibit a parallel to sub-parallel alignment. This property is referred to as **Foliation**.



Metamorphic Textures: Foliation

- **Foliation** refers to any planar (nearly flat) arrangement of mineral grains or structural features within rock.
- It typically occurs as a result of Regional Metamorphism.
- It occurs in the following ways:

1) **Rotation** of platy (micas) or elongated minerals (amphiboles) into a new orientation
2) **Recrystallization** of minerals forming in a preferred orientation.
3) **Changing the shape** of equidimensional (متساوي الأبعاد) grains into elongated ones in a preferred orientation.
Typically in high temp. where minerals are ductile.



Metamorphic Rock Textures

Texture is used to describe the size, shape, and arrangement of grains within a rock.

2 types:

- Foliated
- Non-foliated

quartzite

Foliated Metamorphic Rocks

Gneiss

Slate

Schist

Phyllite

Examples of Foliated Textures

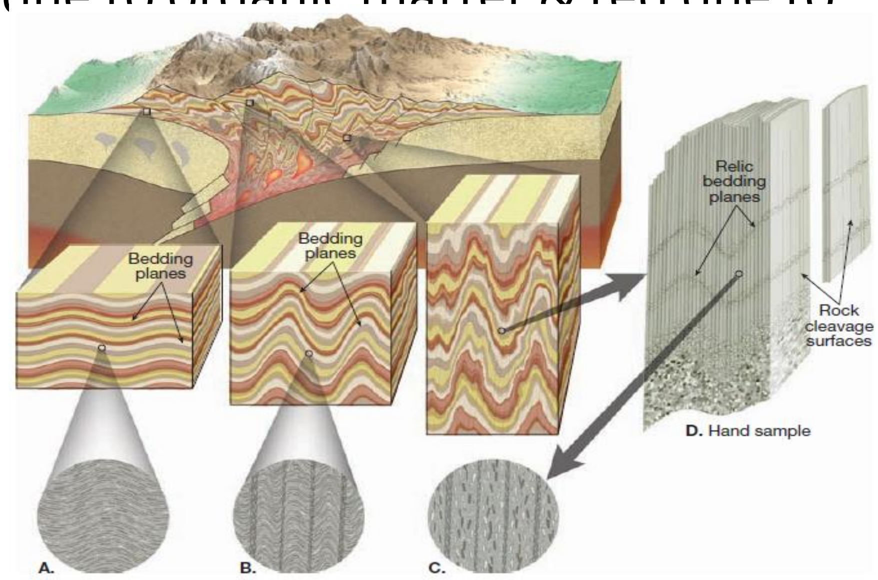
Schist has minerals (such as mica) that have grown large enough to be seen by the unaided eye

Slate is a rock with excellent rock cleavage, as it breaks in flat slabs.

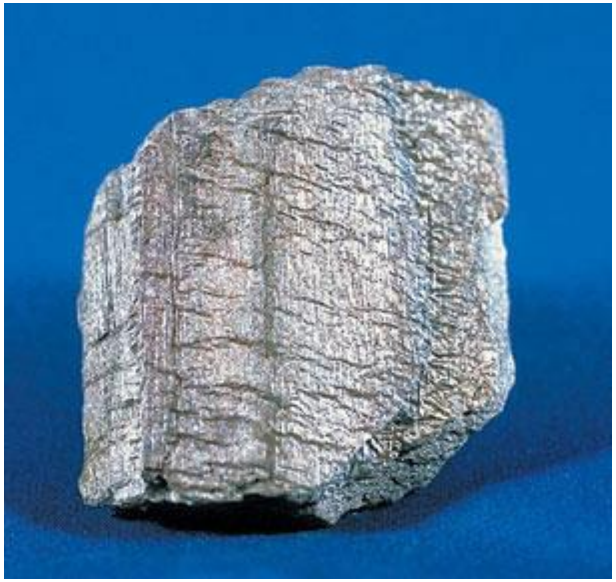
Gneiss results from high-grade metamorphism

Metamorphic Textures: Foliation

- **Slate**
  - A very fine grained rock composed of minute (دقيق) mica flakes that break along thin, flat slabs (excellent cleavage), so it is used for roofs & tiles.
  - **Shale is the parent rock**; the transformation from shale to slate is typical to **low-grade metamorphism**.
  Shales are strongly stresses & folded resulting in microfolds. Further deformation causes breakage and recrystallization into a new preferred orientation oblique (مائل) to the previous one.
  - Slate comes in different colors; black due to organic matter & red due to iron oxide.



Metamorphic Textures: Foliation

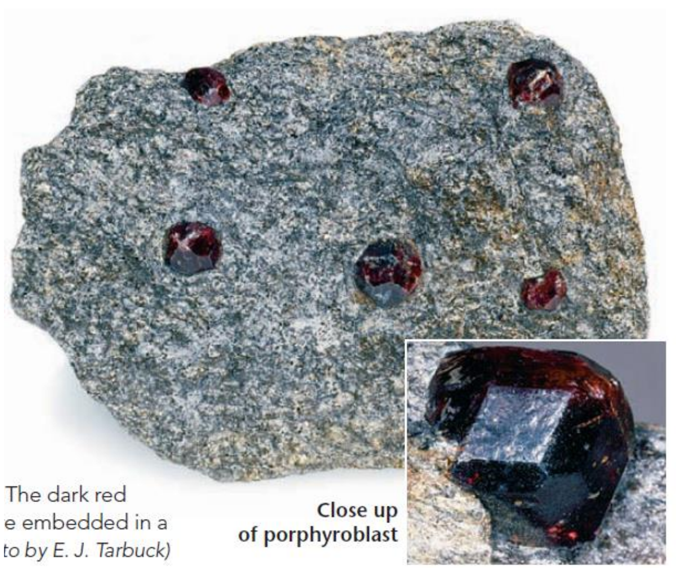


Phyllite

- Phyllite is composed mainly of **very fine** crystals of either muscovite or chlorite, or both & usually exhibits rock cleavage.
- Parent rock also shale.
- Phyllite represents a gradation in the degree of metamorphism between slate and schist.
- Its constituent platy minerals are larger than those in slate but not yet large enough to be readily identifiable with the unaided eye. Although phyllite appears similar to slate, it can be easily distinguished from slate by its **glossy sheen** (لمعان) and its sometimes wavy surface.

Metamorphic Textures: Foliation

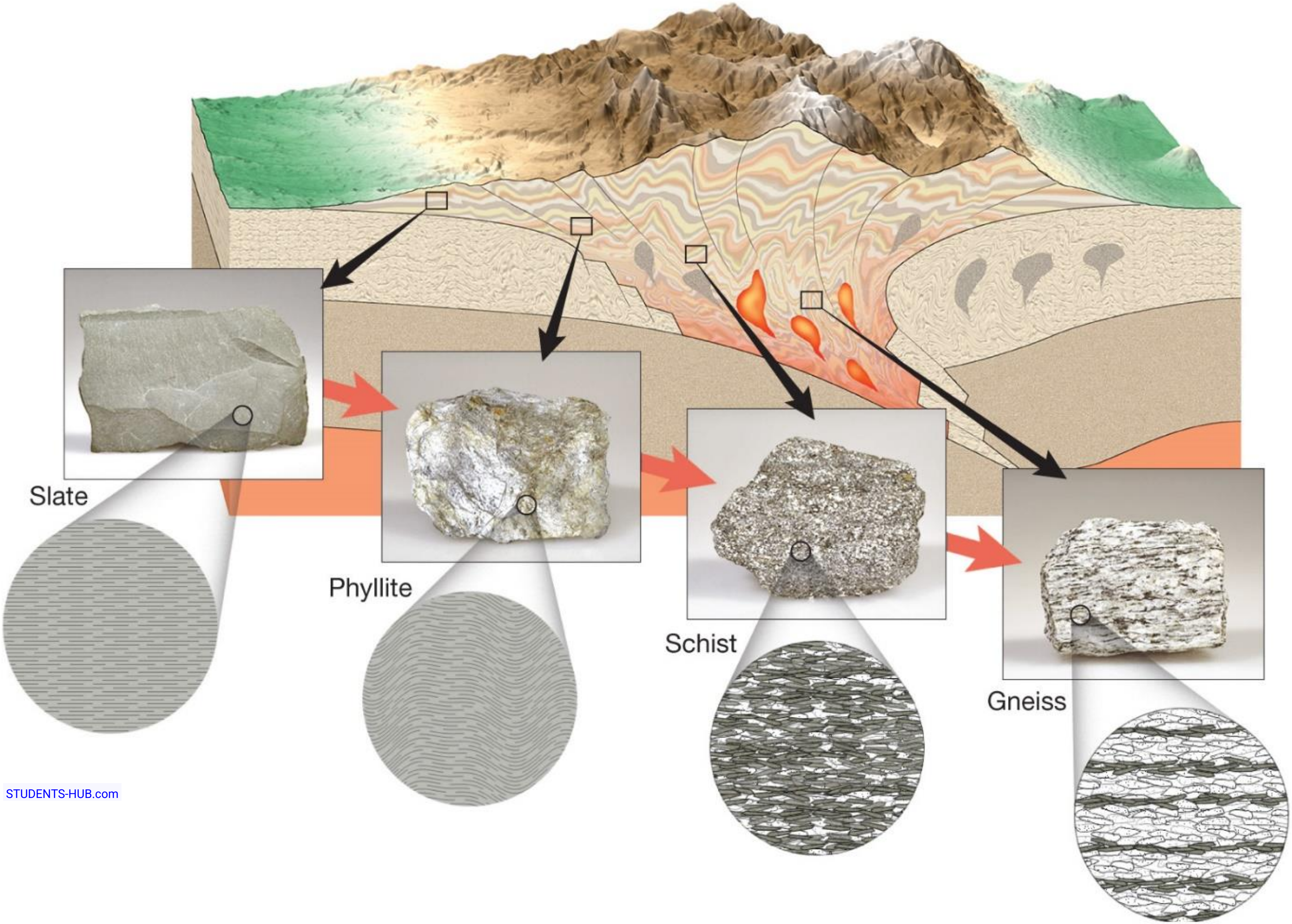
- **Schist (Schistosity)**
- Micas (muscovite & biotite) grow large & visible.
- Medium- to high-grade metamorphism.
- Parallel alignment of large mica crystals (strongly foliated).
- Schist often has other minerals due to recrystallization such as Quartz, Feldspars, garnet, etc.
- Large non-mica minerals are called porphyroblasts.



Metamorphic Textures: Foliation

- **Gneiss (Gneissic)**
- Pronounced "Nice".
- Occurs during high-grade metamorphism.
- Ions migrations results in the separation of minerals, giving the rock a banded appearance.
- Parent rocks maybe granite, rhyolite, diorite or shale.

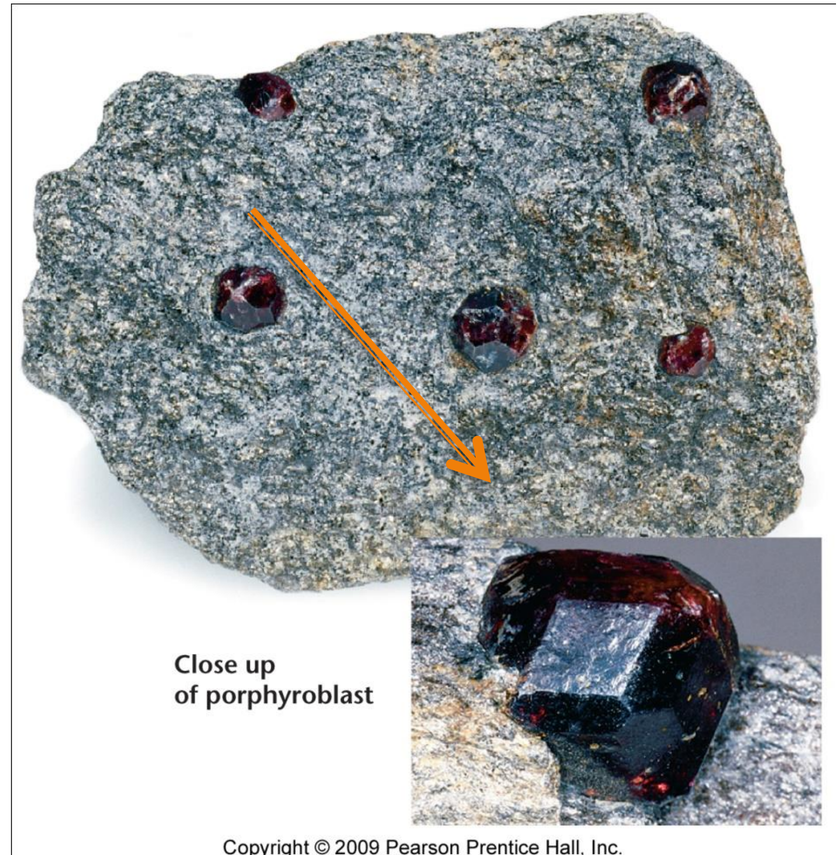
Gneissic texture: segregation of dark silicates (biotite, amphibole, etc.) and light silicate minerals (quartz , Na & K Feldspar)


Slate
Phyllite
Schist
Gneiss

Nonfoliated Metamorphic Texture

Marble (Parent rock Limestone):
Coarse, crystalline rock composed of calcite (hardness=3); used as building stone

Porphyroblasts are large grains that are surrounded by a fine-grains of other minerals. GARNETS



Quartzite (Parent rock quartz sandstone):
A very hard metamorphic rock, forms under moderate to high grade metamorphism

The exterior of the Taj Mahal is constructed mainly of the metamorphic rock marble.

Rock Name	Texture	Grain Size	Comments	Original Parent Rock
Slate (Increasing Metamorphism ↓)	Foliated	Very fine	Excellent rock cleavage, smooth dull surfaces	Shale, mudstone, or siltstone
Phyllite	Foliated	Fine	Breaks along wavy surfaces, glossy sheen	Shale, mudstone, or siltstone
Schist	Foliated	Medium to Coarse	Micaceous minerals dominate, scaly foliation	Shale, mudstone, or siltstone
Gneiss	Foliated	Medium to Coarse	Compositional banding due to segregation of minerals	Shale, granite, or volcanic rocks
Migmatite	Foliated	Medium to Coarse	Banded rock with zones of light-colored crystalline minerals	Shale, granite, or volcanic rocks
Mylonite	Weakly Foliated	Fine	When very fine-grained, resembles chert, often breaks into slabs	Any rock type
Metaconglomerate	Weakly Foliated	Coarse-grained	Stretched pebbles with preferred orientation	Quartz-rich conglomerate
Marble	Nonfoliated	Medium to coarse	Interlocking calcite or dolomite grains	Limestone, dolostone
Quartzite	Nonfoliated	Medium to coarse	Fused quartz grains, massive, very hard	Quartz sandstone
Hornfels	Nonfoliated	Fine	Usually, dark massive rock with dull luster	Any rock type
Anthracite	Nonfoliated	Fine	Shiny black rock that may exhibit conchoidal fracture	Bituminous coal
Fault breccia	Nonfoliated	Medium to very coarse	Broken fragments in a haphazard arrangement	Any rock type

RUNNING & GROUNDWATERWATER

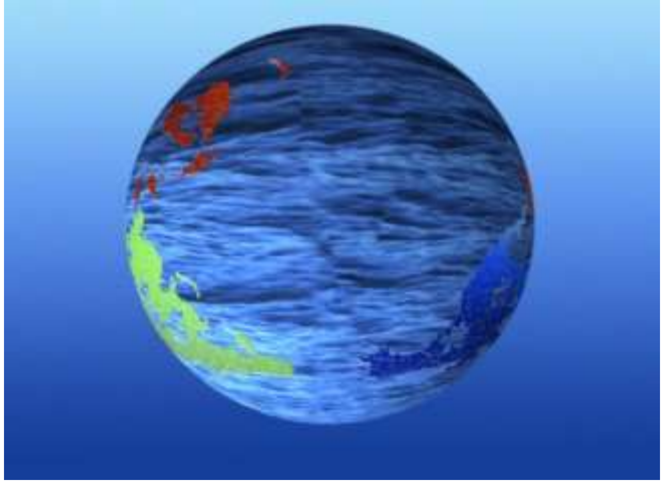
1- Running Water↓

General: Earth = The Blue Planet

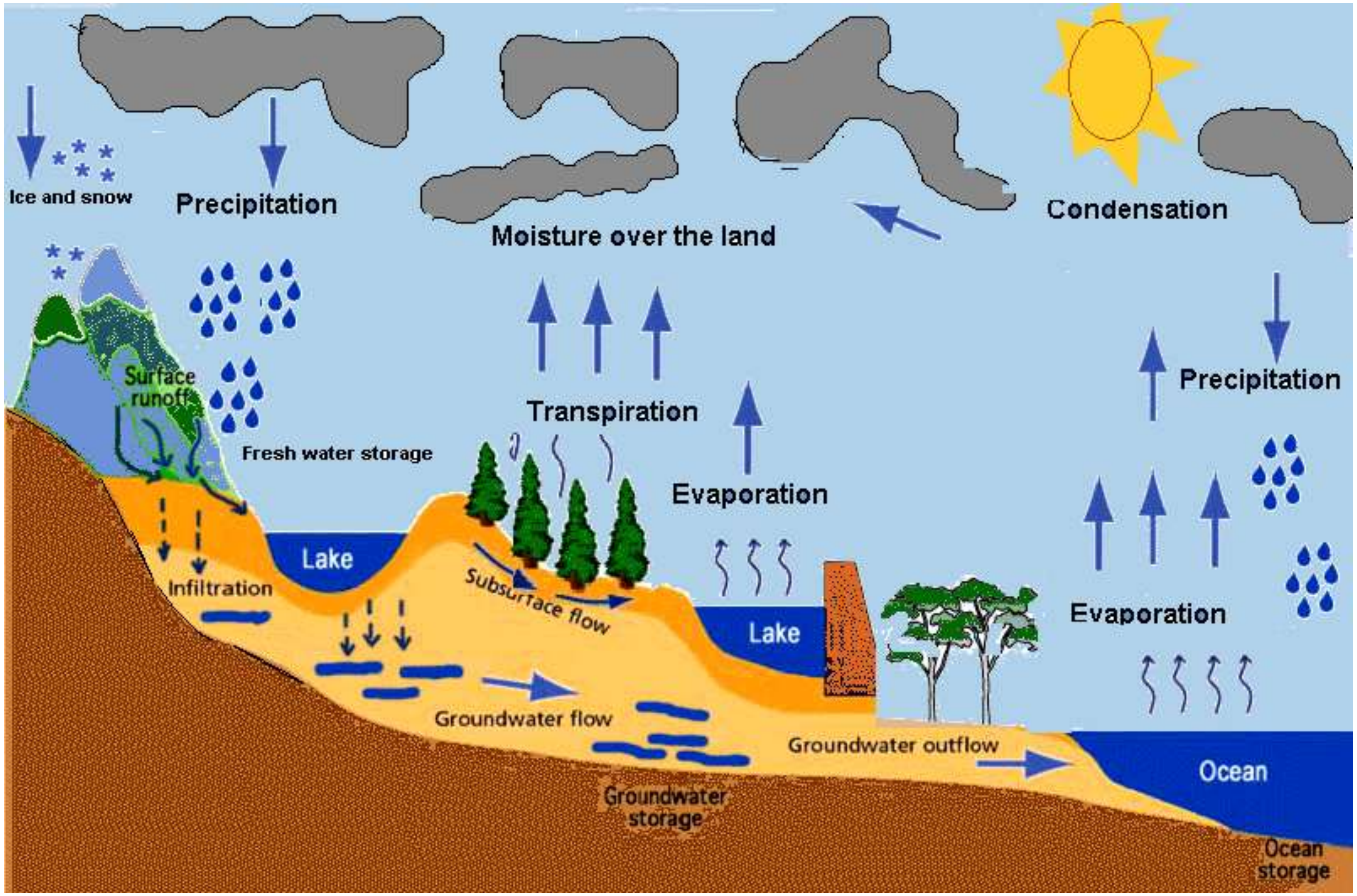
1) Amount of water on Earth approx. 1.3 Billion Kilometer Cubic meters, spread as follows:

- 97.2% Oceans & Seas.
- 2.15% Ice Sheets & Glaciers.
- 0.65% Lakes, Rivers,

Atmosphere & Groundwater.



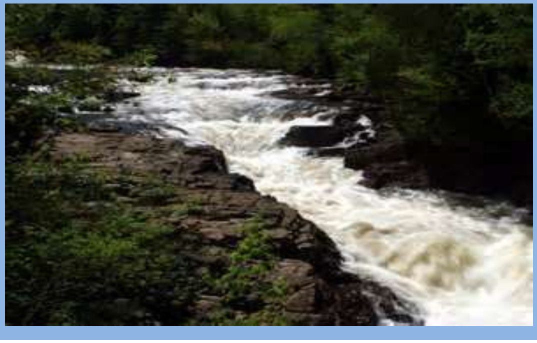
2) Hydrological Cycle:



1:1) Runoff: Is that amount of water which exceeds the soaking (absorption) capacity of the land. It flows to the lower areas (Oceans, Lakes, Seas, Dams, …). It is the most important agent of Earths' Wearing.

- Importance to people:
- 1- Energy source. 2- Transportation. 3- Sport. 4- Tourism. 5- Fishing.
- 6- Irrigation. 7- Source of fertile soils.

….Stream →



- Channelized flow path of any size. Supplied by the runoff & underground water.
- River is used to describe main stream into which all tributaries flow. Water flows under the influence of gravity.

…Velocity of water in a stream differs and so its erodability.

Velocity depends on:

- **1- Gradient (slope) of the stream channel.**

> steep > velocity.

- **2- Shape, size and roughness of the channel. The channel cross-section determines the amount of water in contact with the channel and hence affects the frictional drag; the most efficient channel is the one with the least perimeter for its cross section.**

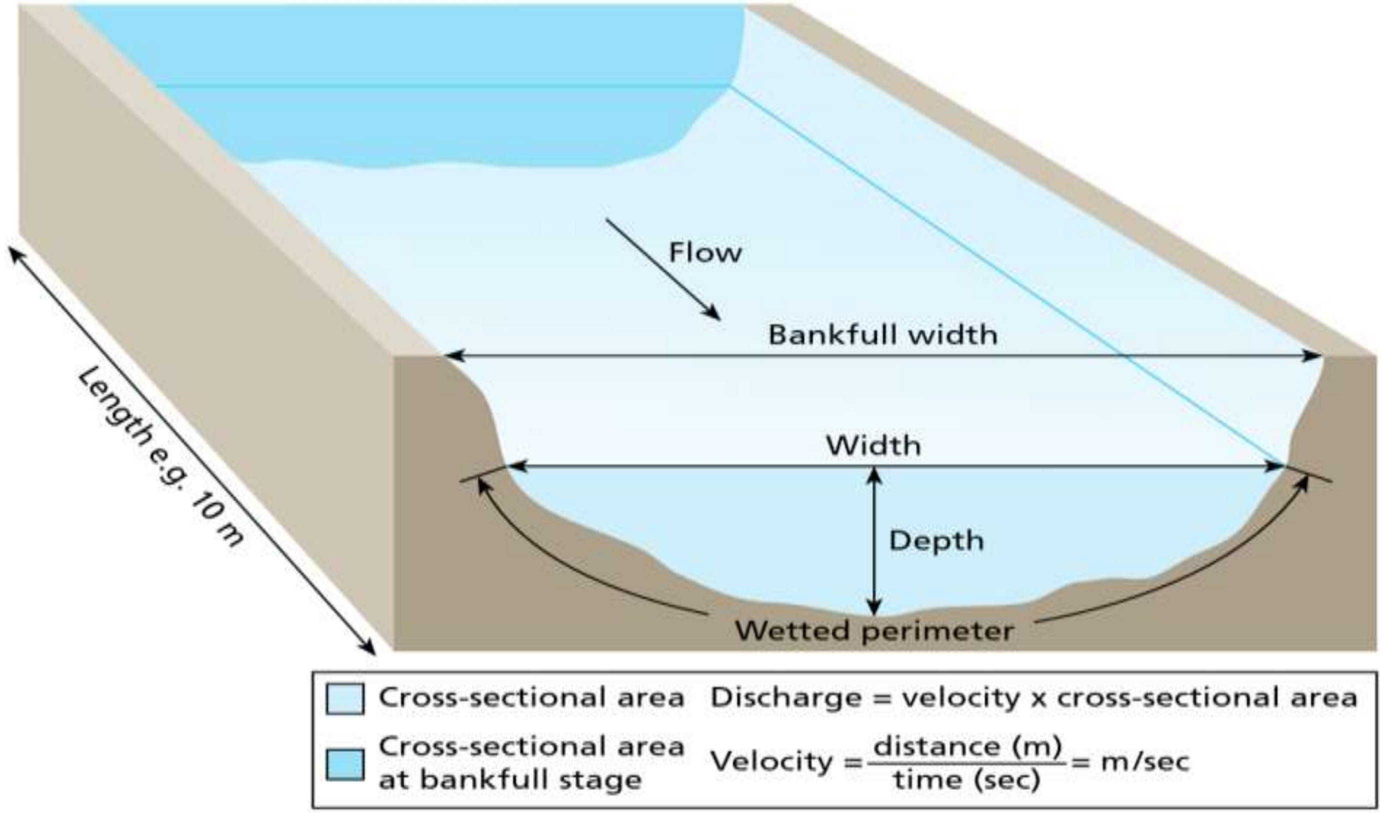


Figure 5.6 Discharge in a river

The wide shallow perimeter means decrease in current velocity and visa versa

3- Discharge: Amount of water in M^3 passing the wetted cross section in a given unit of time.

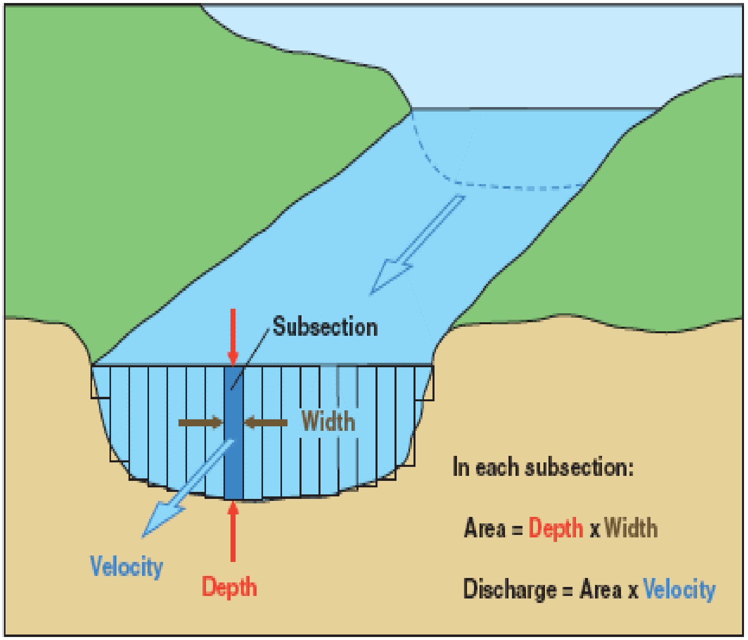
Example:

- **D= Cross Section(m2) X Velocity (m/Sec)**

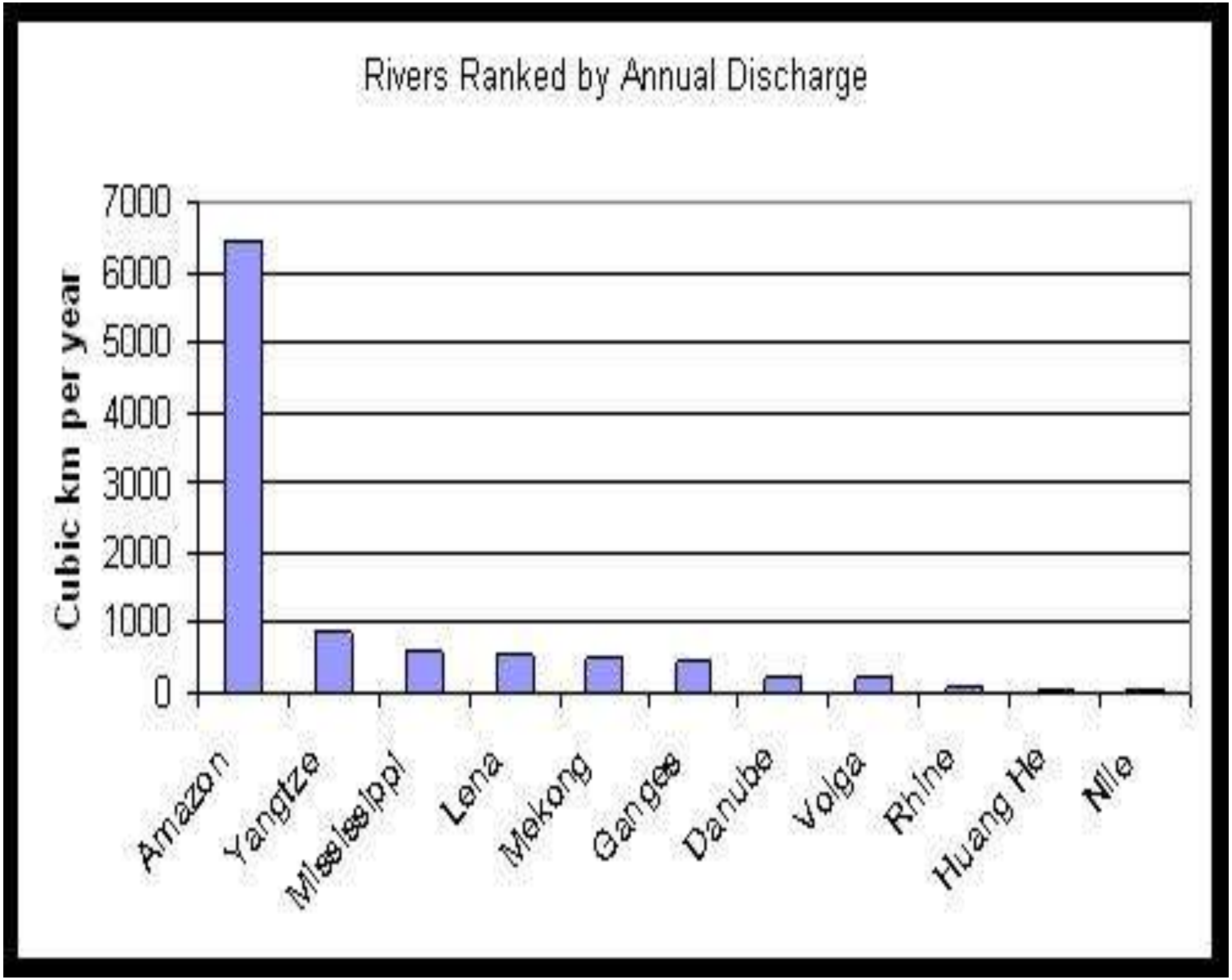
=M^3/Sec

e.g. - Amazon discharges 15% of world Fresh water in the ocean.

- Missisippi 17300 M3/sec.



Current-meter discharge measurements are made by determining the discharge in each subsection of a channel cross section and summing the subsection discharges to obtain a total discharge.


Rivers Ranked by Annual Discharge
Cubic km per year
7000
6000
5000
4000
3000
2000
1000
0
Amazon
Yangtze
Mississippi
Lena
Mekong
Ganges
Danube
Volga
Rhine
Huang He
Nile

Work of Streams:

- **1) Erosion: Carrying sediments works as abrasive agent on the floor and sides of the river. Angular pebbles will get circular shape and <u>Potholes</u>↓ will form.**

2) Transportation: Streams are the most important erosional agent because they carry large quantities of materials produced by weathering.

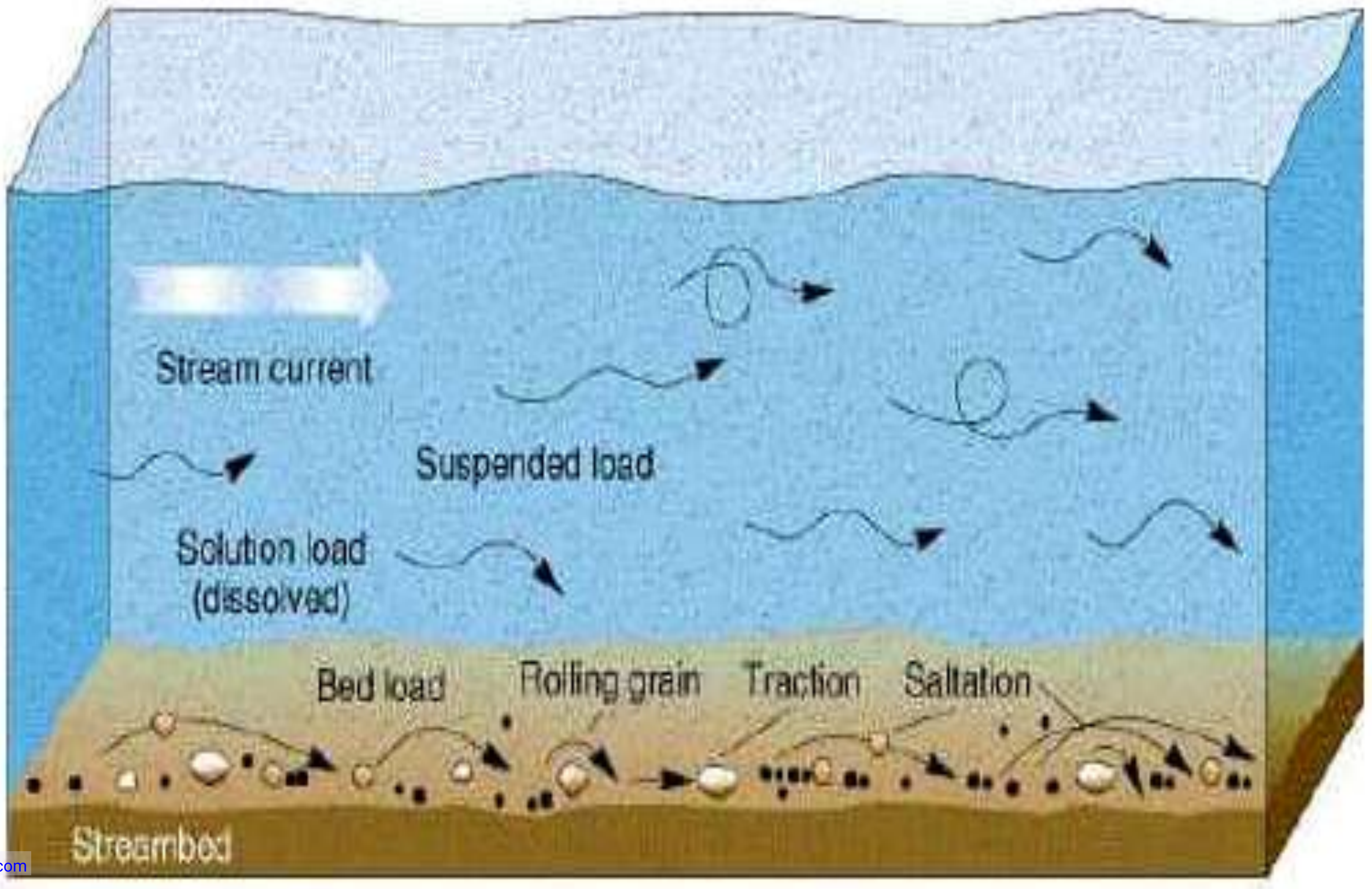
How material is transported by stream water? Answer: In 3 ways:

1- In solution (dissolved load): Brought to the stream by groundwater or the running water.

Solvents are measured in ppm (=parts per million). Type and quantity of solvents depends on the climatic conditions and the geological setting (mineralogical composition of the rocks, the geothermal gradient, the geo-structures, ….)

2- In suspension (=suspended load): As fine sands, clays, silts, even pebbles in floods' time. Water with suspensions is denser than plain water and can carry heavier particles as suspended.

3- Along the bottom (bed load): **Larger particles are transported along the river bottom leading to the grinding action. Particles move along the bottom by rolling, sliding, traction or saltation. Bed load counts approx. for 10% of total stream load; max. during flooding.**


Stream current
Suspended load
Solution load
(dissolved)
Bed load
Rolling grain
Traction
Saltation
Streambed

STREAM ABILITY TO CARRY LOADS IS MEASURED BY 2 CRITERIA:

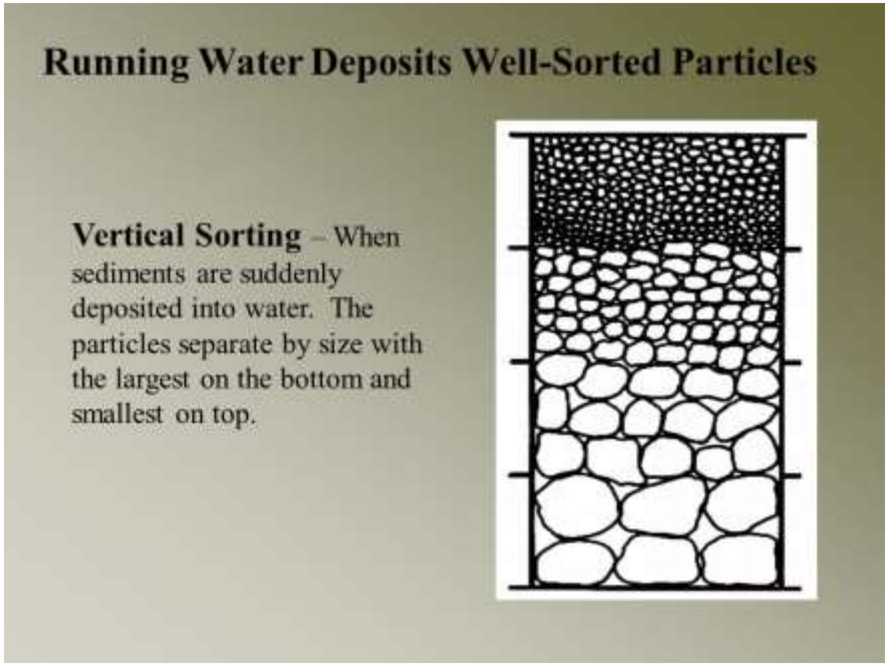
1- **Stream competence:** Is a measure of the max. size the stream can carry; a function of velocity→ Q is proportional with V^2 this means if velocity doubles the force of water increases 4 times.

2- **Stream capacity:** The max. load (quantity) a stream can carry; it is a function of discharge and this means the more the water discharge the more the quantity a stream can carry.

3- Deposition:

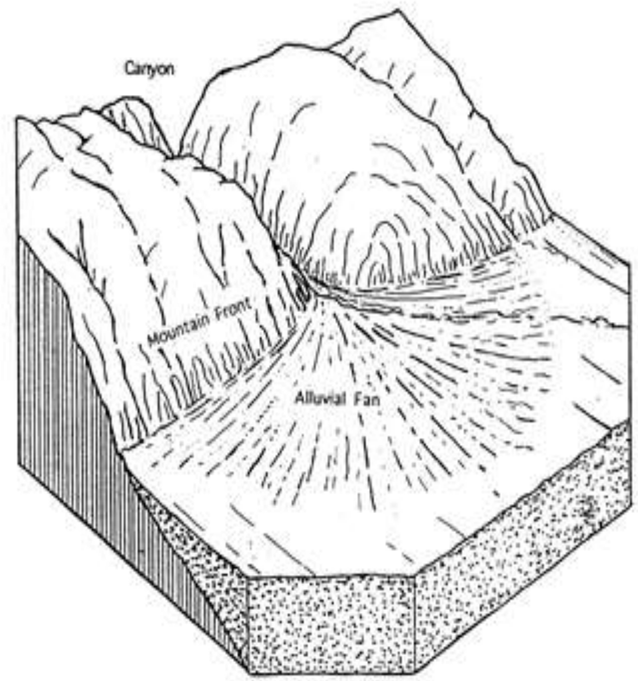
* When stream velocity decreases its competence decreases. A particle starts to settle out from the water when the stream velocity drops below the critical settling velocity of that particle.

.The gradual drop in the velocity leads to what we say "SORTING" of the deposited sediments.

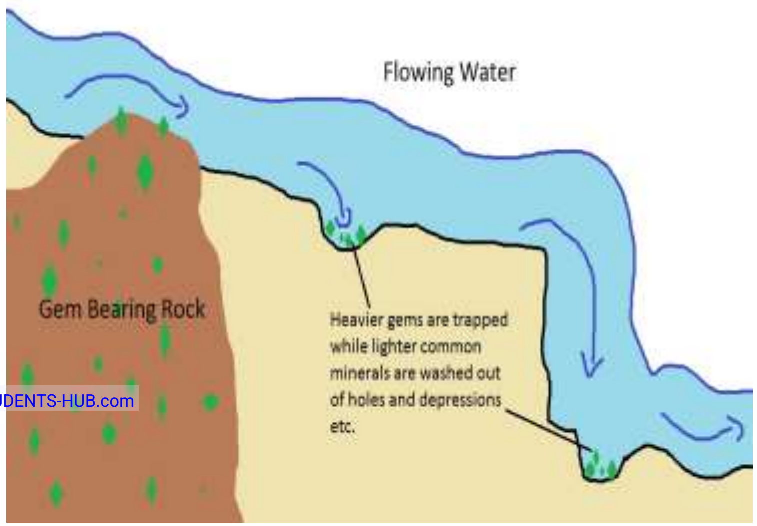


The well-sorted material deposited by a stream is called <u>ALLUVIUM.</u>

<u>Alluvial Fans</u> form when stream leaves narrow area to open area so a sudden drop of sediments occur in open area due to reduce in gradient



<u>PLACER DEPOSITS:</u> **It is a way in which valuable minerals (Gold, Diamond, Platinum) are concentrated into economically significant accumulations. Placers are a sorting type according to specific gravity (heavy minerals settle quickly).**



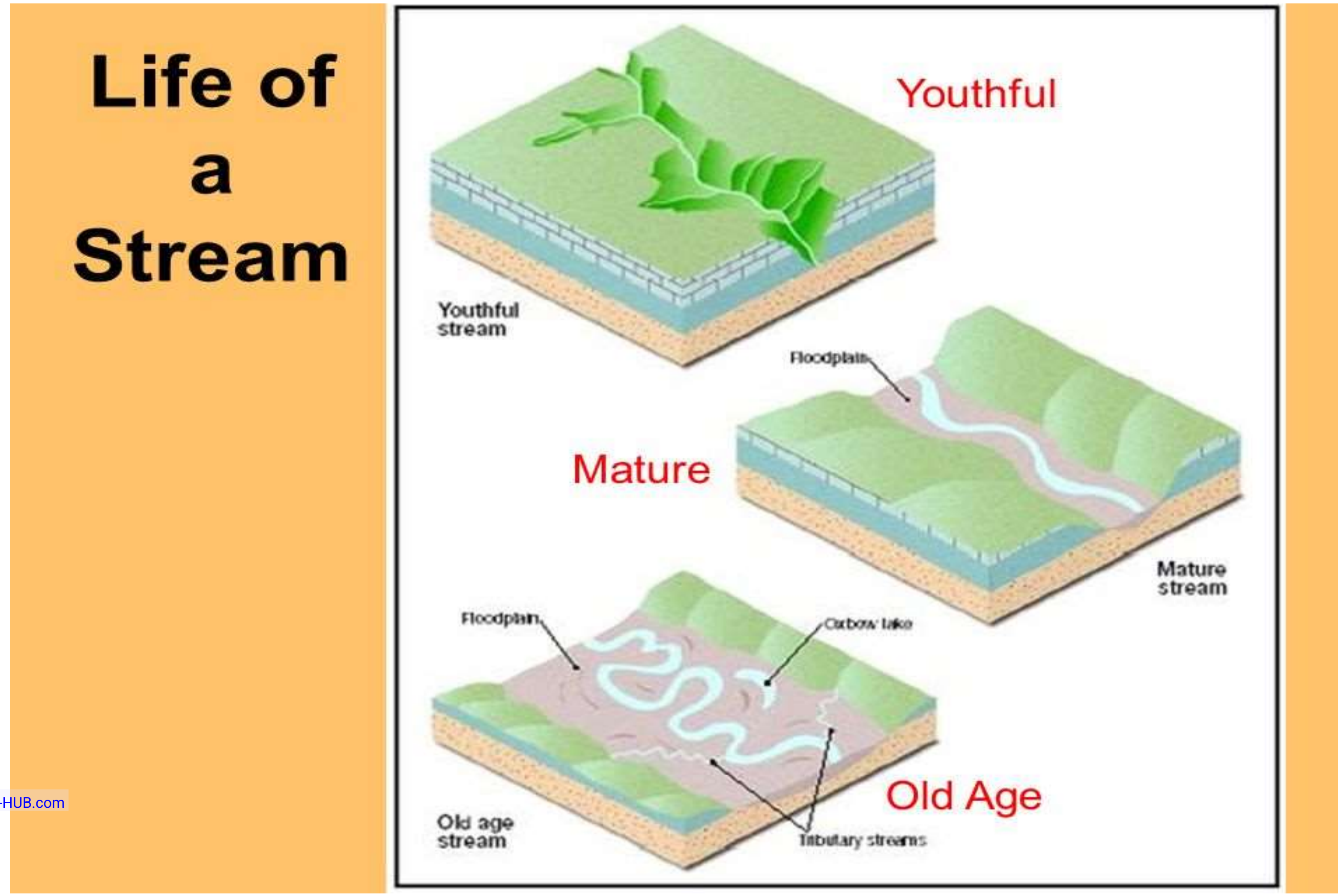

gold area

Stream Valleys:

1) Narrow V-shaped: Indicate immaturity of the river channel and that the primary work of the stream is down-cutting towards base level. Features of V-shaped valleys are the "Rapids" & "Falls".

2- **Wide valley with flat floor: Indicates maturity; sides of these valleys are shaped by a combination of weathering, sheet flow and mass wasting.**

Stream Evolution with time



ENCE 231: Engineering Geology
Fall Semester 2018/2019

Department of Civil Engineering-Birzeit University, Palestine

Chapter 10: Groundwater

Course Instructors: Saheem Murshid & Nidal Atallah

Information Source: Essentials of Geology (Lutgens et al., Eds. 9 & 11)

Groundwater المياه الجوفية

- **What is Groundwater?**
- Groundwater is the water from rainfall & surface water that infiltrates the ground and is stored inside the ground.
- The study of groundwater is called "Hydrogeology".
- Many people think that groundwater occurs in the form of underground rivers. In reality, it is the water stored in the **pore spaces of soil & rock** and **in joints & fractures in bedrock**.

The Importance of Groundwater

- Groundwater provides close to 50% of drinking water worldwide.

1) While it account for less than 1% of all water in the hydrosphere, it accounts for 14% of all freshwater (after glaciers) and if we exclude glaciers it accounts for 94% of freshwater ("the largest reservoir of fresh water readily available to humans")

Fresh Water of the Hydrosphere

Parts of the Hydrosphere	Volume of Fresh Water (km^3)	Share of Total Volume of Fresh Water (percent)	Share of Total Volume of Liquid Fresh Water (percent)
Ice sheets and glaciers	24,000,000	84.945	0
Groundwater	4,000,000	14.158	94.05
Lakes and reservoirs	155,000	0.549	3.64
Soil moisture	83,000	0.294	1.95
Water vapor in the atmosphere	14,000	0.049	0.33
River water	1,200	0.004	0.03
Total	28,253,200	100.00	100.00

The Importance of Groundwater

2) Geologically groundwater is an important erosional agent. Groundwater dissolves rock and creates caves & on the surface sinkholes.

3) It also provide streams with water.

Caverns or Caves

A sinkhole

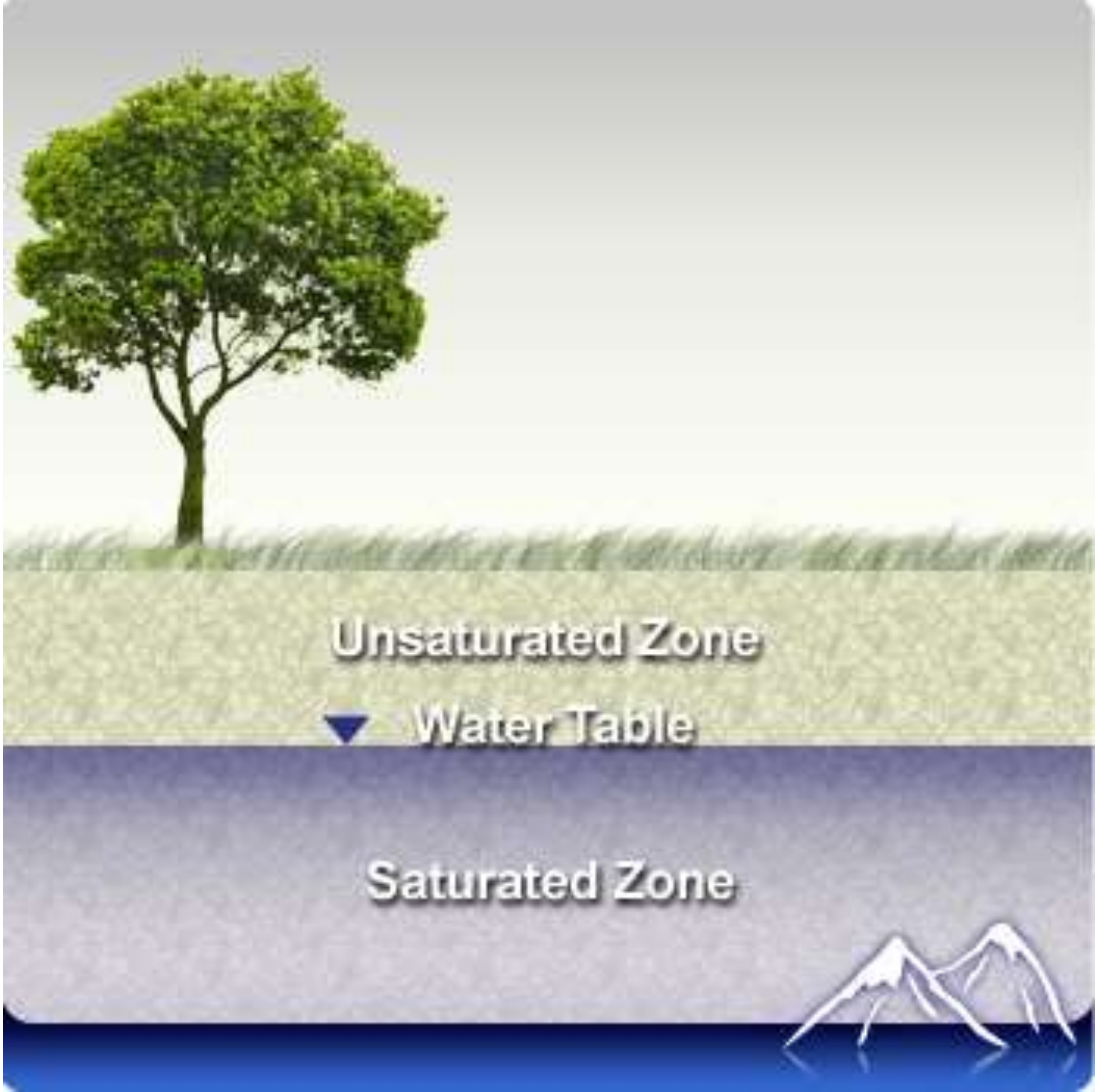
Distribution of Water

- As rain falls some of the water runs off, some evaporates, and the rest soaks into the ground (groundwater).
- Each of these three paths depends on:
  a) slope steepness, b) the nature of surface material, c) intensity of rainfall, and d) the type & amount of vegetation.

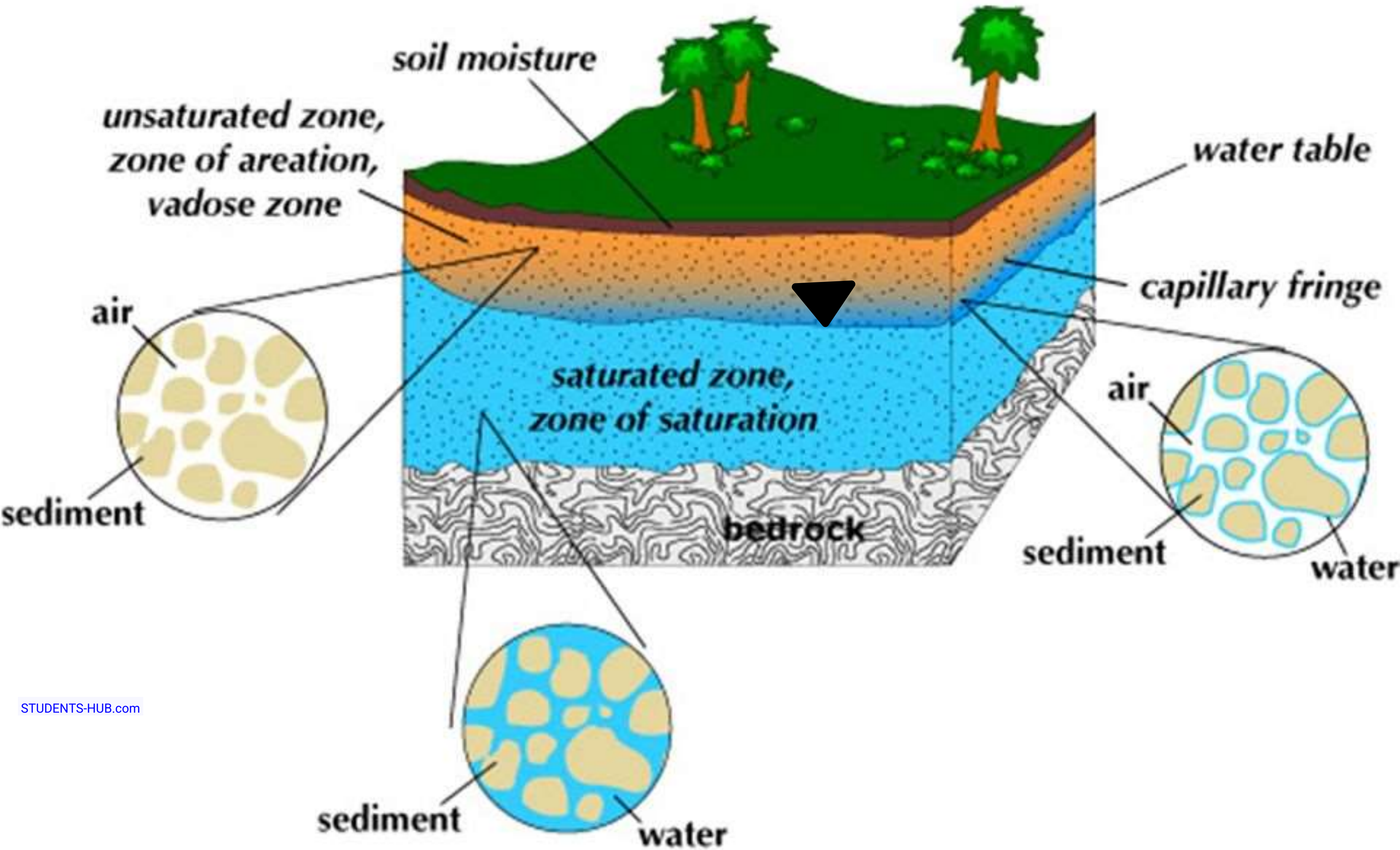
  Example: Steep slope underlain by impermeable material vs. gentle slope with permeable material….

Distribution of Groundwater

- As water percolates into the ground, some is held near the surface (between particles) in the zone of soil moisture and is used by plants.
- The rest will continue to infiltrate/ percolate the ground under it reaches a zone where pores are completely filled with water, referred to as the **Zone of Saturation**. Water here is considered **Groundwater**. The upper limit of this zone is known as **the Water Table**.
- The area above this zone that is not saturated is called the **Zone of Aeration**. Pores here are filled with air.


Unsaturated Zone
Water Table
Saturated Zone

The Water Table



Groundwater Distribution

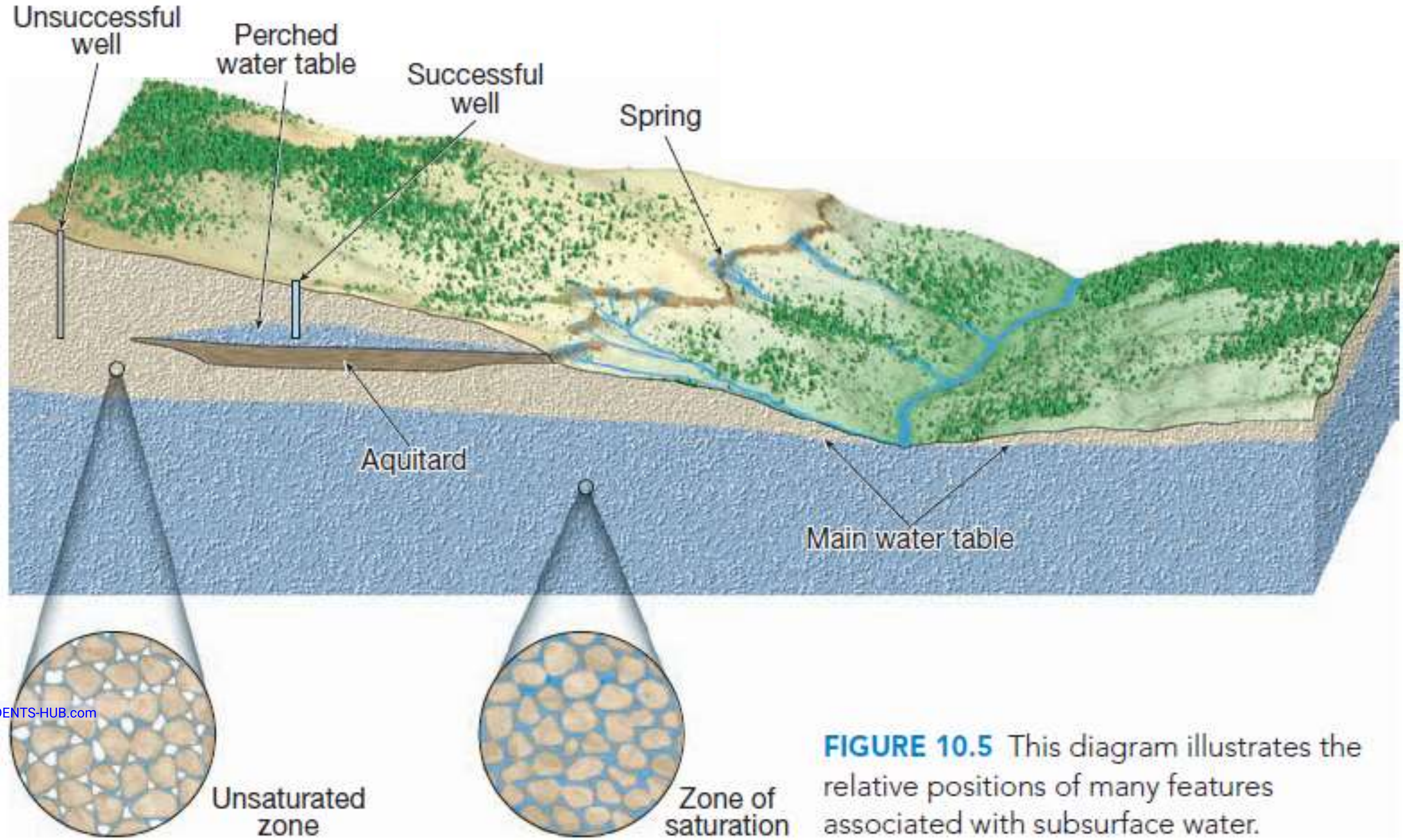
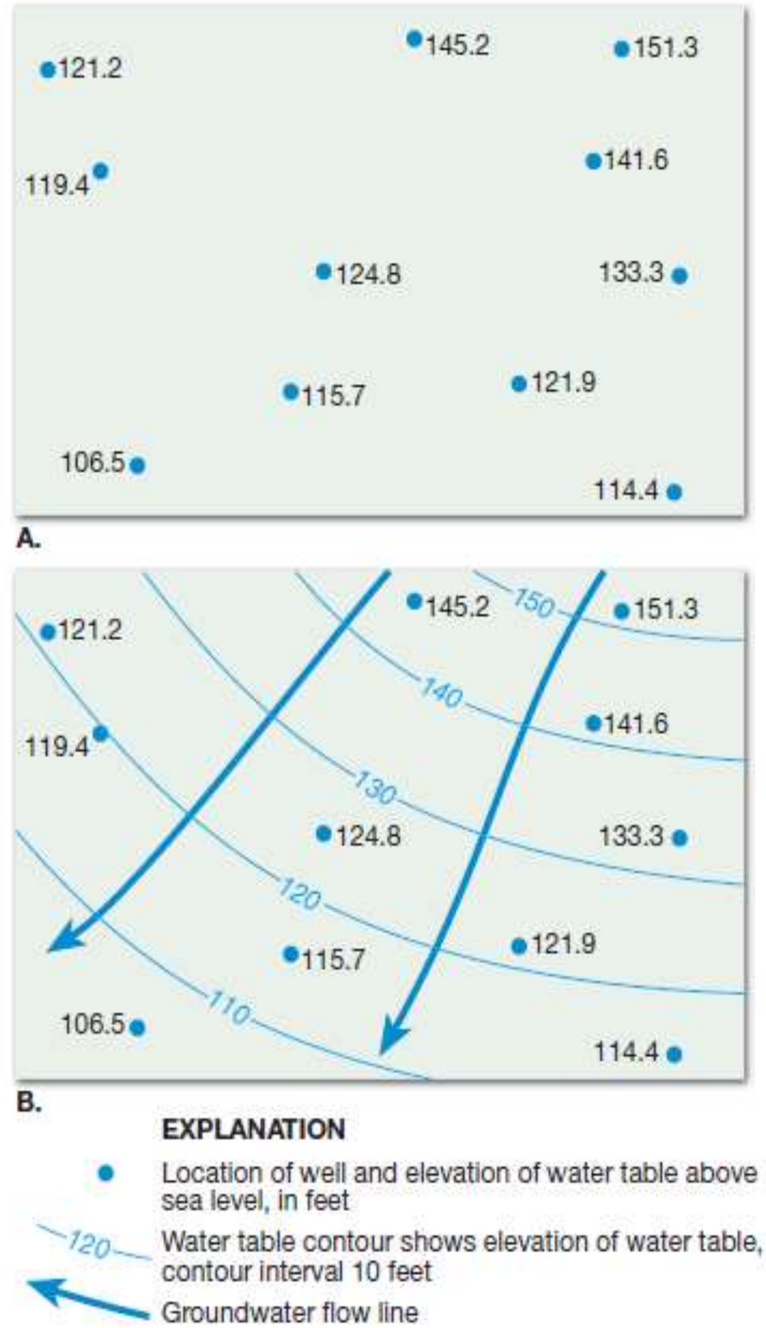


FIGURE 10.5 This diagram illustrates the relative positions of many features associated with subsurface water.

Water Table

- **The depth of the water table** varies greatly; from zero (when at the surface) to hundreds of meters below the surface.
- **Seasonal variations** occur depending on the amount of water added (related to quantity, distribution, & timing of rain).
- The water table is typically **a subdued replica (نسخة) of the surface topography (التضاريس).**
- **The water table may drop** dramatically if groundwater is overused (pumped) and in extended periods of drought (مواسم جفاف طويلة).

- We can use maps to show the depth of the water table and the flow of groundwater.
- These **flow nets** show us the direction of groundwater movement (from high elevation to lower elevation).
- Gravity is the single most important force driving GW movement.

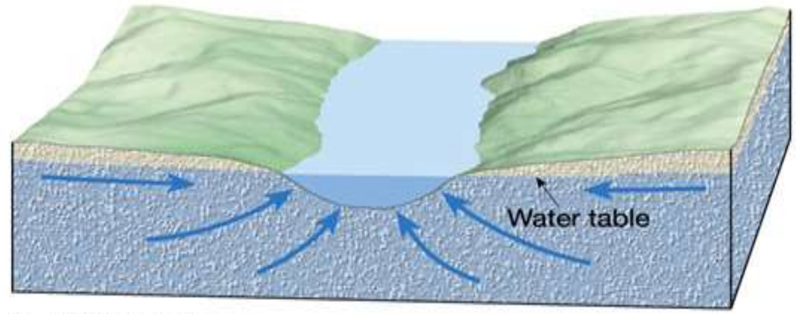


Interaction Between Groundwater & Streams

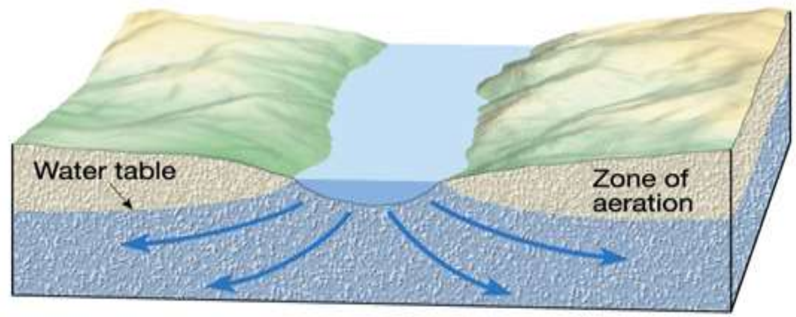
1) **Gaining Stream:**
Streams that gain water from the inflow of groundwater.
Occurs in humid areas.

2) **Loosing Stream:**
Streams that loose water to groundwater through outflow from streambed.
Types: connected & disconnected (arid region) from the WT.

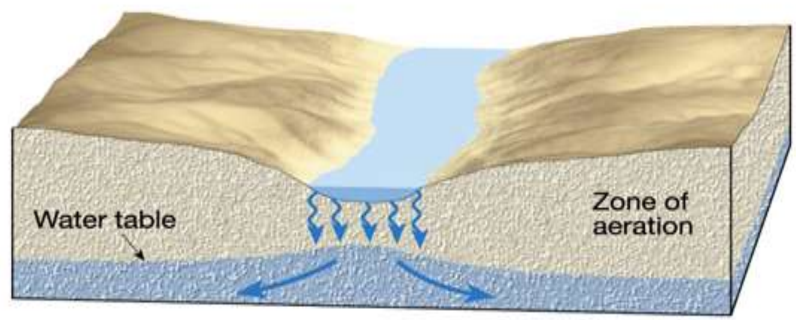
*** Note:** in some cases a stream might be both gaining & loosing in different sections or depending on the supply of GW.



A. Gaining stream



B. Losing stream (connected)



C. Losing stream (disconnected)

Storage & Movement of Groundwater

- The rate of groundwater movement is strongly influenced by the subsurface material, especially **Porosity (المسامية) & Permeability (النفاذية)**.
- **Porosity:** (the voids or opennings)
It is the percentage of the total volume of rock or sediment that consists of pore space.
It amount of pore space depends on the size & shape of grains, how they are packed together, the degree of sorting, and (in some sed. rocks) the amount of cementing material.
Porosity influences the quantity of groundwater that can be stored and it can **vary greatly** from 10-50% of the total volume.

Storage & Movement of Groundwater

2) Permeability (k): (also referred to as Hydraulic Conductivity)

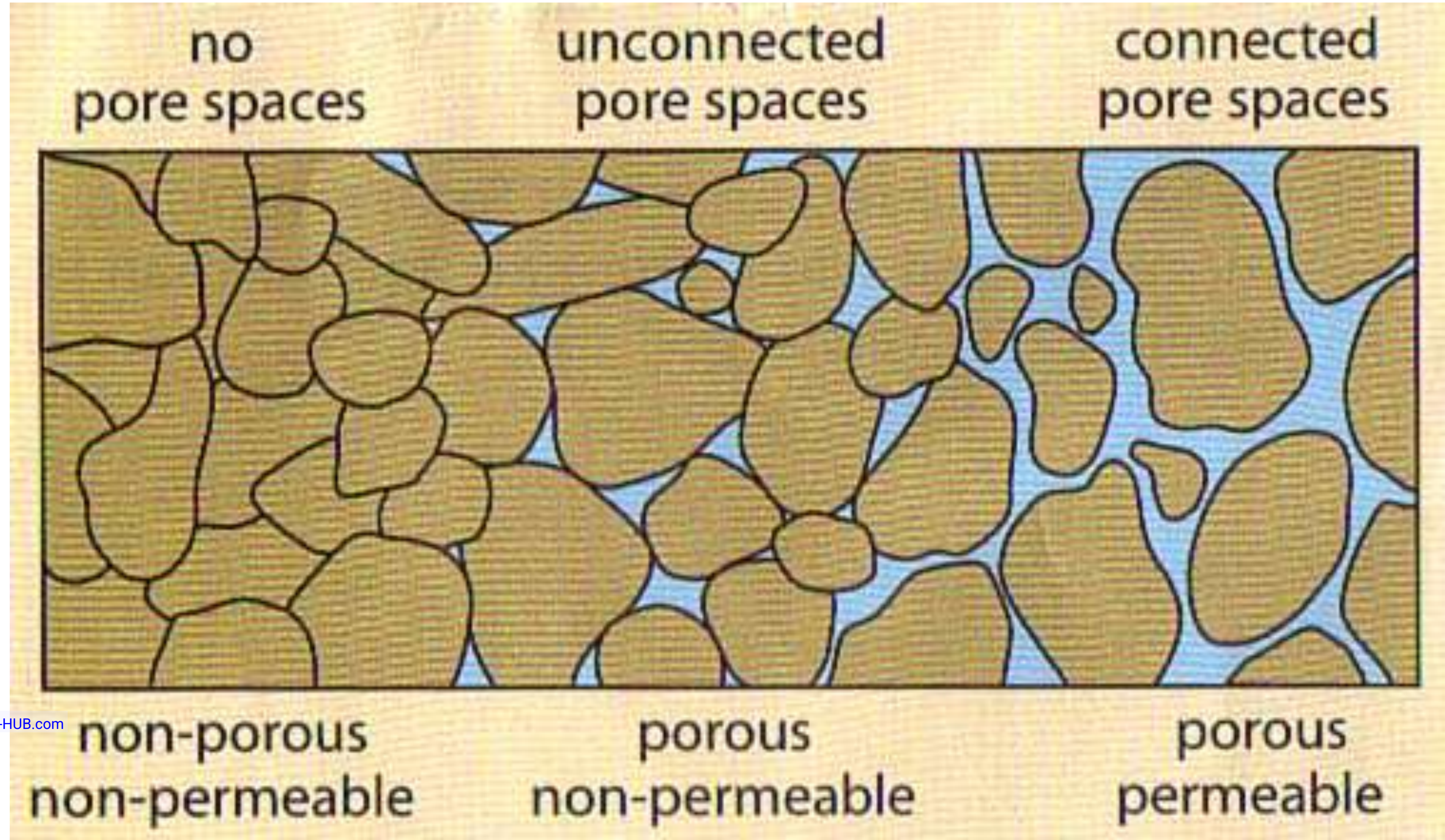
It the ease with which a fluid can pass through a certain material.

- Porosity is not a good indicator of how much fluid a material is able to transfer/move. **The pores must be connected & large enough to allow flow.**

Example: Clay has a high porosity (50%), so it's able to store a lot of water, but the pores are too small to allow water to flow through it, so it has a low permeability. **(Permeability= Gravel > Sand > Silt > Clay)**

- Permeability & groundwater flow are also influenced by joints, faults, & cavities (الفجوات والتشققات).

Porosity & Permeability



Specific yield is defined as the volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of the water table.

Bear (1979) relates specific yield to total porosity as follows:

$$n = S_y + S_r$$

where n is total porosity [dimensionless], S_y is specific yield [dimensionless] and S_r is specific retention [dimensionless], the amount of water retained by capillary forces during gravity drainage of an unconfined aquifer. Thus, specific yield, which is sometimes called *effective porosity*, is less than the total porosity of an unconfined aquifer (Bear 1979).

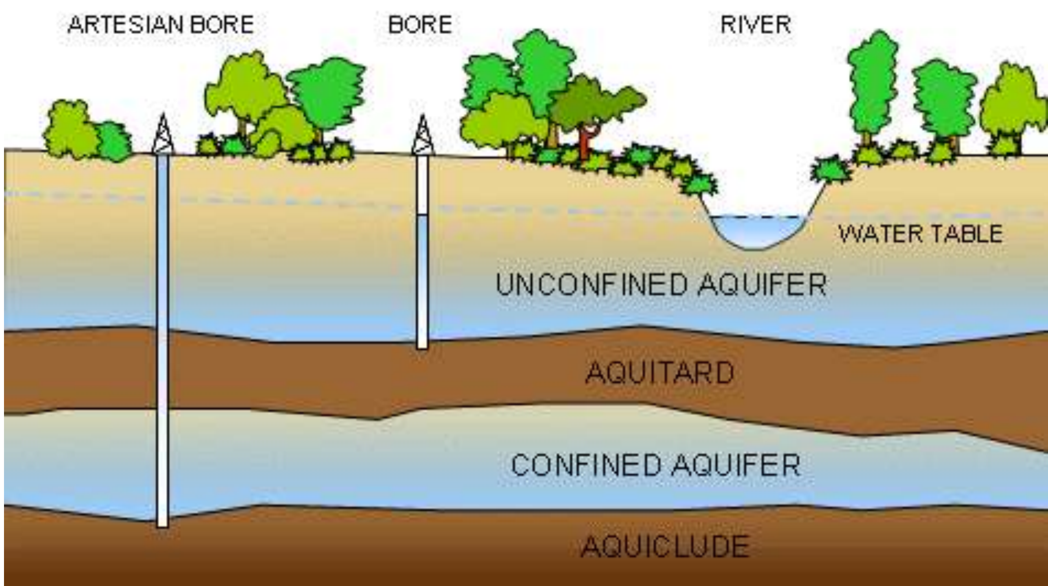
Representative Values

Heath (1983) reports the following values (in percent by volume) for porosity, specific yield and specific retention:

Material	Porosity (%)	Specific Yield (%)	Specific Retention (%)
Soil	55	40	15
Clay	50	2	48
Sand	25	22	3
Gravel	20	19	1
Limestone	20	18	2
Sandstone (unconsolidated)	11	6	5
Granite	0.1	0.09	0.01

Storage & Movement of Groundwater

- **Aquifer:**
  Permeable rock strata or sedimens that transmit groundwater freely (ex: gravel & sand).
- **Aquiclude:**
  Impereable layers that hinder or prevent water movement. (ex: clay)



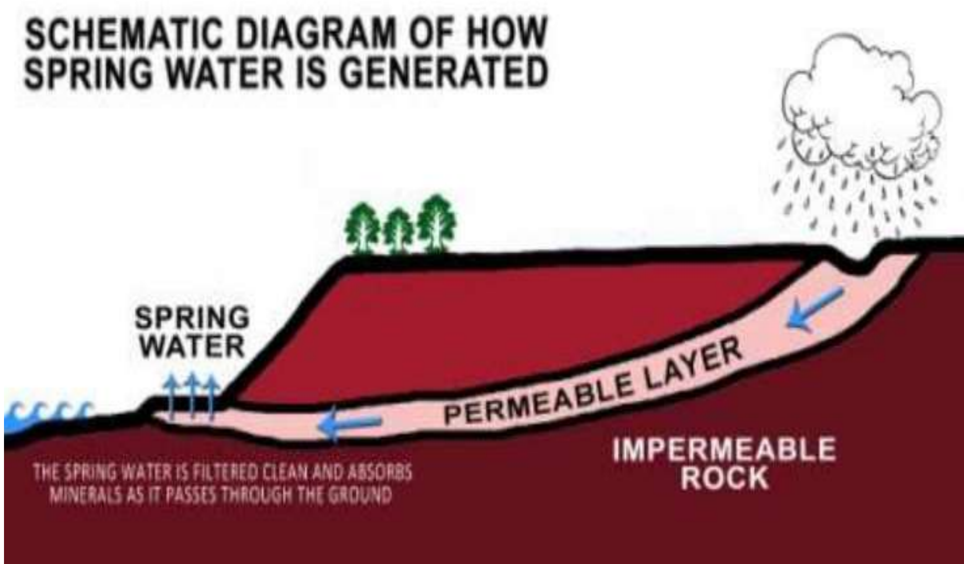
Storage & Movement of Groundwater

- **The movement of groundwater is exceedingly slow**, from pore to pore. The rate of movement may vary from millimeters per year to a kilometer per year.
- The energy that makes groundwater flow is provided by the **force of gravity**; in response to gravity GW moves from areas where the water table is high to areas where it is low.

Springs

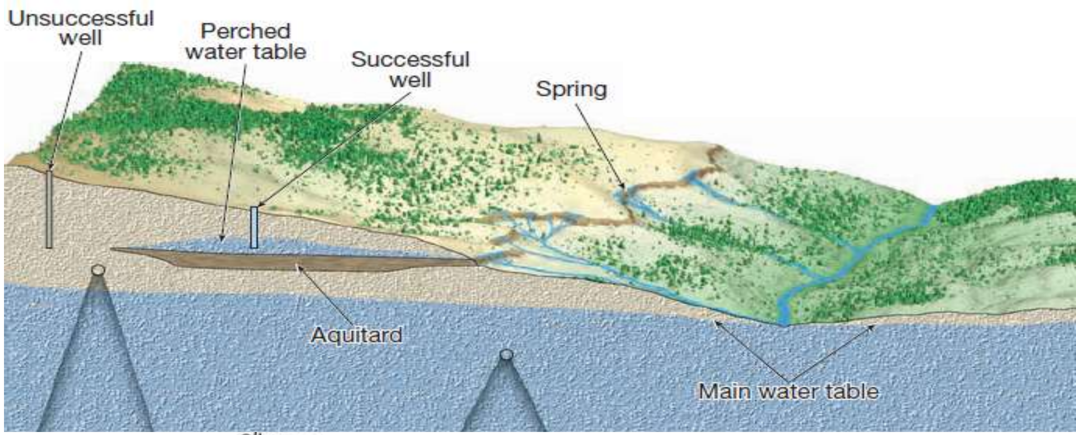
- **The source for springs** is **water from the zone of saturation** and the ultimate from precipitation.
- **Whenever the water table intersects Earth's surface, a natural outflow of water of groundwater occurs, resulting in a spring.**
- **Formation of Springs:**

1) **Sratum Spring:** When an aquitard blocks the downward movement of groundwater and forces it to move horizontally.

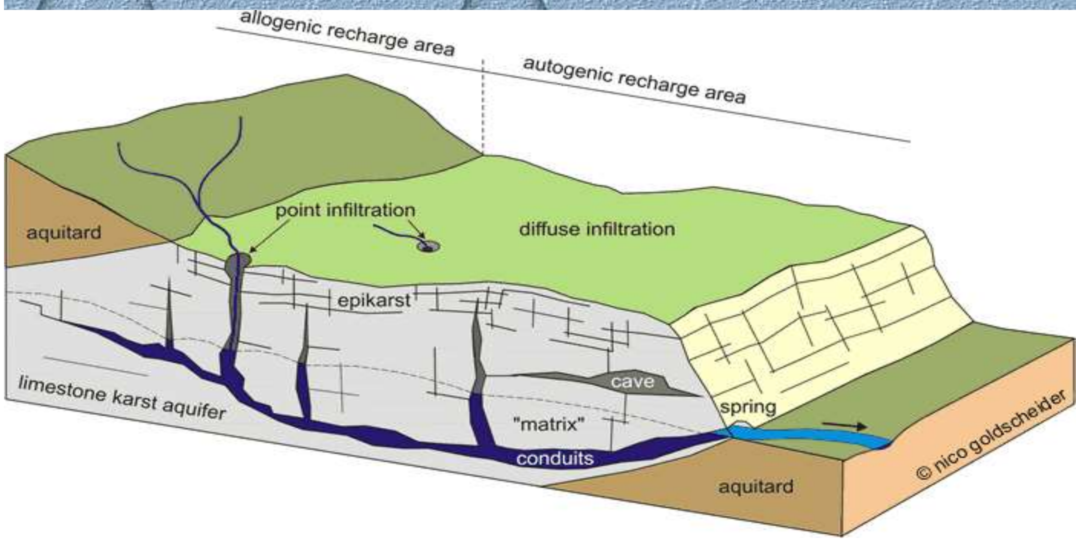


- **Formation of Springs:**

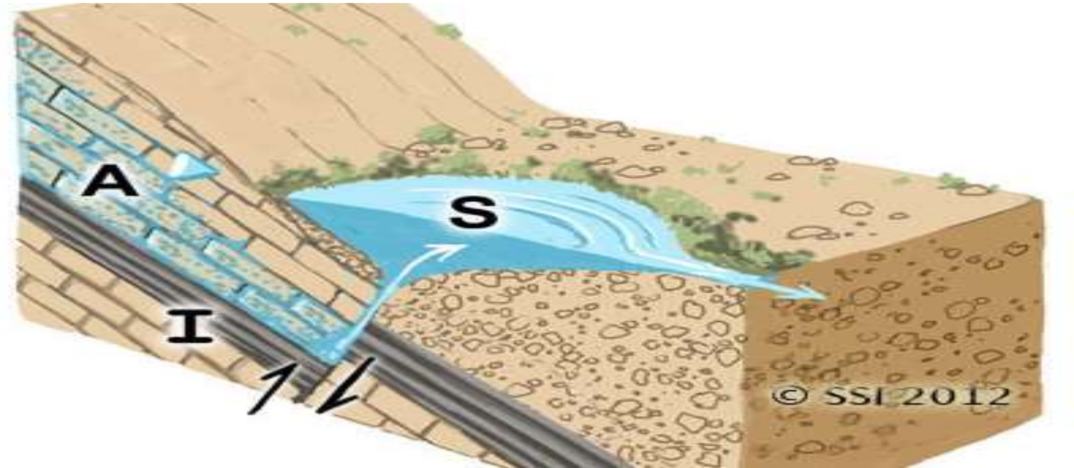
2) When an aquitard is situated above the main water table, some of the water percolating downward is held by the quitard creating a **"perched water table".**



3) Through fractures or **solution channels** (dissolved rock) in impermeable rock.



4) **Fault Spring.**



Wells (الآبار)

- It is a hole bored into the ground to the zone of saturation, where groundwater can be pumped to the surface.
- After pumping the water table is lowered near the well ("drawdown") and with increased pumping create a **"Cone of Depression"**.
- If overpumped, it may result in a large cone of depression and cause the Water Table to be lowered substantially affecting nearby wells.

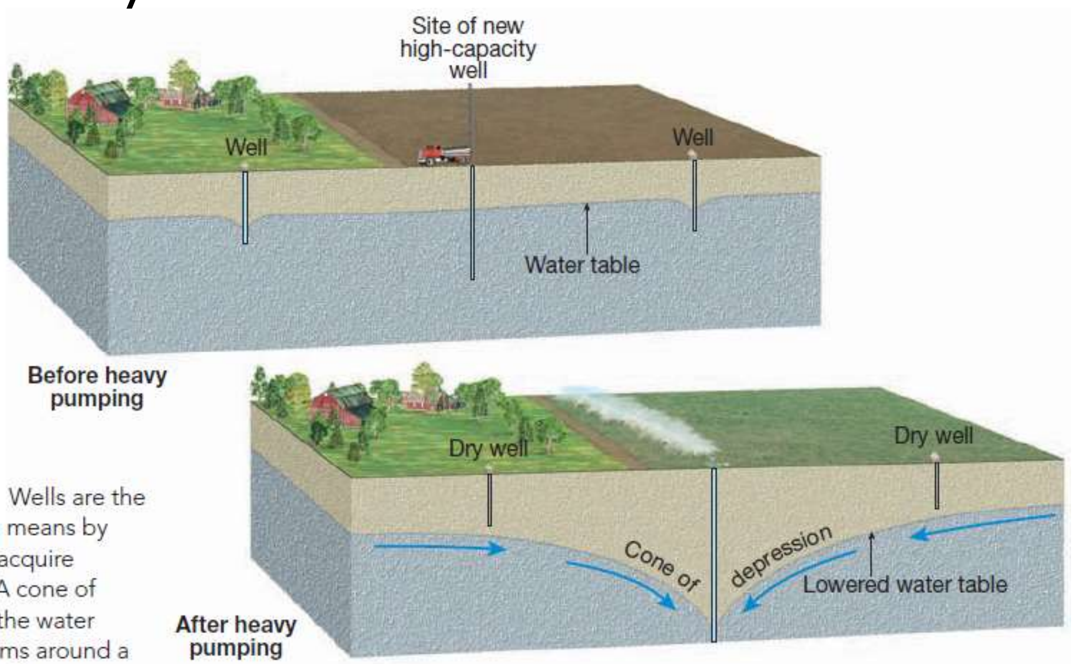


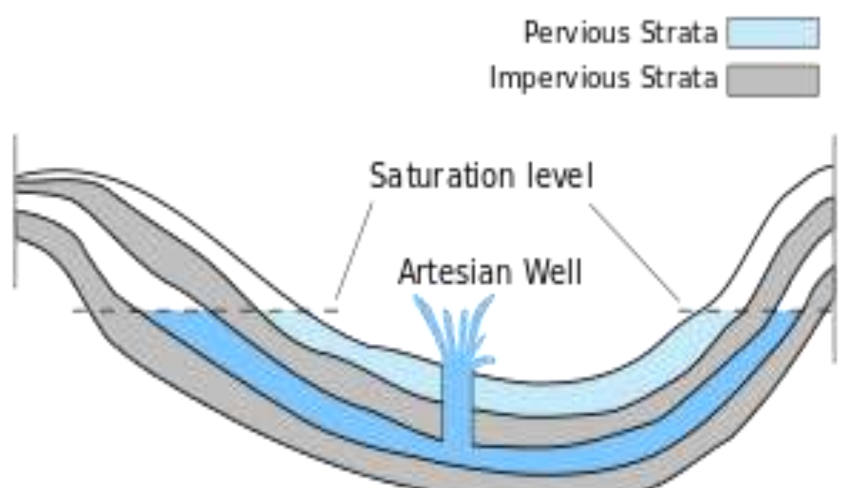
FIGURE 10.11 Wells are the most common means by which people acquire groundwater. A cone of depression in the water table often forms around a pumping well. If heavy pumping lowers the water table, some wells may be left dry. *(Photo by ASP/YPP/agefotostock)*

Well drilling rig

Artesian Wells

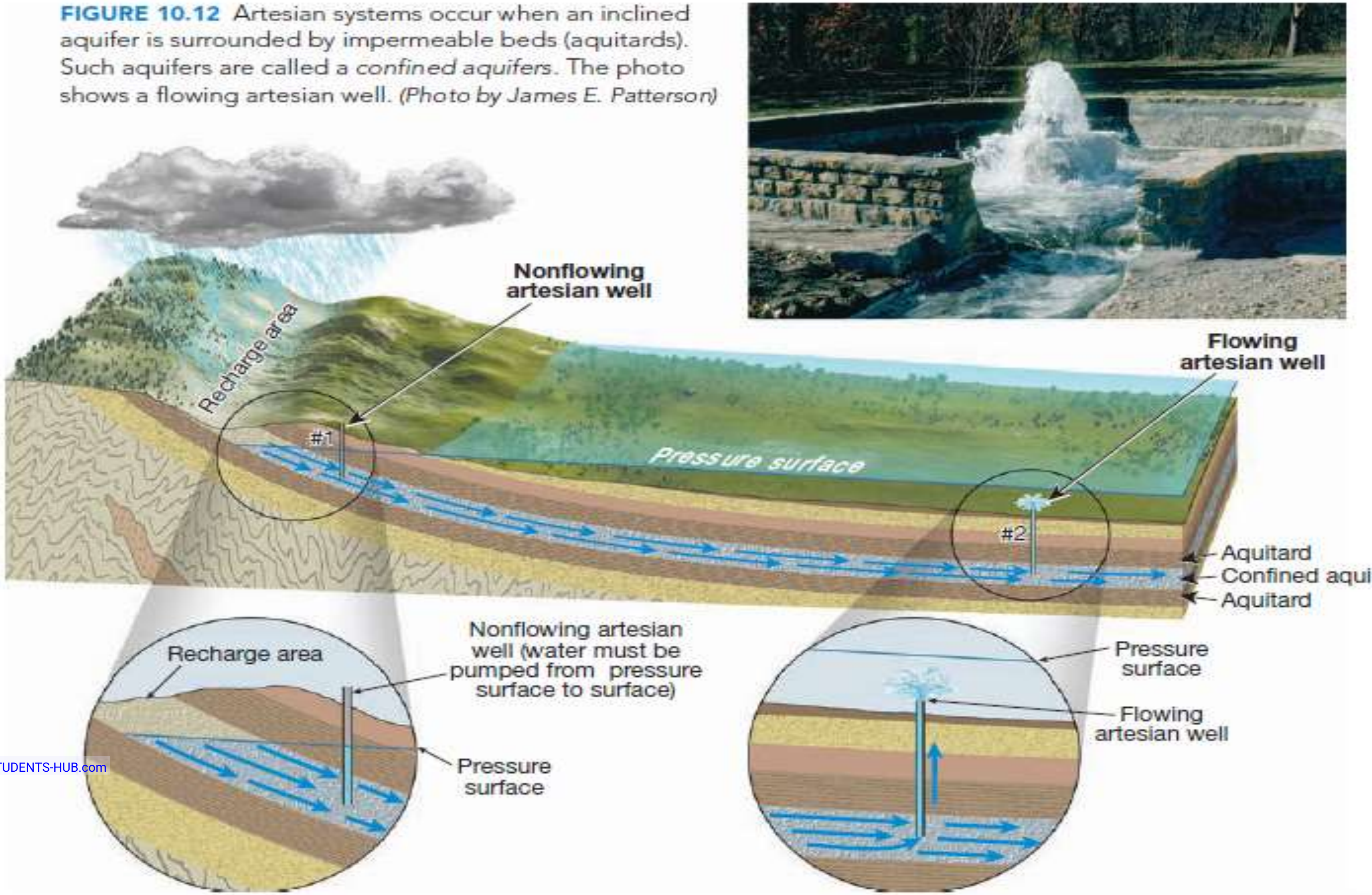
- When groundwater is under pressure and rises well above the level of the aquifer or where the water was first encountered.
- **<u>Conditions needed:</u>**

1) Water must be confined to an aquifer the is inclined so that one end is exposed at the surface, where it can receive water.
2) Impermeable layers (Aquitards), both above and below the aquifer, preventing it from escaping.



Flowing vs. Non-flowing Artesian Wells

FIGURE 10.12 Artesian systems occur when an inclined aquifer is surrounded by impermeable beds (aquitards). Such aquifers are called a *confined aquifers*. The photo shows a flowing artesian well. *(Photo by James E. Patterson)*



Environmental & Eng. Problems Associated with Groundwater

Some of the main issues:

1) **Overexploitation/ overuse**
2) **Groundwater withdrawal & sinking**
3) **Groundwater contamination.**

- All this has led some to consider groundwater as **“a non-renewable resource”**

1) Over-Use of Groundwater

- Caused by over-pumping or over-use/ over-exploitation: **The discharge exceeds the recharge in the groundwater budget (like a person in dept).**
- The GW can be described as being "mined"!
- This cases the depletion (استنفاذ) of GW resources.
- If the problem is prolonged, even if pumping were to stop, it could potentially take hundreds or even thousands of years for the groundwater resource to be replenished (إعادة تعبئتها) or recovered (تعافيها).

1) Over-Use of Groundwater: Gaza Strip & the Coastal Aquifer

- In Gaza, over 4,000 private agricultural and domestic wells.
- The aquifer is replenished with an annual 85 Mcm while abstracted with over 165 Mcm/Year. (**95% over-abstraction**).
- This is causing **a drop** in the water table of about **1.6 Meters per year**. It is damaging the already depleted coastal aquifer and posing a the threat of irreversible environmental damage.
- **Salt-water Intrusion.**

2) Land Subsidence

- Over-pumping of a GW resources→ a drop in the water table →may cause land subsidence.
- Especially in areas underlain by thick layer of loose soil, which is compacted by overburden, causing the land to subside.

  Example: Mexico City; 7 Meter drop.

Groundwater Pollution/ Contamination

- A serious issues especially in areas that depend on GW as the main source of water.
- **Contamination from Sewage:**
- From a septic tank, or leakage from sewage pipeline, or farm wastes (fertilizers), or chemical contaminants.
- If sewage water contaminated with bacteria enters the ground, **it may be purified through natural processes** (the bacteria mechanically filtered by sediment on its way down or destroyed through oxidation or/and consumed by other organisms).
- However, for this to occur, the aquifer must be the correct composition. **For example:** if aquifer extremely permeable (coarse gravel, or fractured rock, or cavernous limestone)→ water travels quickly→ not enough contact with surrounding material to be cleansed/ purified.

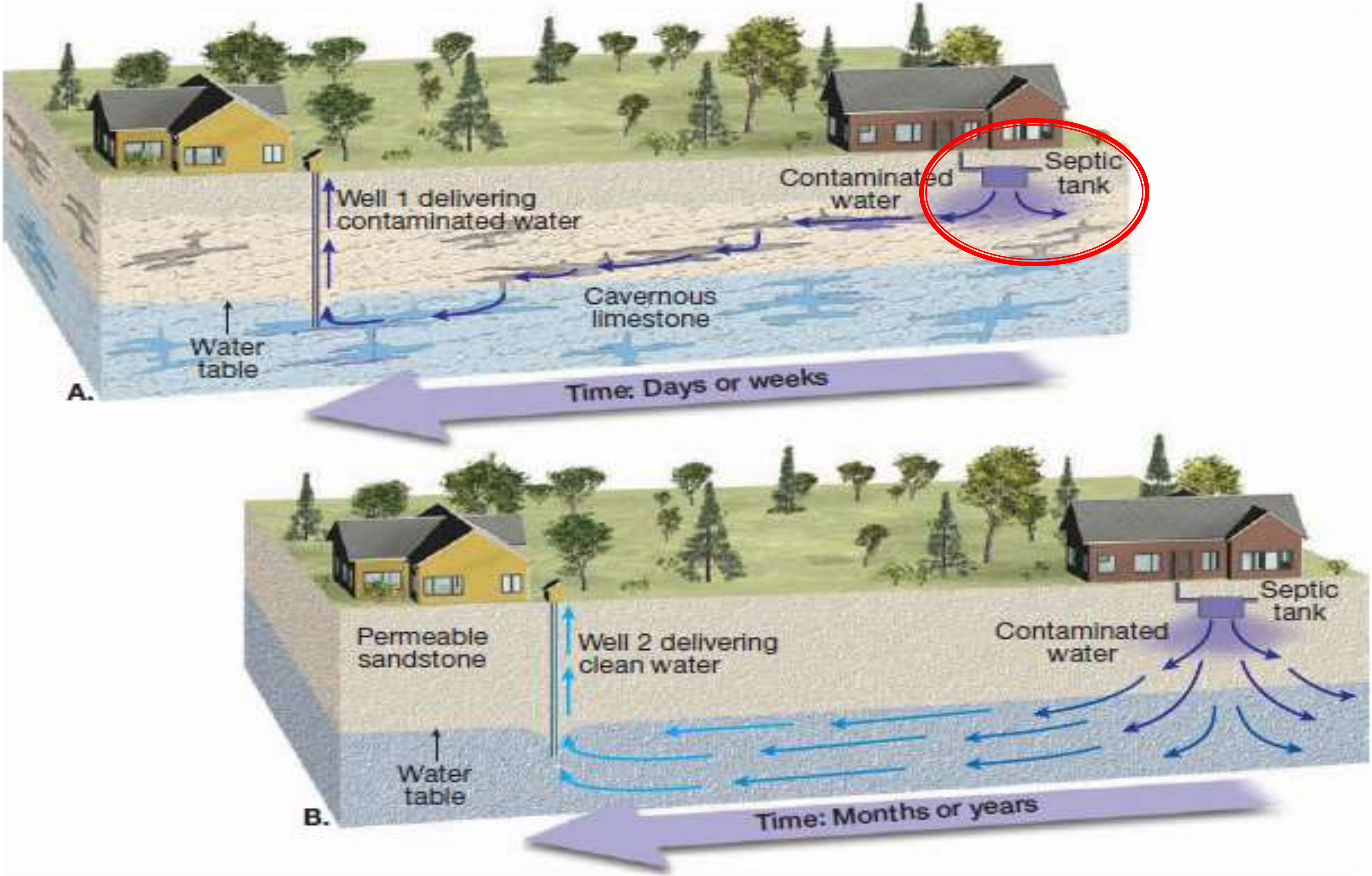


FIGURE 10.16 **A.** Although the contaminated water has traveled more than 100 meters before reaching Well 1, the water moves too rapidly through the cavernous limestone to be purified. **B.** As the discharge from the septic tank percolates through the permeable sandstone, it is purified in a relatively short distance.

Groundwater Pollution/ Contamination

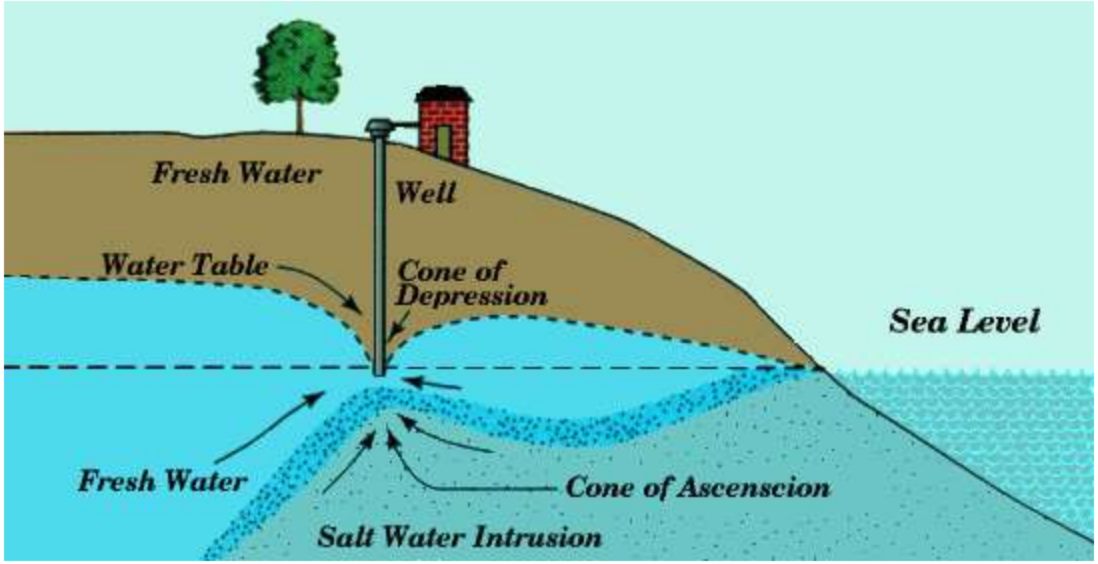
- **Some Solutions…**

  Its not an easy process but remediation (المعالجة) must be done.

1) Stopping the source of pollution.
2) Pumping the polluted water, treating it, and re-ejecting it into the ground.
3) Injection of cleansing chemicals.
4) Leaving a resource without usage for a long time.

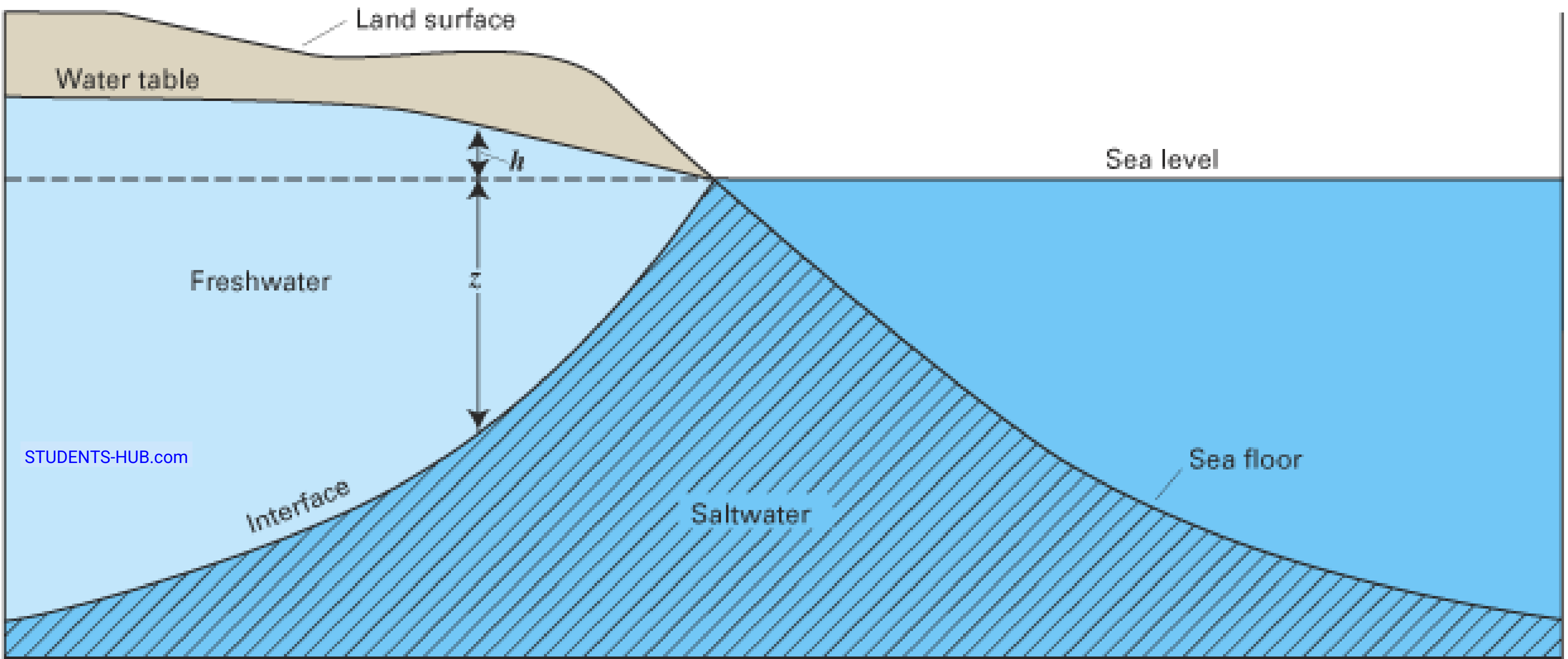
Groundwater Contamination: Salt Water Intrusion/ Contamination

- **Salt Water Intrusion** is a phenomenon that occurs in over-used coastal aquifers, when sea water intrudes or enters the fresh water aquifer.
- Fresh water is less dense & will float on top of salty water forming a lense-shaped body.



Groundwater Contamination

- the Ghyben–Herzberg ratio: h=40 z
  For every foot drop in the water table above sea level (h), there will be 40 feet of freshwater below sea level (z). This means that saltwater will intrude to compensate the rise of the freshwater boundary (z).



Note: Today this ratio is considered outdated because it makes many theoretical assumptions & we have better computational techniques to account for variables.

Groundwater Contamination

- **Some General Solutions….**

1) Management of Abstraction.
2) Recharge Wells.
3) Building a large basin to collect surface drainage and allow it to seep in the ground.

The Geologic Work of Groundwater

- The primary erosion is carried out by groundwater that is dissolving rock (mainly limestone).

Water+ carbonic acid→ reaction with limestone→ calcium by carbonate

Creation of limestone caverns just below the water table in the saturated zone as GW follows lines of weakness and joints in rock, with time dissolving rock & creating caves.

Hot Springs & Geysers

- **Hot Springs** have water 6-9 degrees warmer than mean air temp. Water is heated at depth & if it rises, it emerges as a hot spring.
- **Geysers** are intermittent hot springs or fountains where water & steam are ejected with great force into the air (30-60 meters).

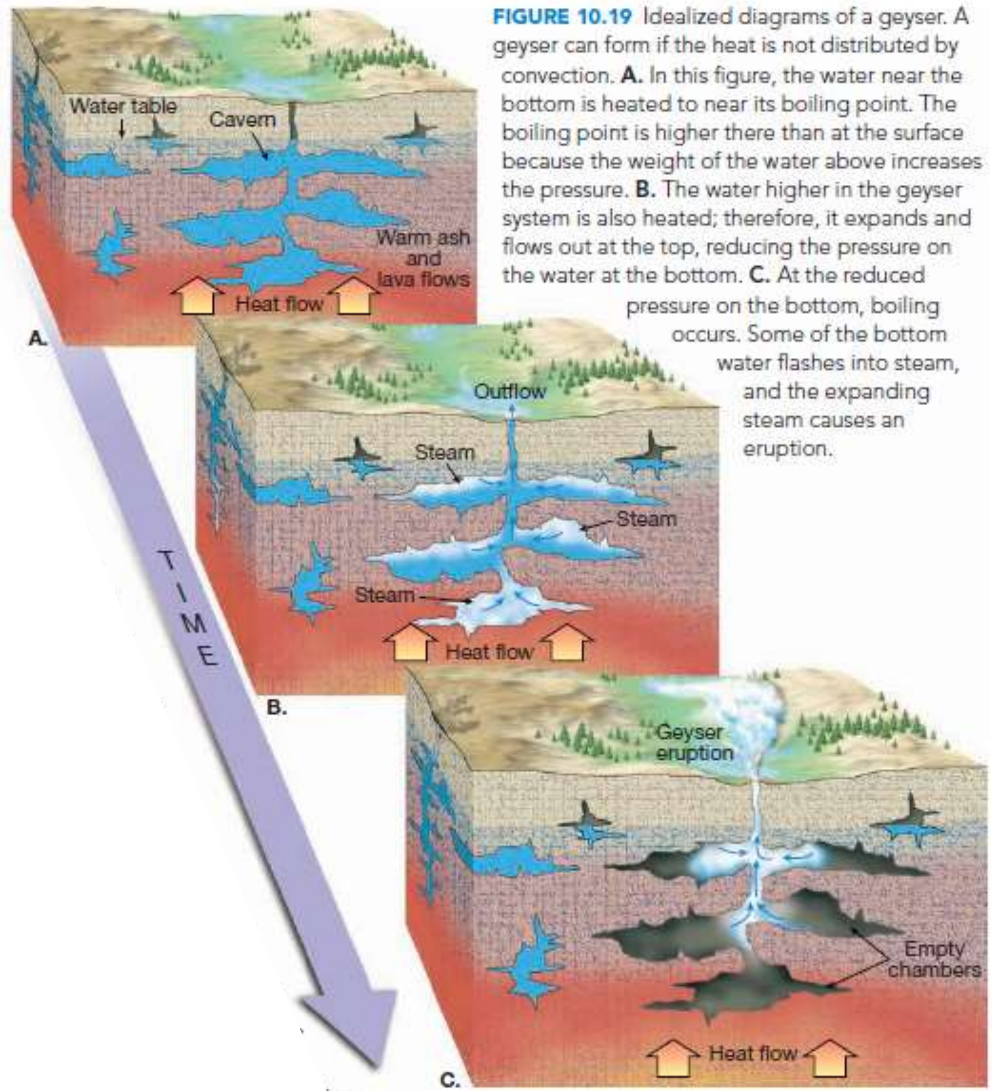


FIGURE 10.19 Idealized diagrams of a geyser. A geyser can form if the heat is not distributed by convection. **A.** In this figure, the water near the bottom is heated to near its boiling point. The boiling point is higher there than at the surface because the weight of the water above increases the pressure. **B.** The water higher in the geyser system is also heated; therefore, it expands and flows out at the top, reducing the pressure on the water at the bottom. **C.** At the reduced pressure on the bottom, boiling occurs. Some of the bottom water flashes into steam, and the expanding steam causes an eruption.

The Geologic Work of Groundwater

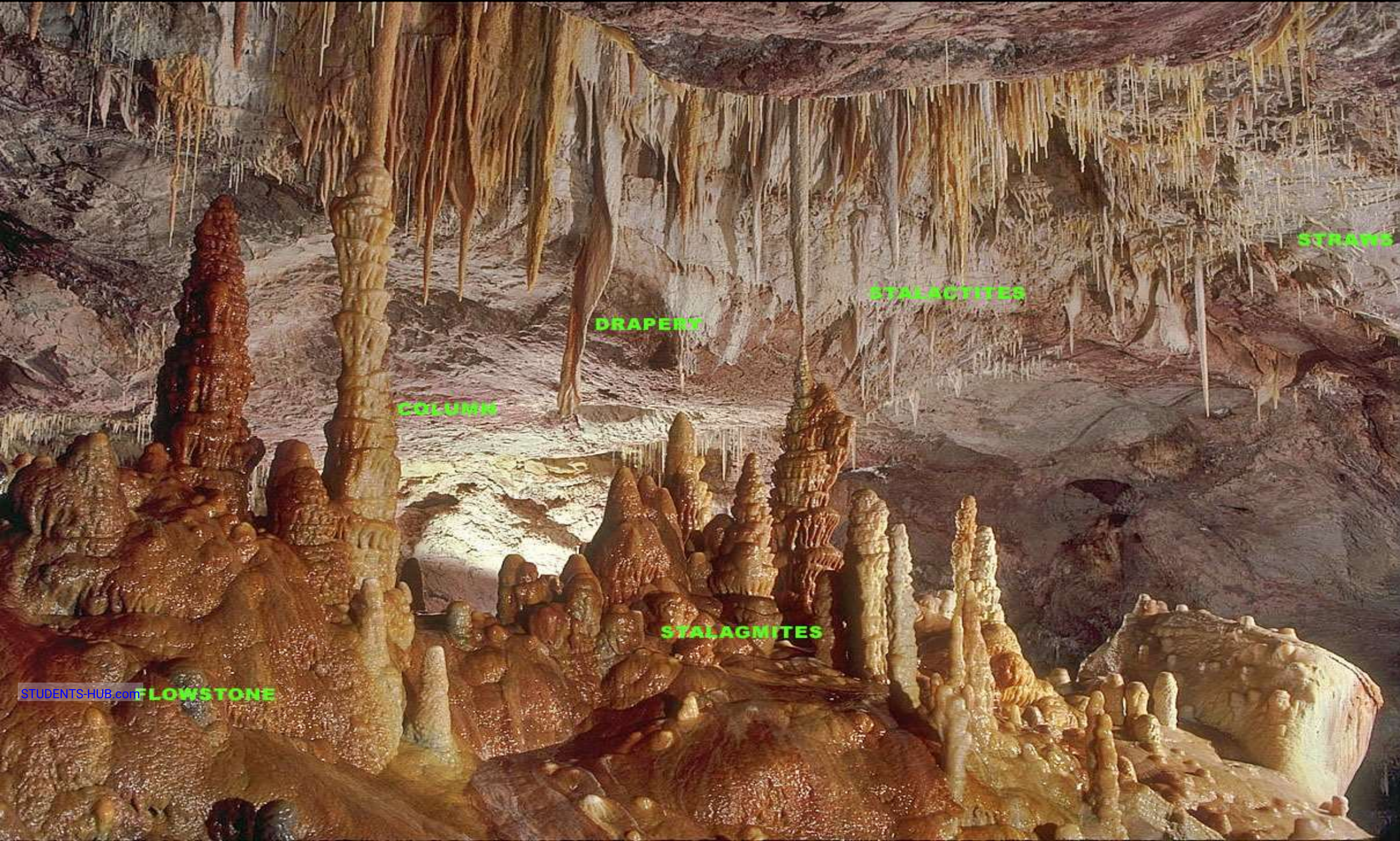
- **Formation of drip stone (or Travertine)**:
  After caves are formed/ carved & become in the aeration zone, dripping of water containing calcium bicarbonate for extended periods will form leave calcite behind it to produce limestone (travertine).
- The following feastures are referred to as **"Speleothems"**:

➢ Stalactites هوابط

➢ Stalagmites صواعد

➢ Columns عواميد (when a stalactite & stalagmite meet).

Stalactites & Stalagmites



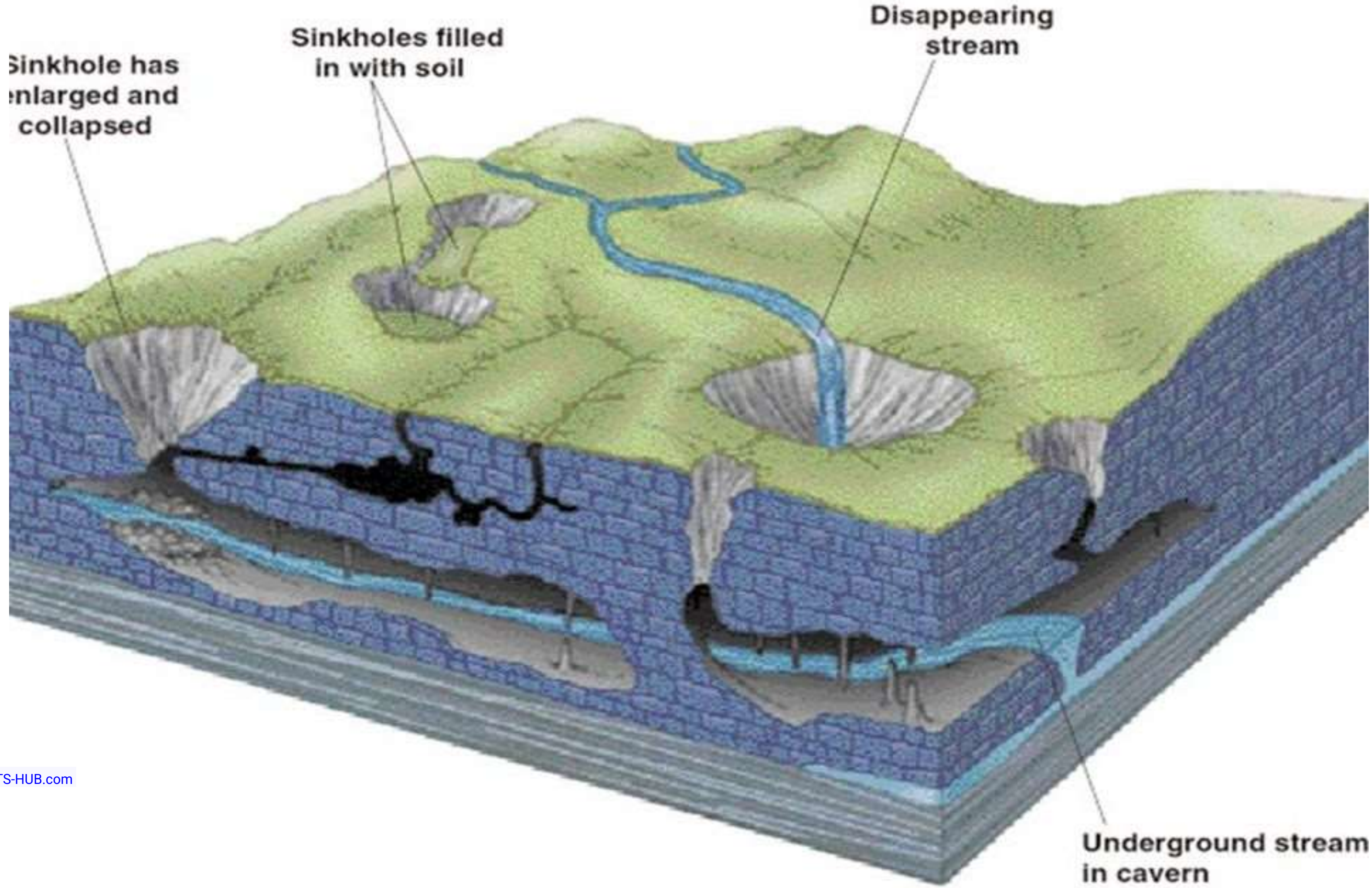
The Geologic Work of Groundwater

- **Karst Topography:**
  When the landscape reflects the erosional work of groundwater; exhibiting irregular terrain punctuates with many depressions called sinkholes (1-50 meters) and lack of surface drainage.
- **2 Types of Sinkhole Formation:**

1) gradual dissolution of limestone beneath the soil (as water picks up carbon dioxide forming carbonic acid). It is gradual & Produces gentle slopes.

2) Sudden formation due to the collapse of cavern roof under weight. Produces steep slopes.

KARST TOPOGRAPHY FEATURES



DESERTS & WIND

1- Desert means unoccupied land.

Second after polar areas of least population.

2-Deserts cover > 30% of Land surface forming the largest climatic group.

3- Great Sahara (North Africa) is the largest.

Distribution & Causes of Dry Lands:

Climatologists define "Dry Land" as one in which yearly precipitation is less than the potential loss of water by evaporation. So, "Dryness" is not a function of precipitation only but also "Evaporation" which in turn depends on Temperature; example:

250 mm rain/yr in Nevada may support only sparse vegetation while the same amount in Scandinavia is sufficient to support forests.

Temperature

1- The highest temperature ever recorded on Earth was 58 °C in the Libyan desert. The coldest temperature ever measured was -88 °C at Vostok Station in Antarctica.

2- Not all deserts are hot; Gobi Desert (China & Mongolia) has an average high temperature of -19C in January.

In the water-deficient regions 2 climatic types are common; they are:

1- DESERT = arid.

2- STEPPE (السهوب) = semi-arid; steppe is a transitional zone between dry and humid climates.

Geological Processes dominate in Deserts are related to:

1- Tectonic Forces.

2- Running Water.

3- Wind.

4- > Radiation.

Because these processes combine in different ways from place to place, the appearance of Deserts' Landscapes varies a great deal as well.

Weathering

- Although mechanical weathering predominates (resulting in unaltered rock & mineral fragments), chemical weathering still plays a role…
- Over time chemical weathering results in clays, thin soil, & oxidation of silicate minerals.

1- The Role of Water

- Contrary to common belief that wind is the most important erosional agent, it is actually **RUNNING WATER** that does most of the erosional work (especially Heavy rainfall).
- **most of the desert topography (landscape) is formed in cooperation with the running water**

The Role of Water

- Deserts have **ephemeral streams** (streams that occur during rainfall, so not filled with water year round).
- **Heavy Rainfall→ Flash Floods in Stream Beds→ Extensive Erosion (especially that is no vegetation)**

Heavy Rainfall →

The Role of Water

- Video of a Flashflood….

https://www.youtube.com/watch?v=ORZQUIk8vxg

The Role of Water

- **<u>Class Question:</u>**

  The Nile runs through about 3,000 KM of the Sahara Desert, so how does it have water year-round???

Basins and Ranges Landscape

1- Deserts are subjected continually to SMOOTHENING their odd features through time by both sporadic rain & wind.

Stages of Landscape Evolution of Basin & Range

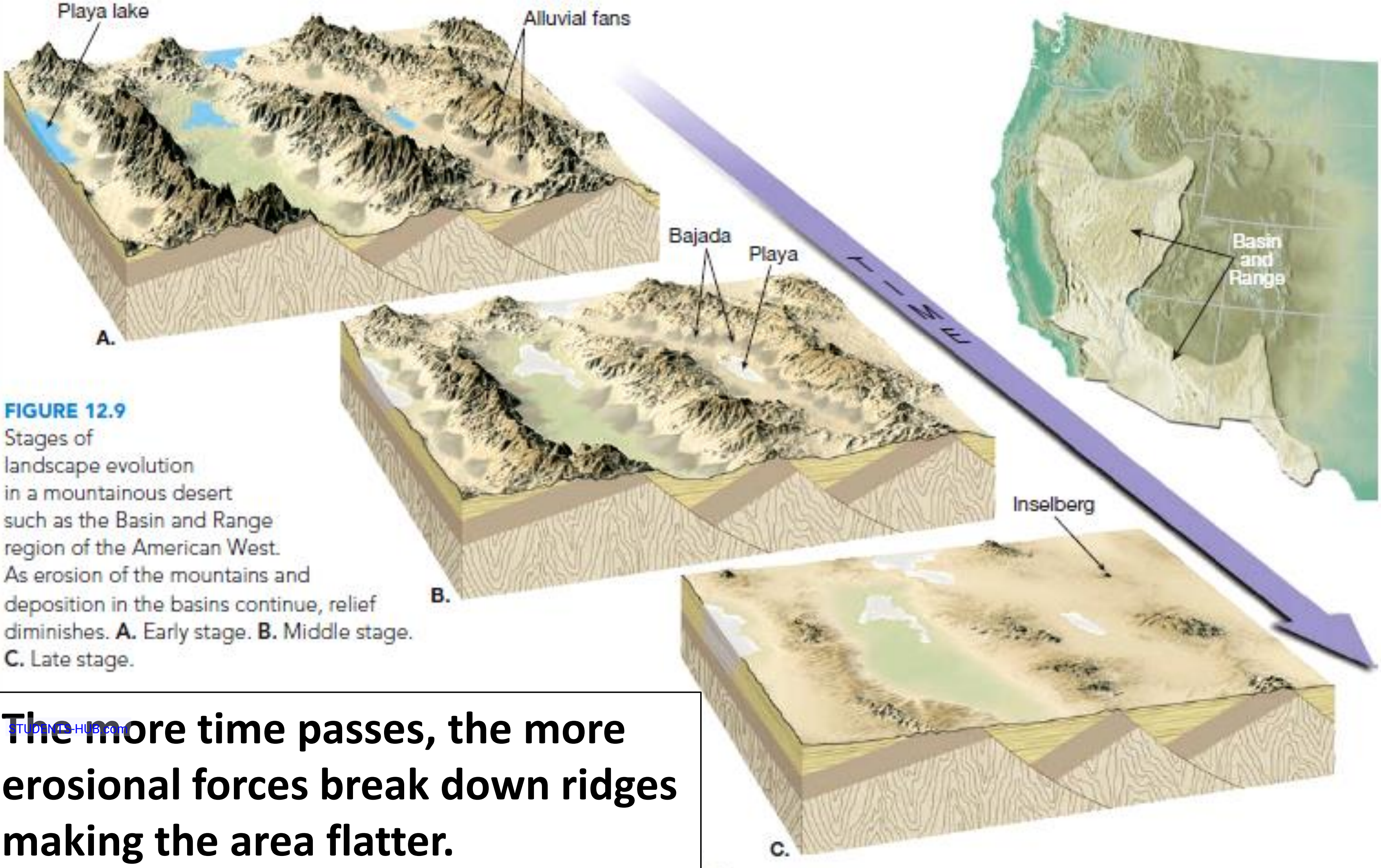


FIGURE 12.9 Stages of landscape evolution in a mountainous desert such as the Basin and Range region of the American West. As erosion of the mountains and deposition in the basins continue, relief diminishes. **A.** Early stage. **B.** Middle stage. **C.** Late stage.

The more time passes, the more erosional forces break down ridges making the area flatter.

PLAYA LAKES: بحيرات القيعان

Are seasonal lakes with cycles of silt/clay/salts depositional character. Most of the coming water evaporates, less infiltrates.

When dry, it is referred to as "Playa".

2- WIND EROSION

FIRST: **Transports sediments; moving air carries and transports the loose debris (فتات) [mainly sand] as follows:**

A) Bed load: Saltation – a Latin word meaning "to jump": mostly sand and it skips & bounced short heights

"the movement of hard particles such as sand over an uneven surface in a turbulent flow of air or water".

B) Suspended load: Mostly fine particles such as silt & clay (more silt) that are carried high in the air by wind, which for short or far distances.

[dust from the Sahara was found in the West Indies].

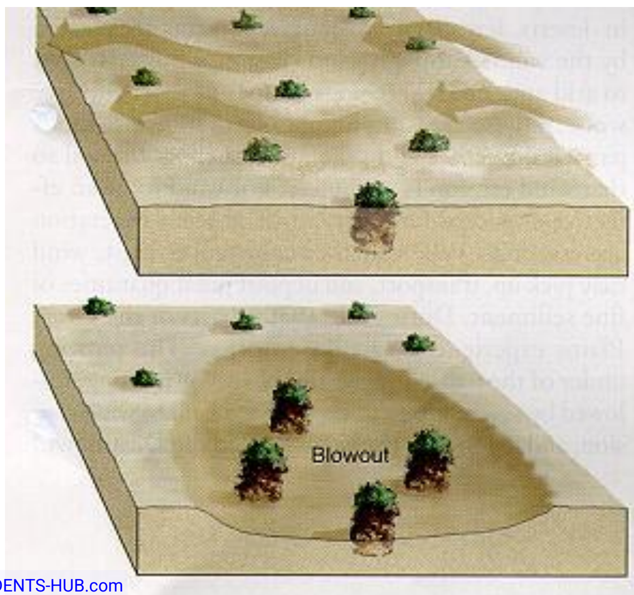
Second: **Wind Erosion:**

a- Deflation (السفوف): The lifting and removal of loose material by wind.

For the wind to be effective the land should be dry & free of vegetation. This process gives rise to the formation of many topographic features like:↓

- Blowouts:↓

- **They are sandy depressions caused by the removal of sediments by the wind.**



- Desert Pavements:↓

- **Is a layer of coarse pebbles and gravels, too large to be moved by the wind, that covers portions of many deserts *[this method of wind action is similar to sieving]***

Wind Abrasion:

- Sand and other wind loads collide with surface during wind blowing times, leading to the cutting and polishing exposed rock surfaces.

Rock pudding.

Wind Deposits: 1) Mounds & Ridges 2) Loess

Conspicuous landforms mainly 2 types:

1) Mounds ↓(هضاب) and Ridges ↓(سلاسل تلال): These are made up of sand from the winds' bed load called "DUNES".

2- As well as Extensive blankets of silt called "LOESS" that once were carried by wind. ***"LOESS is a loosely compacted yellowish-gray deposit of windblown sediment of which extensive deposits occur, e.g., in eastern China and the American Midwest".***

TYPES OF SAND DUNES:

Factors influencing the formation and size of dunes:

1- Wind direction: Regular or random.

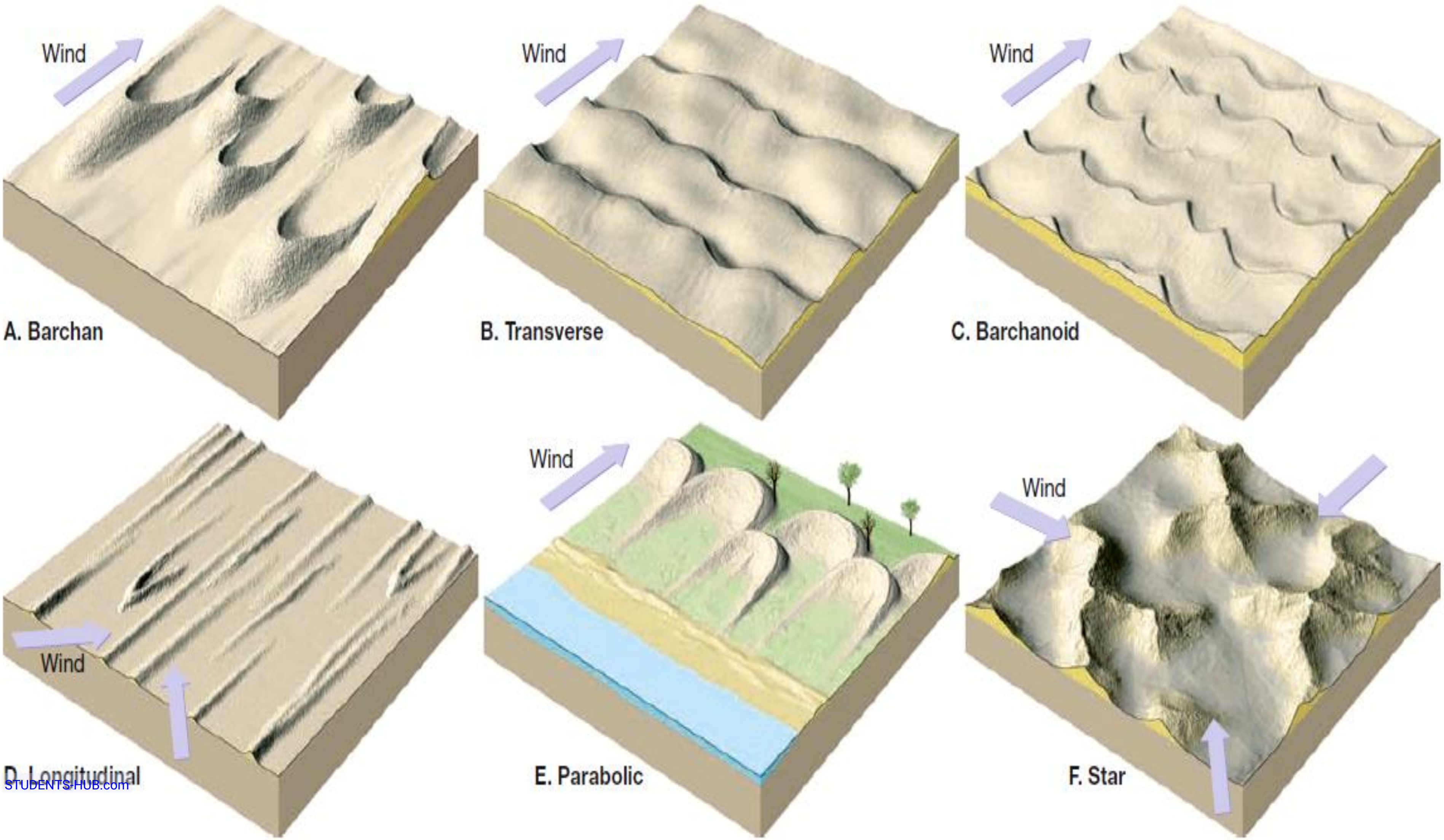
2- Amount of vegetation.

3- Wind Velocity.

4- Availability of sand.

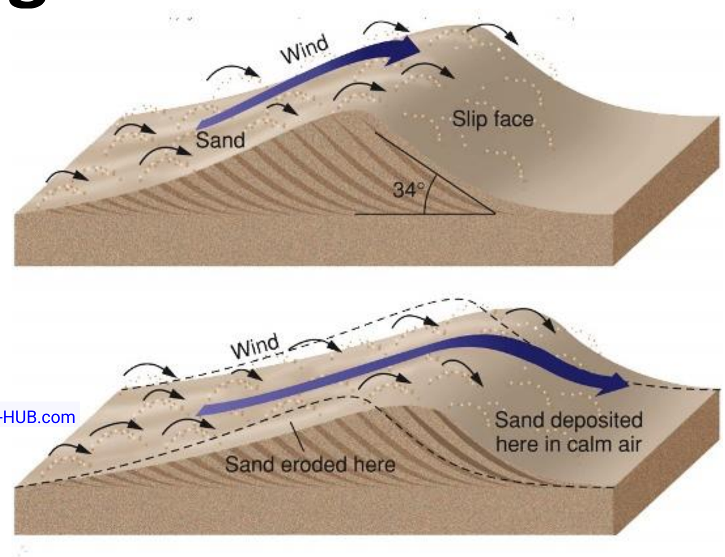
5- Man-made structures.

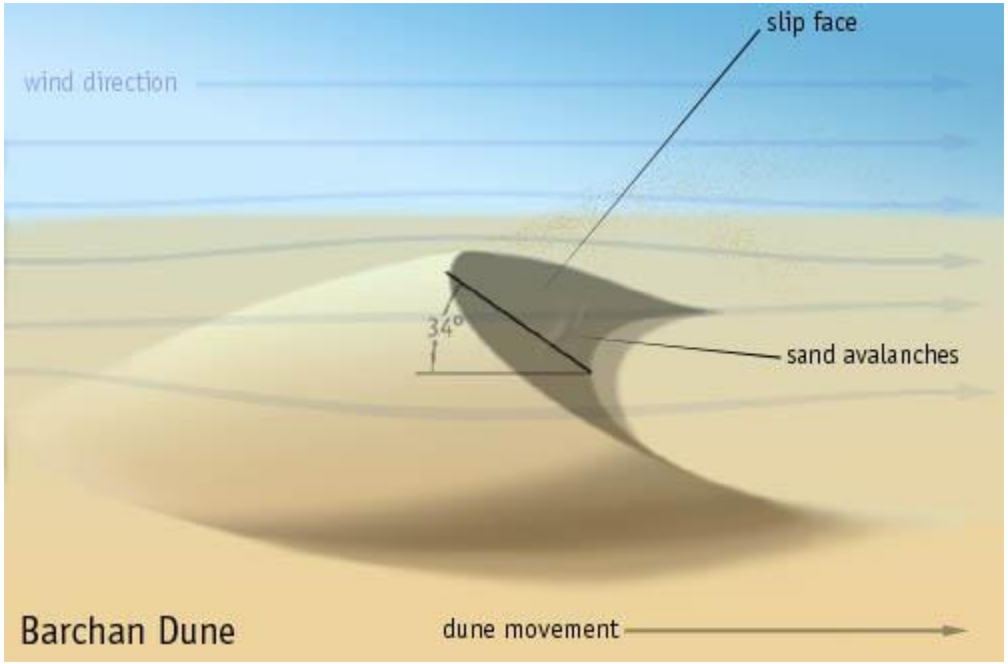
FIGURE 12.19 Sand dune types. **A.** Barchan dunes. **B.** Transverse dunes. **C.** Barchanoid dunes. **D.** Longitudinal dunes. **E.** Parabolic dunes. **F.** Star dunes.



Sand dunes can be accordingly "found" created in many forms:

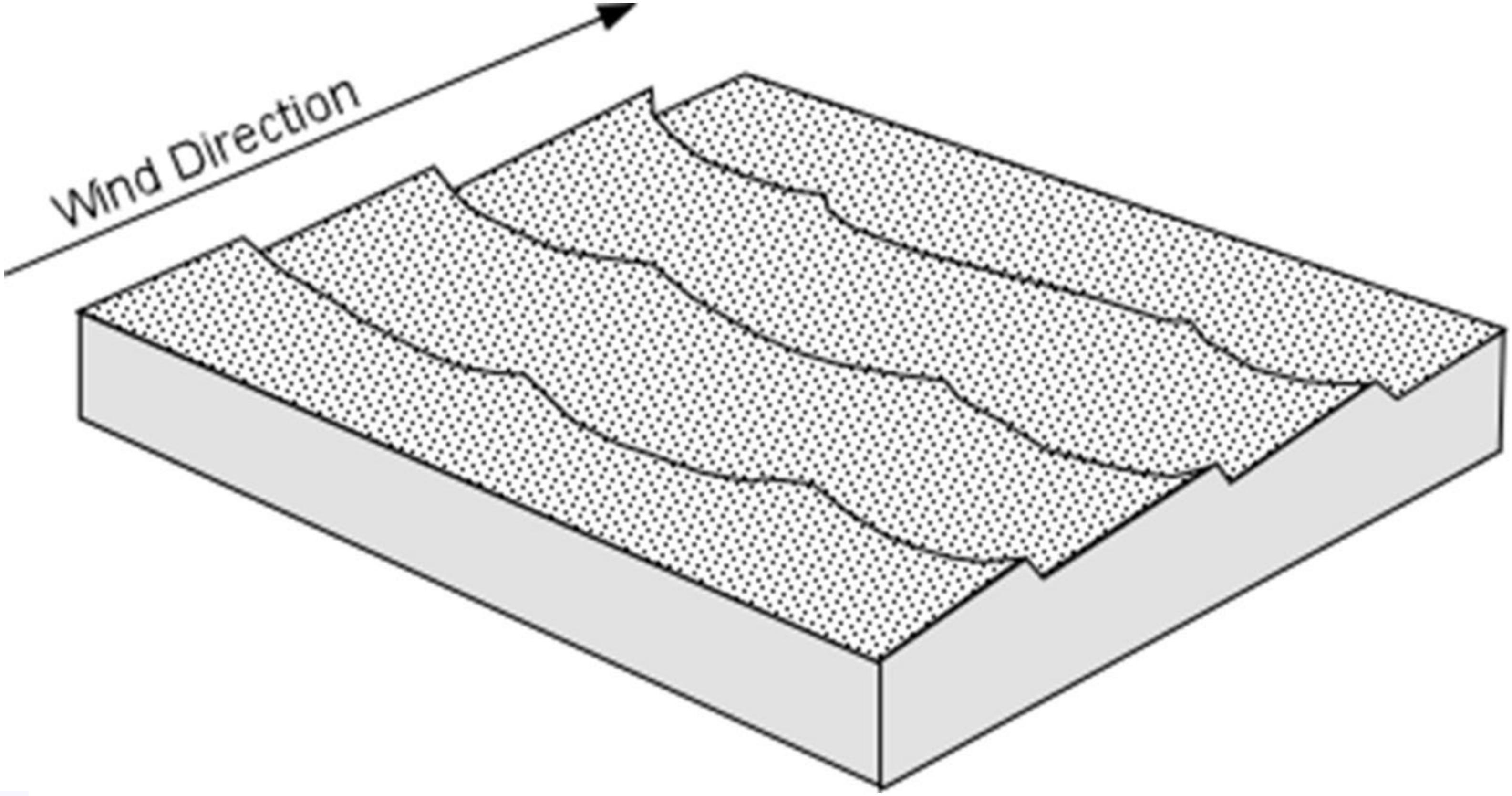
1- **Barchan Dunes: Solitary-shaped with their tips pointing downwind. Form when sand supplies are limited and the surface is hard and lacks vegetation.**





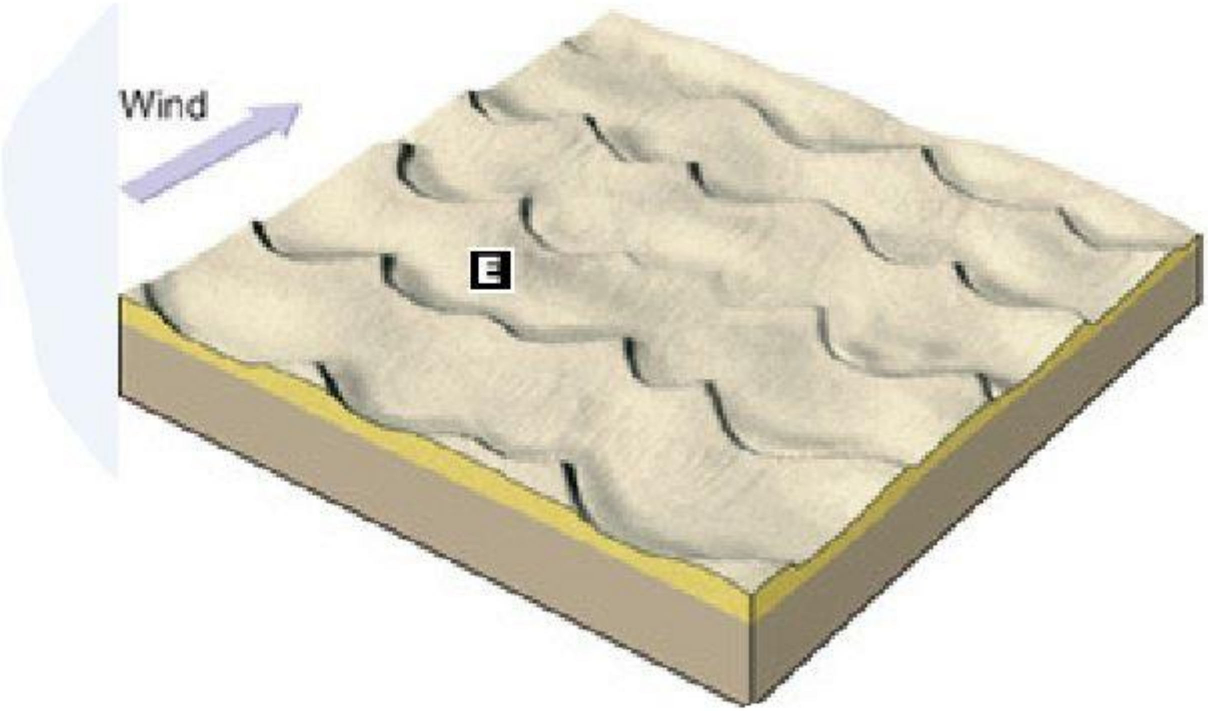
2- Transverse Dunes: Form when wind is steady + plenty of sand + no vegetation. It forms a series of long ridges separated by troughs oriented perpendicular to the wind direction. Some reach 200 m in height; 1-3 km across and extend to 100 km or more forming **SAND SEA**.

Transverse sand dune↓



Transverse Sand Dunes↓

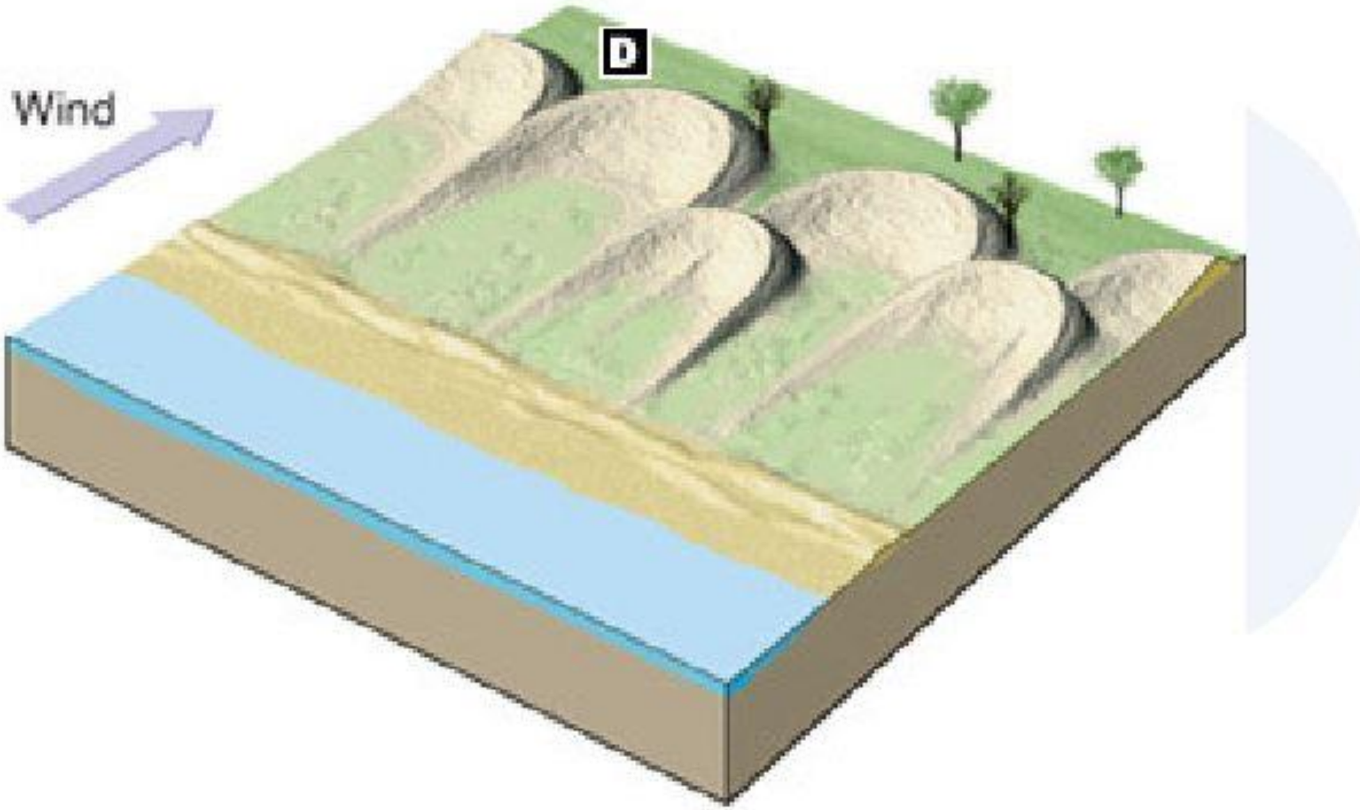
3- Barchanoid Dunes: Similar to transverse but with scalloped (اكليلية) rows of sand orientation.



Barchanoid Sand dune↓

4- Longitudinal Dunes: Long ridges of sand parallel to the wind direction & many reach 100 m height and 100 km long. Form where sand supplies are moderate and wind direction varies a little.

5- Parabolic Dunes↓: When vegetation cover exists and covers the sand. Similar to barchan but mainly near shores.



6- **Star Dunes↓**: Isolated hills of sand with complex form. Confined to Sahara & Arabia. Reflect wind direction variations. Many reach 90 m height in the center.

.... Star Dune↓

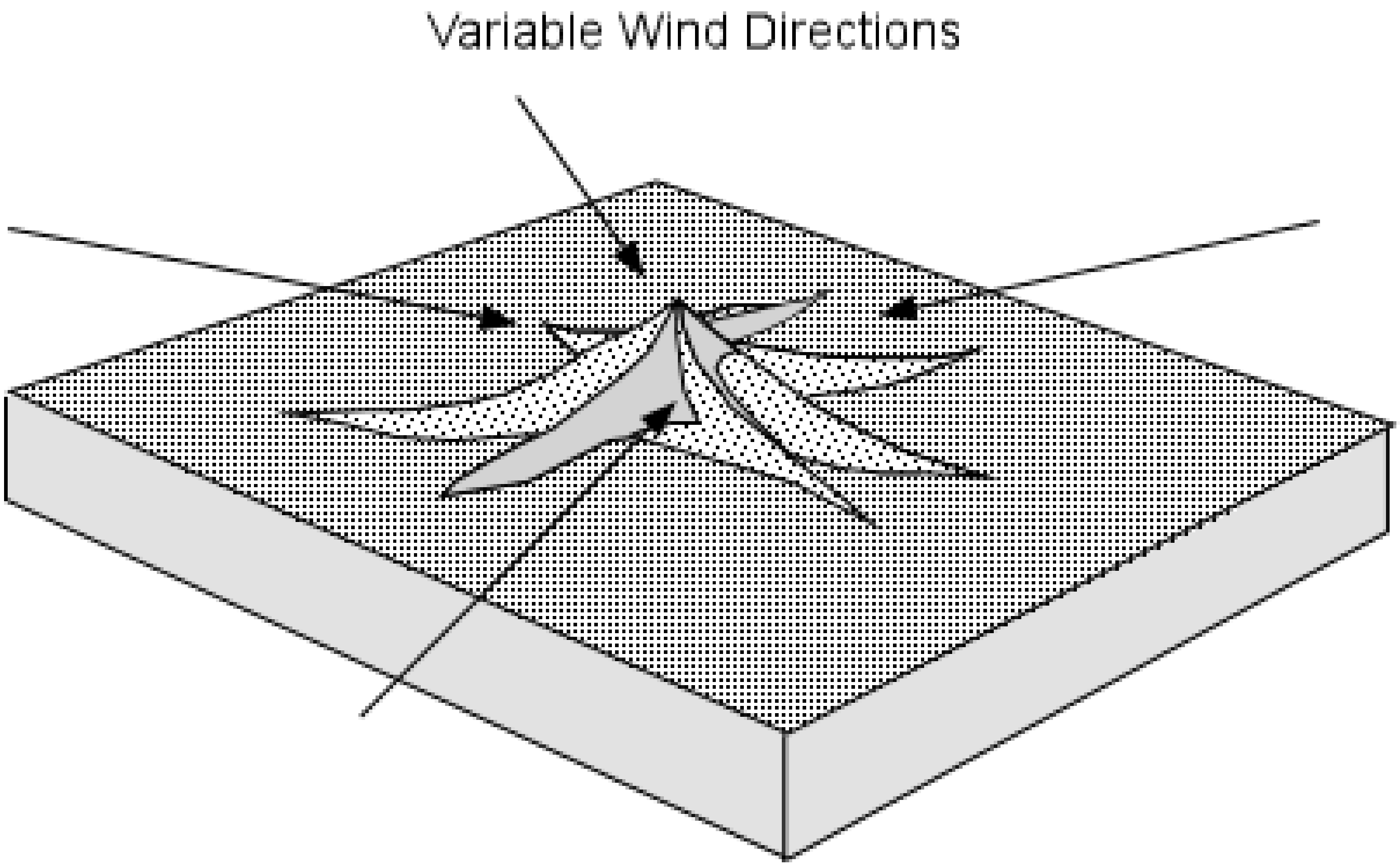
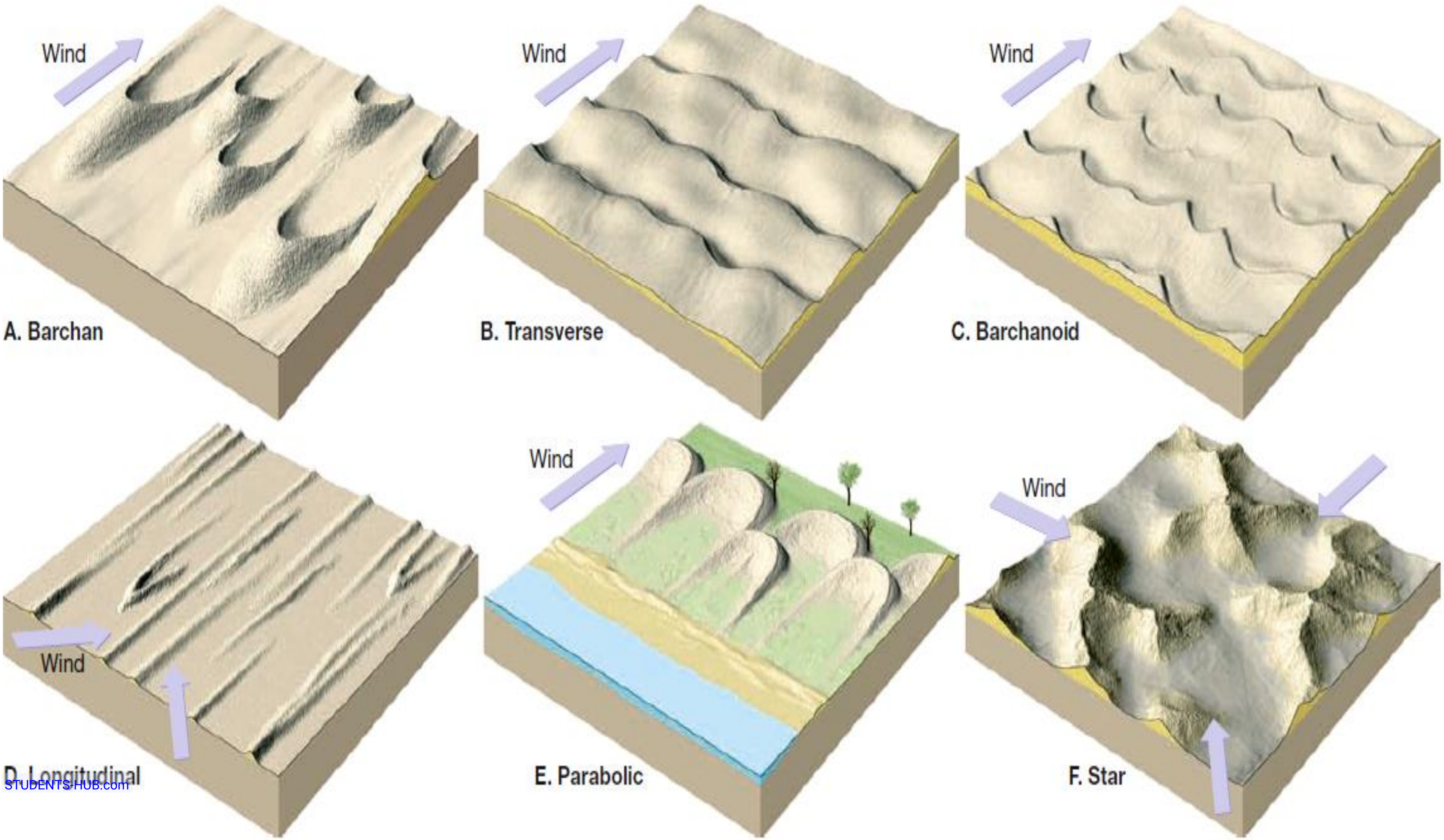


FIGURE 12.19 Sand dune types. **A.** Barchan dunes. **B.** Transverse dunes. **C.** Barchanoid dunes. **D.** Longitudinal dunes. **E.** Parabolic dunes. **F.** Star dunes.



One of the well-known Aeolian Sediments is the LOESS

1- Composed of wind-blown silts.

2- Thick.

3- Lacks any visible layering.

4- Reflect long time of dust storms.

5- When broken by a stream or road cuts they tend to make vertical cliffs.

6- Can be formed by wind or glaciers.

Loess↓

Loess↓

Role of man in DESERTIFICATION

1- Global warming.

2- Trees cutting.

3- Overgrazing.

4- Resources Depletion.

5- Overpopulation.

6- Environmental pollution.

7- Modeling revolution.

8- Urbanization …………… etc.

Glaciers & Glaciation

- A glacier: Is a thick ice mass that forms over hundreds or thousands of years; it originates on land from the accumulation, compaction and re-crystallization of snow.
- Glaciers are dynamic erosional agents that erode (accumulate), transport and deposit sediments.
- Seen stationary but move at slow motion.

Glaciers Types:

- **1- Valley or Alpine glaciers: A stream of Ice bounded by steep rock walls with small width.**

2) Ice Sheets *(also called continental ice sheets):* Exist in large scale; examples: Antarctica & Greenland

Antarctica: 80% of all glaciers, height/thickness= 4300m, area covered 13.6 million km^2.

Greenland: 1.7 million km^2 ,covers 80% of Greenland, thickness of ice= 1500m.

....Ice sheets↓

-Flow in all directions.

- Thinning seawards and thickening landwards.

- Movement affected by the beneath land topography.

-Die out in oceans.

3) Ice caps: Cover uplands; similar to ice sheets but smaller.

4) Piedmont Glaciers: They cover broad low lands at the base of steep mountains when valley glaciers spread

DATA

- In the world nowadays there are more than 160,000 glacier of all types.

Movement of Glaciers:

- Movement of glaciers is referred as "FLOW"; the movement is of 2 ways:

1) Movement within the ice; ice behaves as brittle solid until the pressure upon it reaches (50-60)m of ice, then the ice will behave as a plastic and flows continuously ; this flow is called a PLASTIC FLOW

2) Slipping along the ground

- - Slow → few centimeters a day.
- - Variable rates.
- In Ice sheets in all directions: radial to semi-radial from the center.
- The beneath land topography is reflected at the surface of a moving flow.
- Some glaciers move rapidly; we call this movement a "SURGE".

GLACIERS FORMATION

- 1) Snow is the raw material.
- 2) Glaciers constantly gaining and loosing ice.
- 3) Snow accumulates in the zone of ACCUMULATION; its outer limit is called the SNOW LINE. Snow line elevation differs from area to area tropical 4500m , polar areas below 0m.

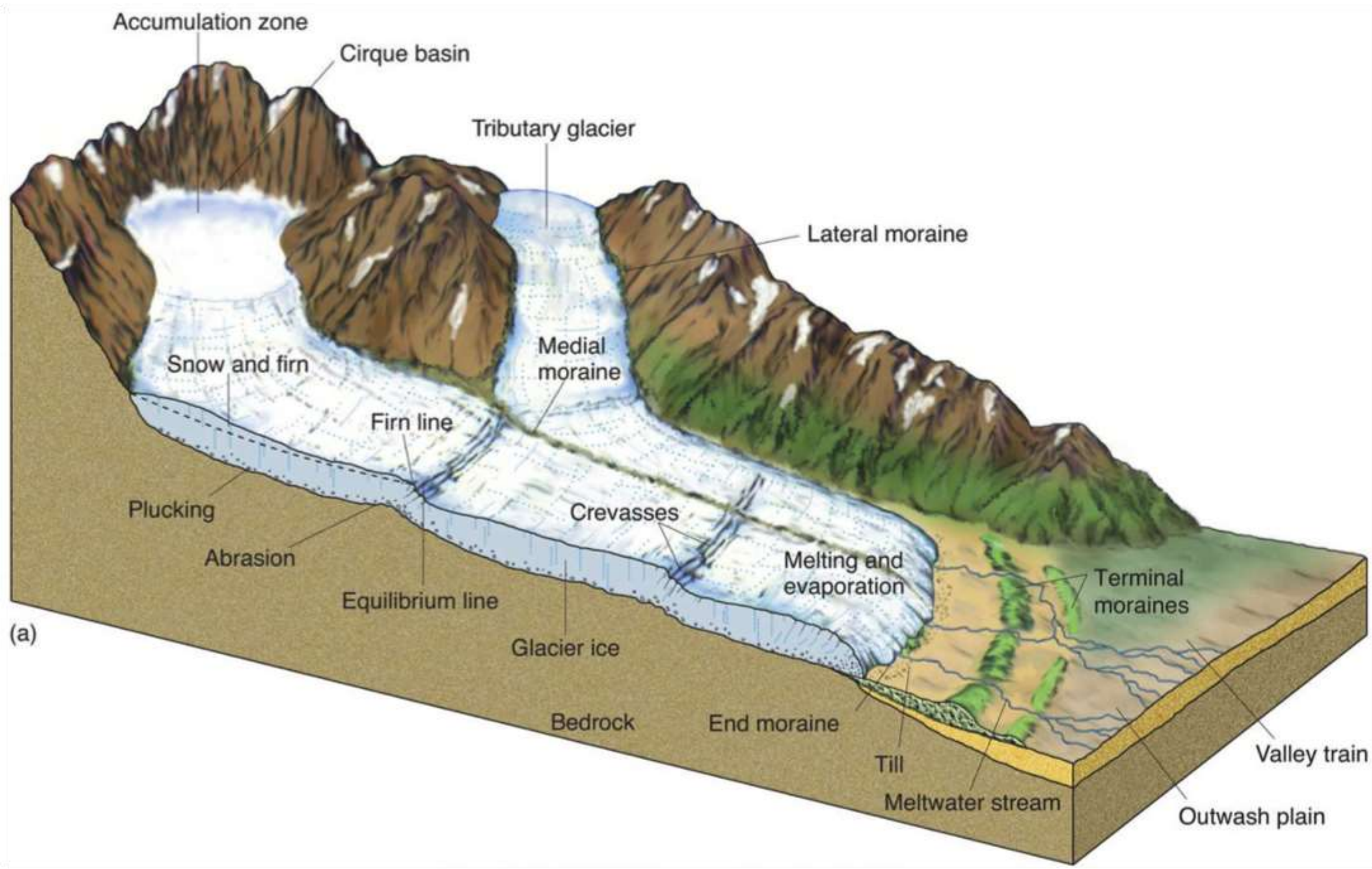
4) **Below the snow line is the ZONE OF WASTAGE.**

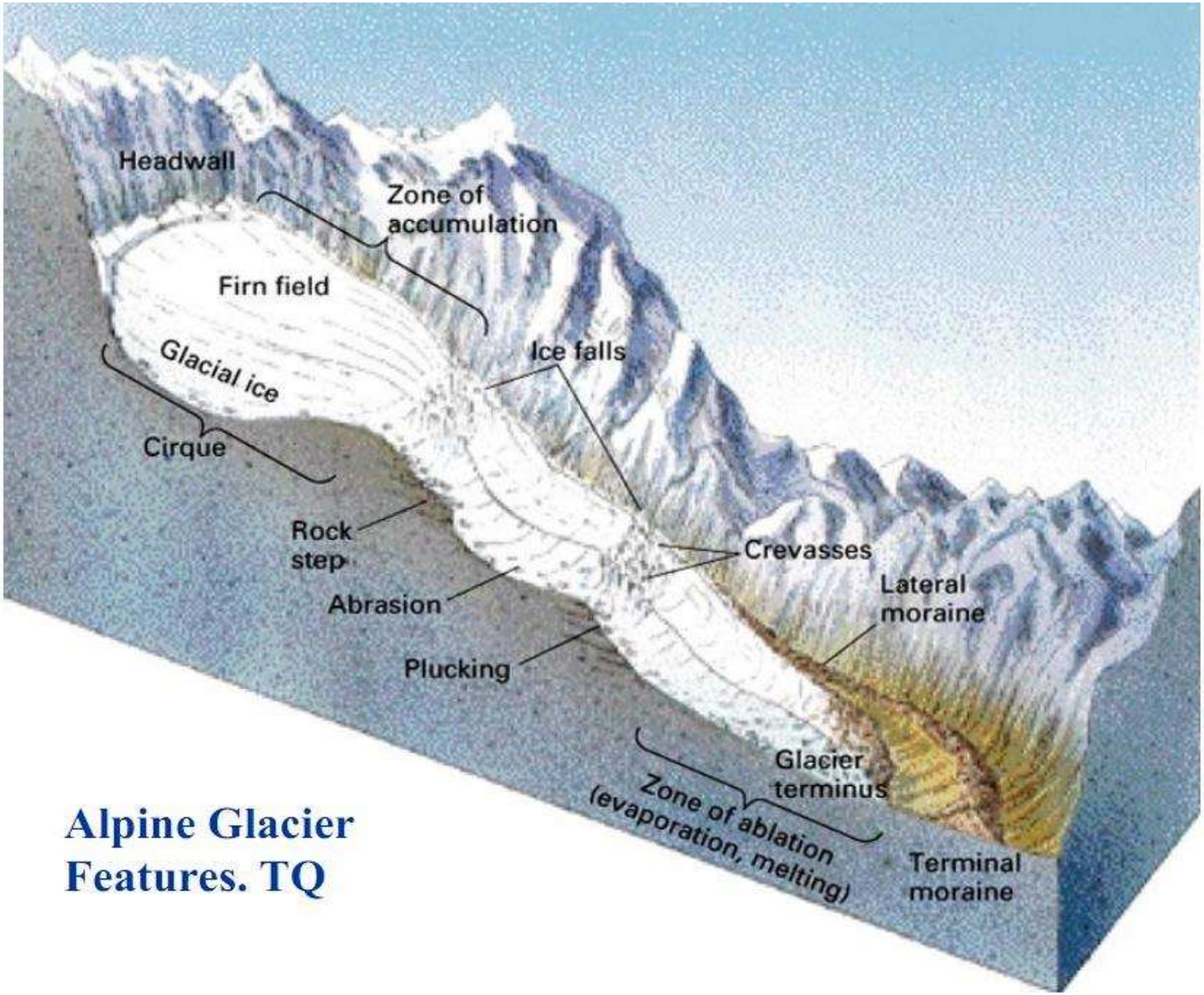
5) **CALVING: The breaking of the ice at the front of the glacier forming Ice bergs**

- Icebergs range from the size of a car to thousands of square kms.
-they are composed of freshwater, not saltwater because they are formed from frozen rain or snow over thousands of years.

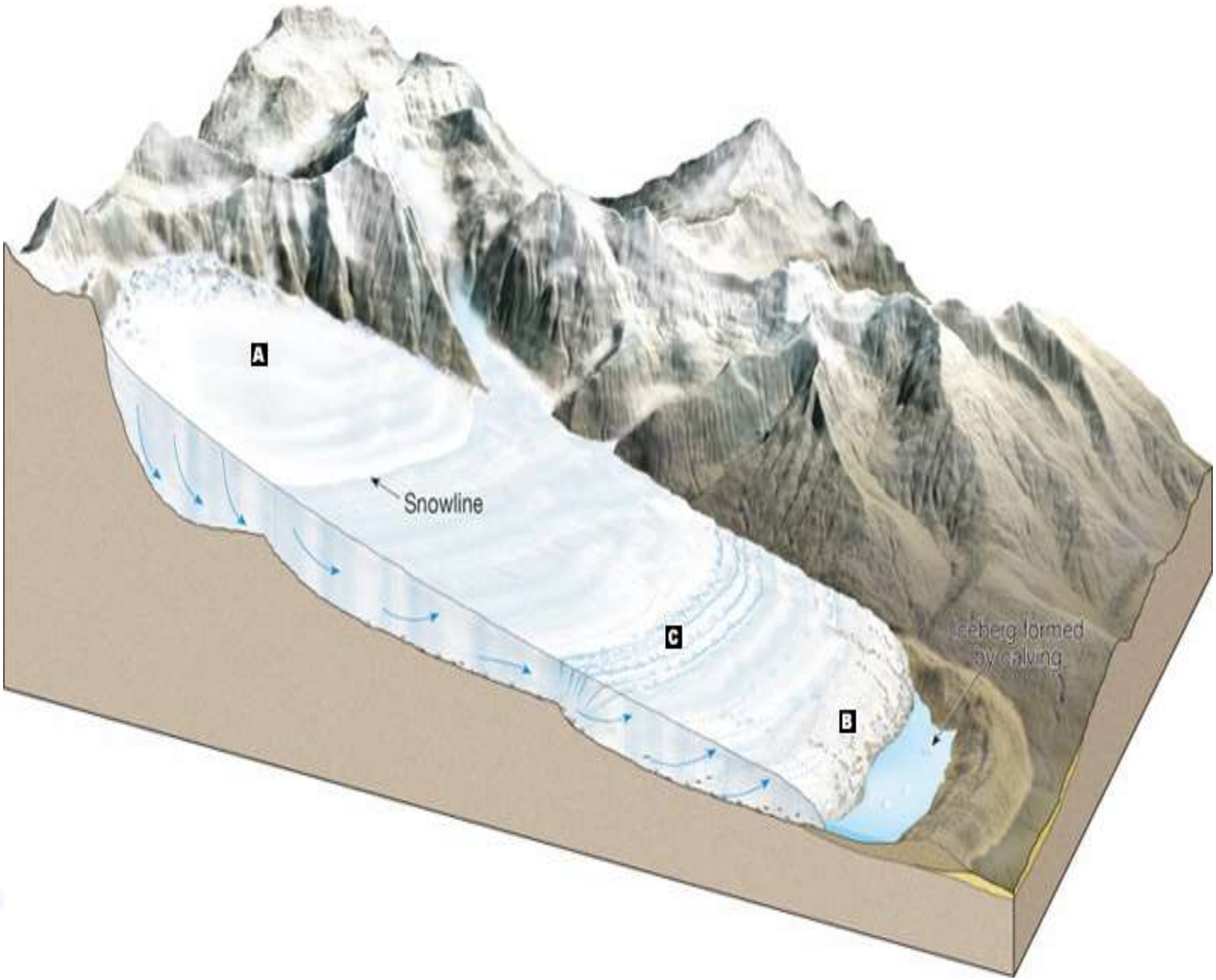
- - Only 10% of the Iceberg appears above the water.

PARTS OF A GLACIER





Alpine Glacier Features. TQ


A
Snowline
C
B
Iceberg formed
by calving

1) Zone of Accumulation: Where snow falls and accumulates. Bounded by snow line downwards.

2) Crevases zone: Where snow starts to melt; bounded by the snow line in the upstream.

3)Zone of wastage: Where snow melts and produces water.

Crossing a Crevase

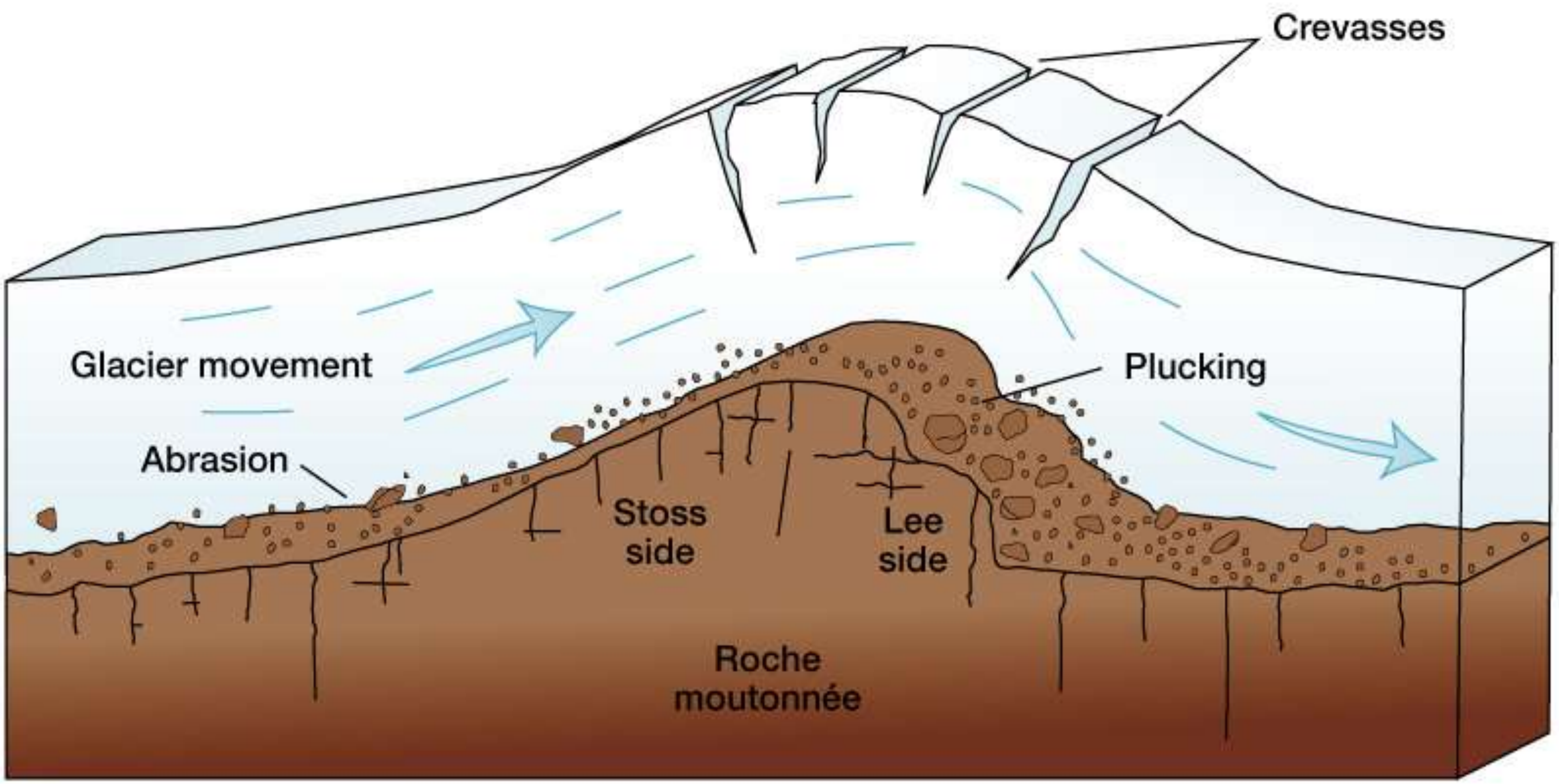
GLACIAL EROSION

Glaciers are capable of great erosion; they can carry all sizes of rocks together. Glaciers erode land in 2 ways:-

- **1- As the glacier flows it covers a fractured bedrock surface, loosen it and lifts blocks of rocks and carries them by a process called "PLUCKING"- قلع- water can inter the fissures, joints and cracks , freezes and breaks the rocks.**

2) Abrasion process: When the ice moves with its carried load (sediments of different sizes and shapes), the rock fragments grind the floor below and pulverizes the rock. This powder is called <u>"ROCK FLOUR"</u> and gives the melted water its milky color. This process leaves grooves and scratches on the surface of the affected rocks called

<u>"GLACIAL STRIATIONS".</u>


Crevasses
Glacier movement
Plucking
Abrasion
Stoss side
Lee side
Roche moutonnée

Glacial Striations↓

The erosional effect of valley glaciers is characterized by sharp and angular topography, while that of ice sheets is less angular

FACTORS AFFECTING GLACIAL MOVEMENT

1- Rate of glacial movement.

2- Thickness of the ice.

3- Shape, abundance and hardness of the rock fragments contained within the moving ice at the base of the glacier; and

4- The erodability of the surface beneath the glacier.

These factors vary in magnitude and time from place to place.

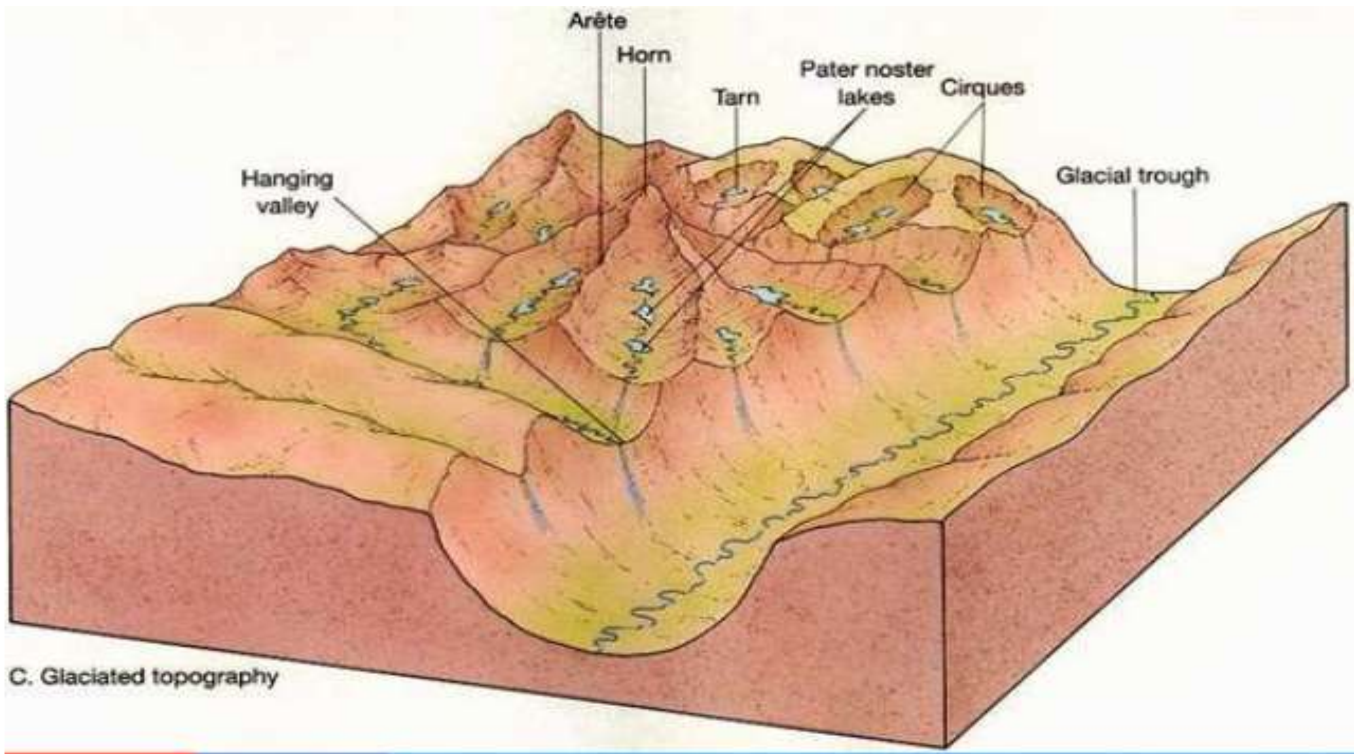
LANDFORMS CREATED BY GLACIAL EROSION

- **There are big differences between effects (features) created by valley glaciers & sheet glaciers. Example: Alpine (or mountain) glaciers are likely to see a sharp & angular topography in spite of that the continental sheet glaciers do enormous work.**

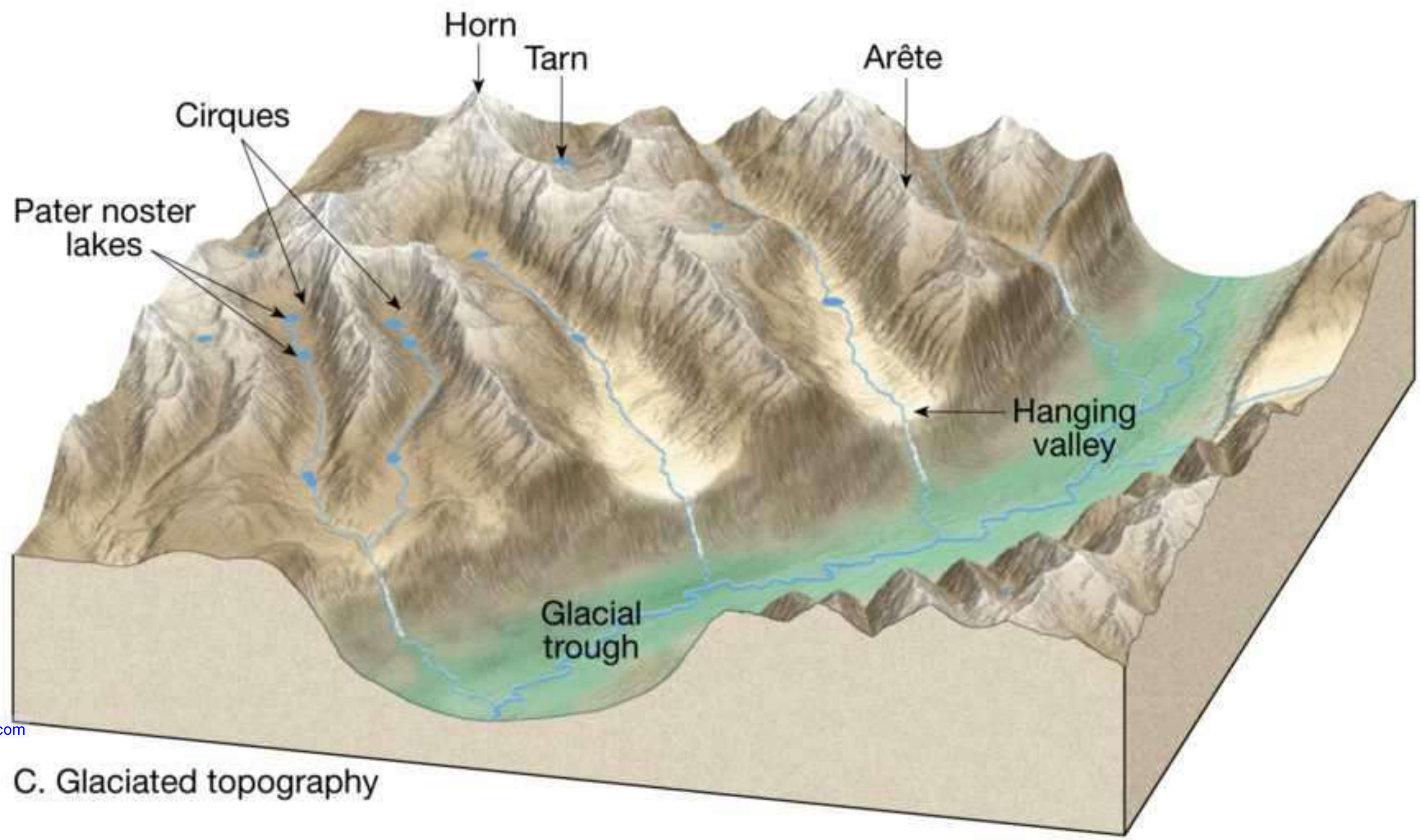
The major difference between glaciers (as erosional agent) and other erosional agents (especially the water) is that most sediments drifted by glaciers consist primarily of <u>mechanically weathered</u> rock debris (approx. <u>no chemicals</u>).

Therefore most of the minerals that dissolve by chemical weathering can be found within the glaciers

Glacial valleys: The V-shape by time transfers to a U-shape called a "GLACIAL TROUPH".



Also the glacier tends to straighten the valley by removing the spurs along and around the glacial channel.



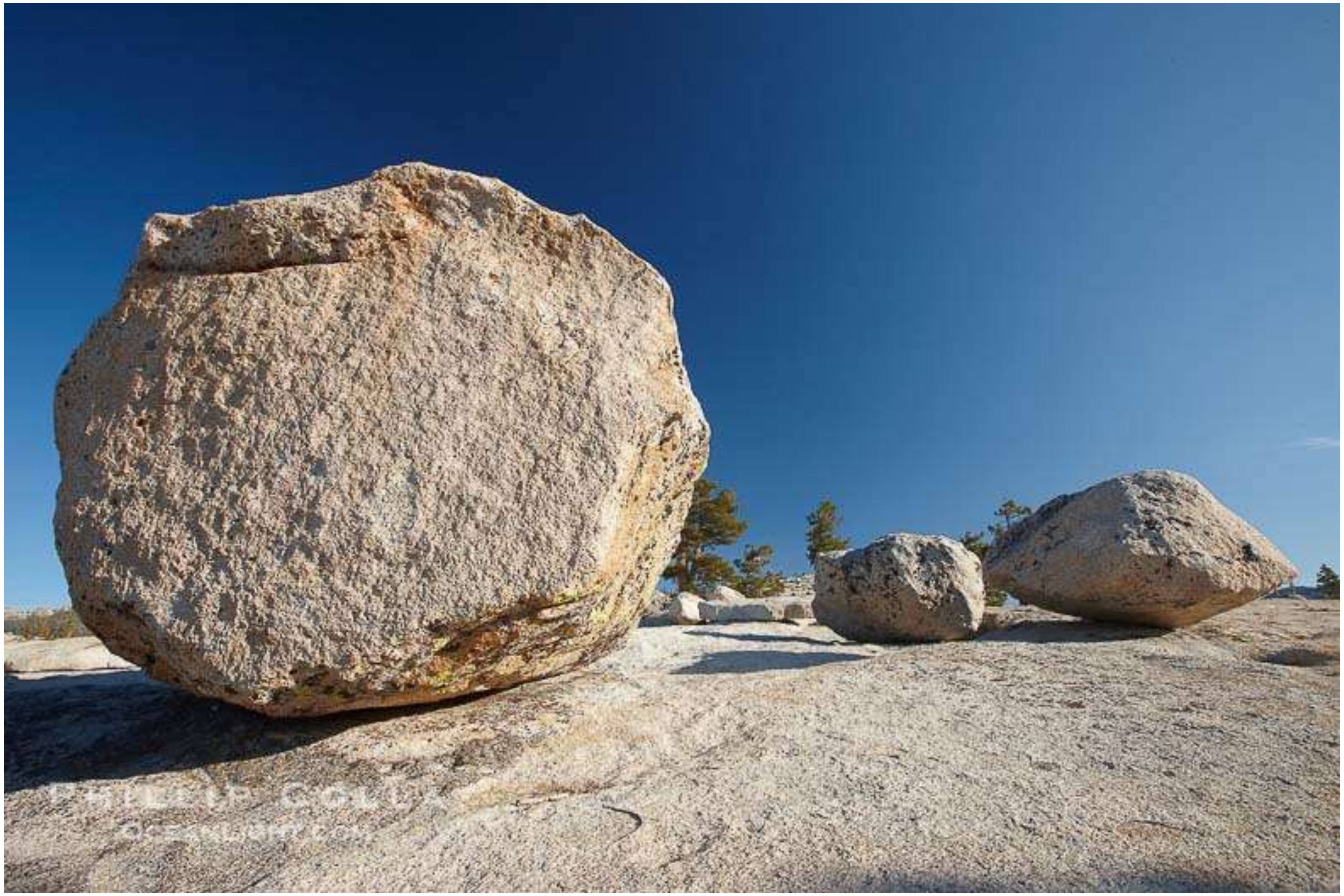
C. Glaciated topography

Glacial Drifts: Are divided into 2 types:

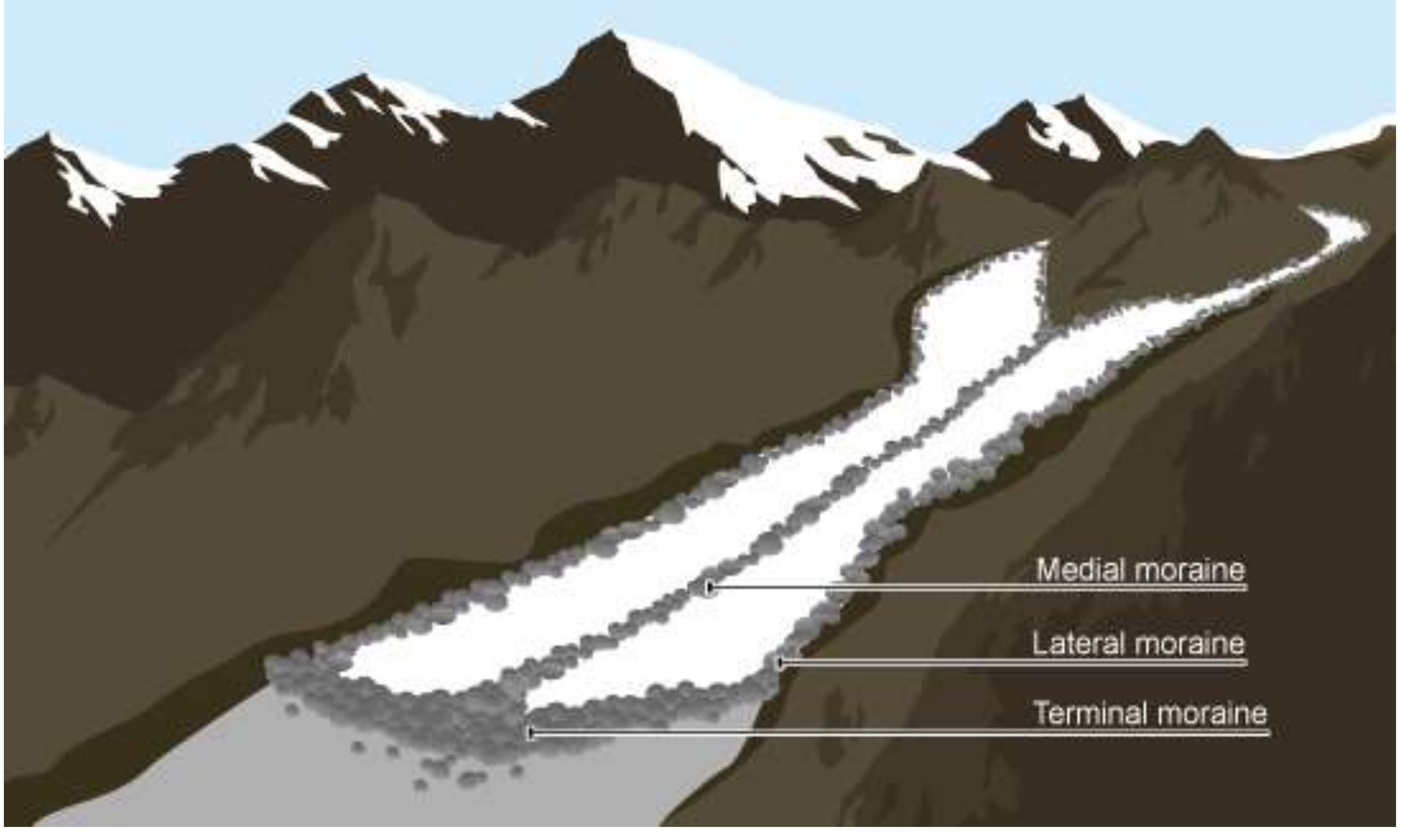
- **1- Till: Materials deposited by the lacier when the glacier melts. A mixture of all grain sized-sediments [THE DRIFT] are accumulated.**

2- Stratified sediments or drifts: These are sediments laid down by glacial melt water.

3- Glacial erratics: Large boulders found in the till or lying free on the till surface



4- Moraines: Layers of ridges of till accumulation. They can form lakes.

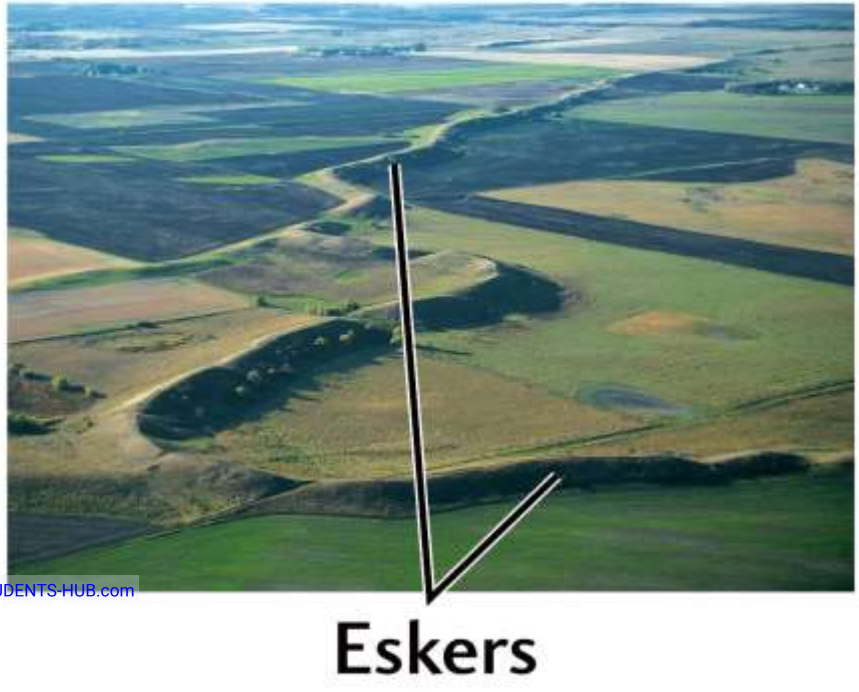


Moraine Lake

5- Kettle holes: When ice is buried within the drift, then melts leaving pits(some of 2 – 50 kms long).

6- Outwash Plains: when the ice sheet melts, the water leaves the glacier and moves into relatively wider area; this water looses momentum and its velocity decreases dropping much of the bed load forming those outwash plains ↓

7- Eskers: Are longitudinal ridges composed largely of sand- and gravel-sized particles. Eskers' size may reach 100m or even 100km in length.



8- There are many other conspicuous features formed by glaciers and glacial melting (uncountable); e.g. kames, drumlins, valley terrains, end mor, ground morains, fyords .....ains

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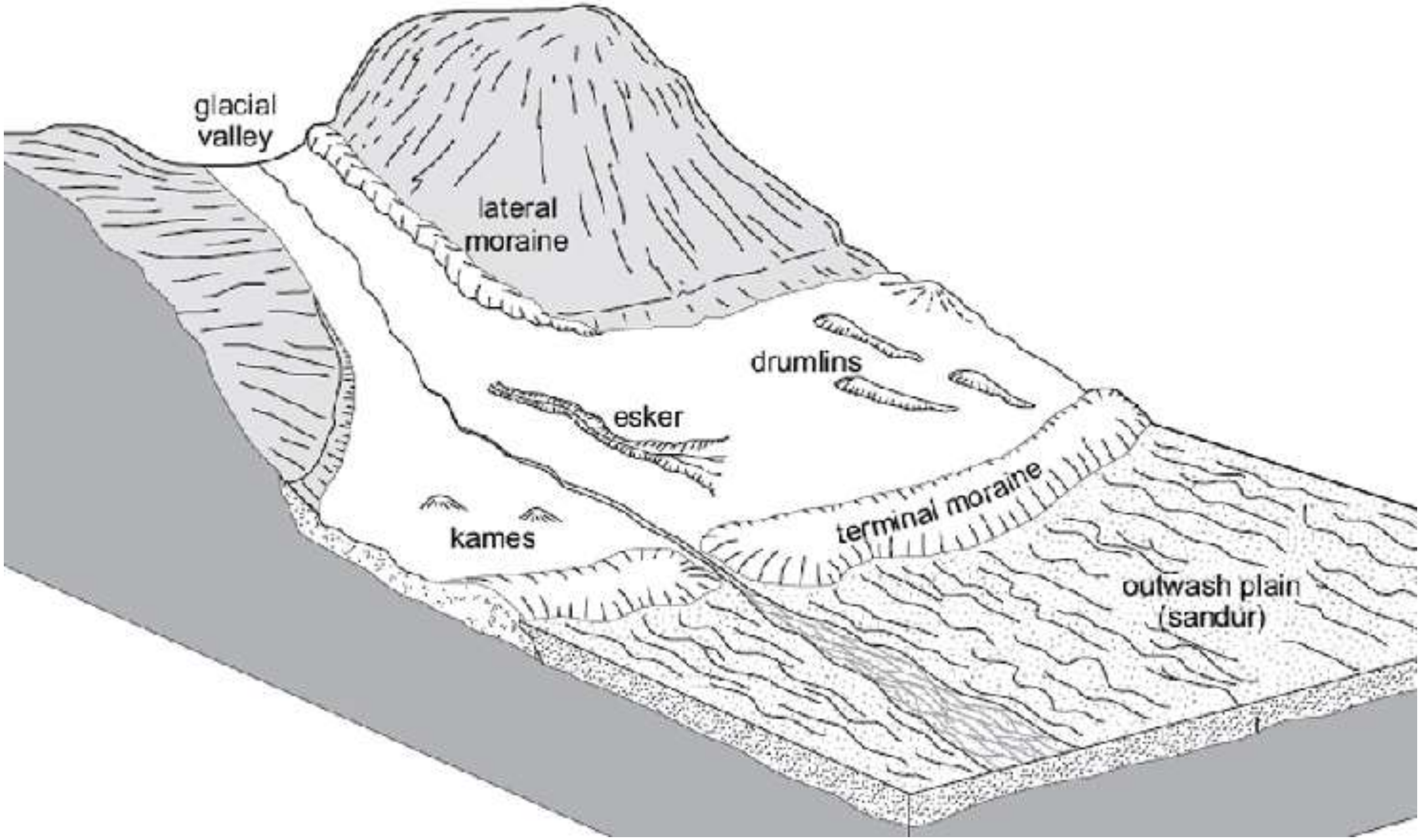
8- There are many other conspicuous features formed by glaciers and glacial melting (uncountable); e.g. kames, drumlins, valley terrains, end moraines, ground moraines, fjords ….. etc

Kames↓

Drumlins↓

Valley Terrains↓

Fjords↓

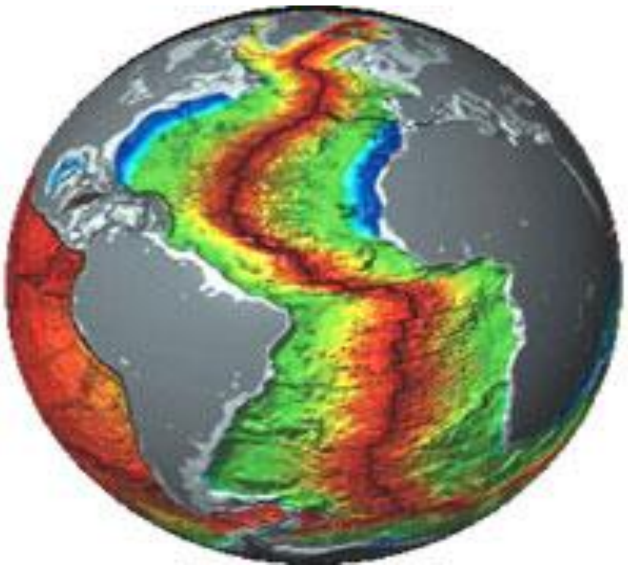

glacial valley
lateral moraine
drumlins
esker
kames
terminal moraine
outwash plain (sandur)

More Information about Glaciers

1) Glaciers nowadays are found in all continents except Australia.
2) North pole ice is not a glacier as glaciers found on land. Ice there is accumulation over seawater.
3) Melting glaciers may disturb the Earth balance and enhance Earthquakes.
4) Earth experienced many ice ages in its life >32 ICE AGES recorded.
5) Plate tectonics & Glaciations: Mountain building & then melting ….

PLATE TECTONICS THEORY

It becomes really a THEORY that answers fully a lot of geological questions



Continental Drift Hypothesis

WEGENER: A German geologist put this hypothesis in 1912 which says:

1- All continents of today were not in their nowadays places.

2- Continents have been subjecting to steady movement away from each other.

3- According to Wegener: The driving force beyond this continental drift is the Tidal force (Alternate cycling of Low & High tide).

4- Wegener said only the Earth crust that moves.

PLATE TECTONICS THEORY

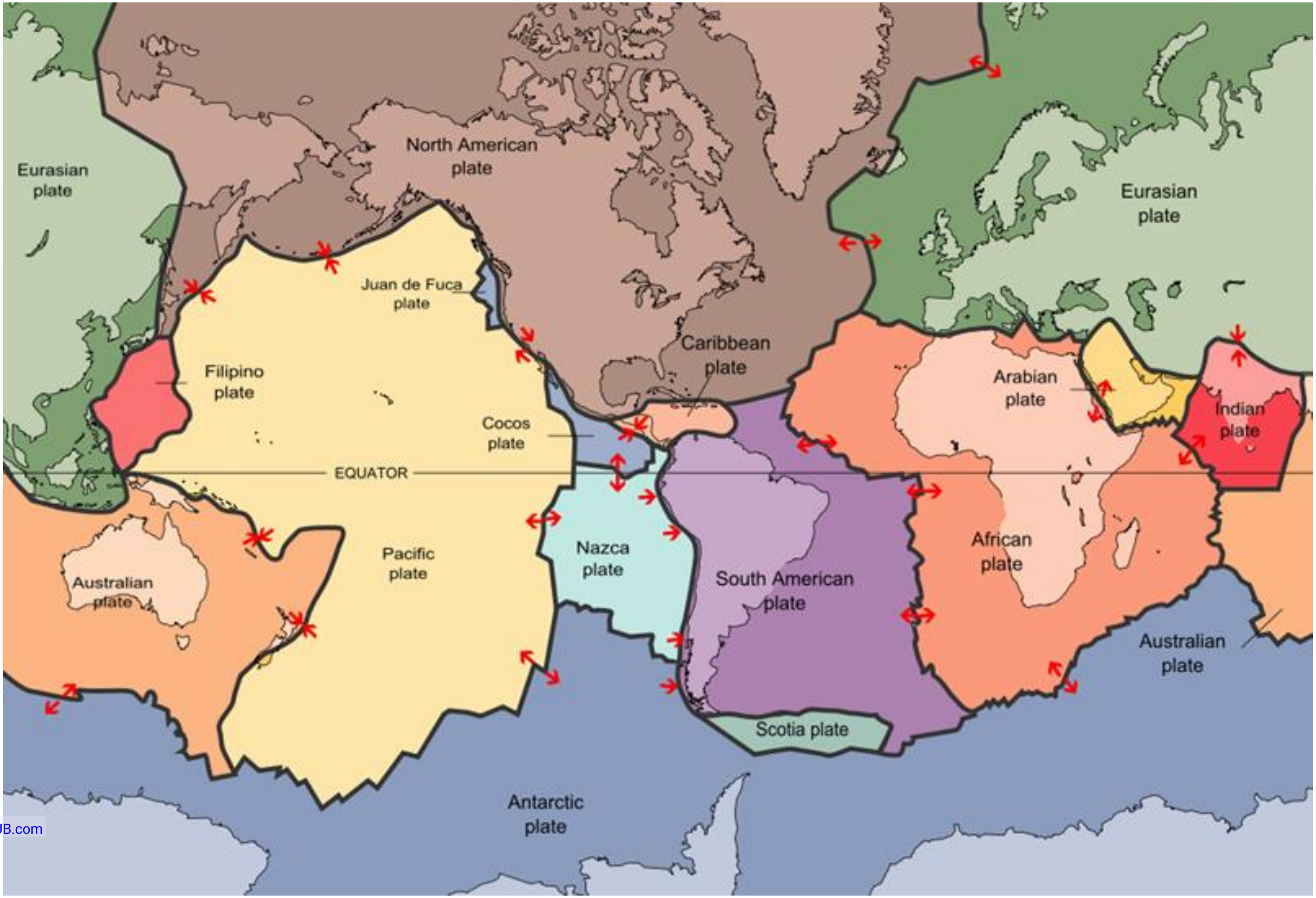
Later on many geologists *(among them Wegener himself)* realized that:

1) Not only the upper thin Earth crust that moves but the whole rigid outer layer of the Earth (both the Lithosphere and what above it "the Earth crust") moves (= slides over the underlying viscous Asthenosphere).

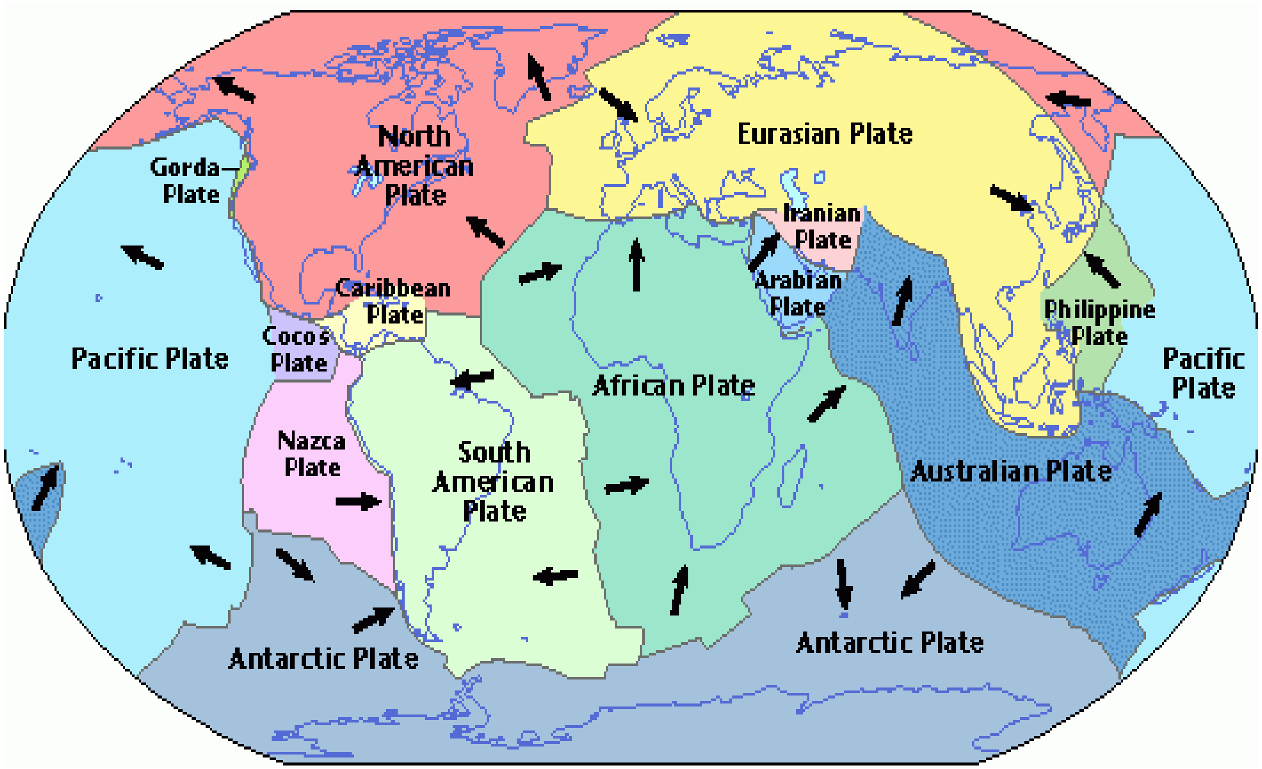
2) This rigid layer is not fully interconnected but divided into slabs, they named them PLATES.

3) A plate (or a slab) may be totally composed of a continent, ocean or both.

……cont.



Eurasian plate
North American plate
Eurasian plate
Juan de Fuca plate
Caribbean plate
Filipino plate
Arabian plate
Indian plate
Cocos plate
EQUATOR
Nazca plate
African plate
Pacific plate
Australian plate
South American plate
Australian plate
Scotia plate
Antarctic plate


Gorda Plate
North American Plate
Eurasian Plate
Iranian Plate
Arabian Plate
Philippine Plate
Pacific Plate
Caribbean Plate
Cocos Plate
Pacific Plate
African Plate
Nazca Plate
South American Plate
Australian Plate
Antarctic Plate
Antarctic Plate

4) The sizes/areas of these plates are not equal, some are very large but many are small.

5) The boundaries between the plates are never linear or regular.

6) When a plate moves apart from the other then at its other end it collides with another one. ***…..cont.***

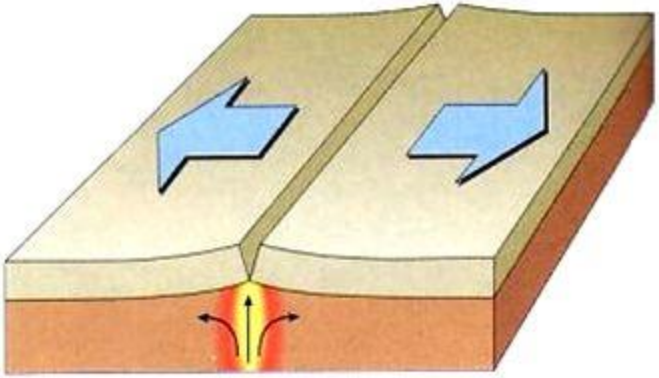
7) Some of these plates do move apart (Divergent Movement), some do collide with each other (Convergent Movement). Another shorter and less significant movement, which is neither divergent nor convergent, but it shows that one plate is cut into two plates moving parallel to each other but in different directions is called a Transverse Movement. The types of stresses exerted can be classified as follows:

a. Divergent= Tensile Stress.

b. Convergent= Compressional stress.

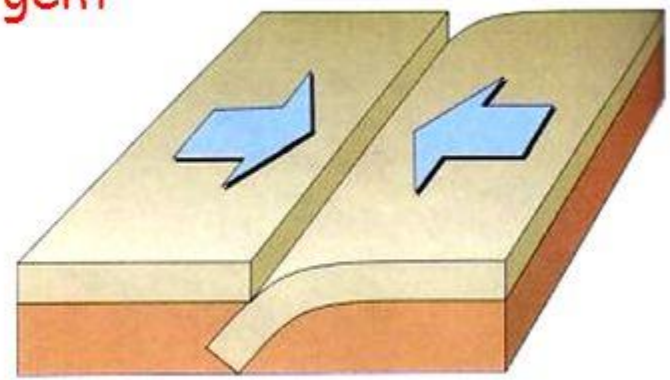
c. Transverse= Shear stress.

Each plate is bounded by these 3 forms



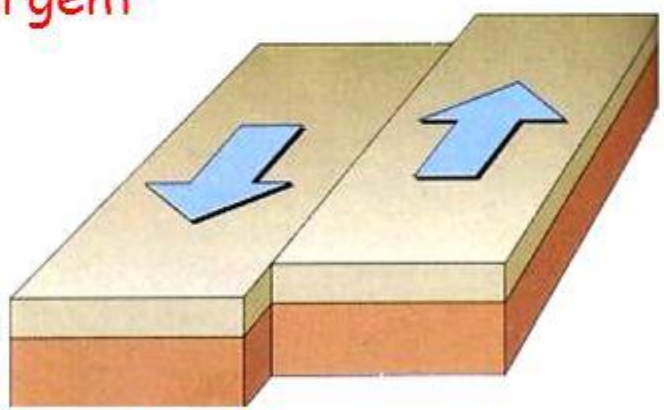
Divergent

✓Plates move apart, resulting in upwelling of material from the Mantle to create new sea floor.



Convergent

✓Plates move together, causing one of the slabs of lithosphere to be consumed into the Mantle as it decends beneath the overriding plate.



Transform Fault

✓Plates slide past each other, without creating or destroying lithosphere.

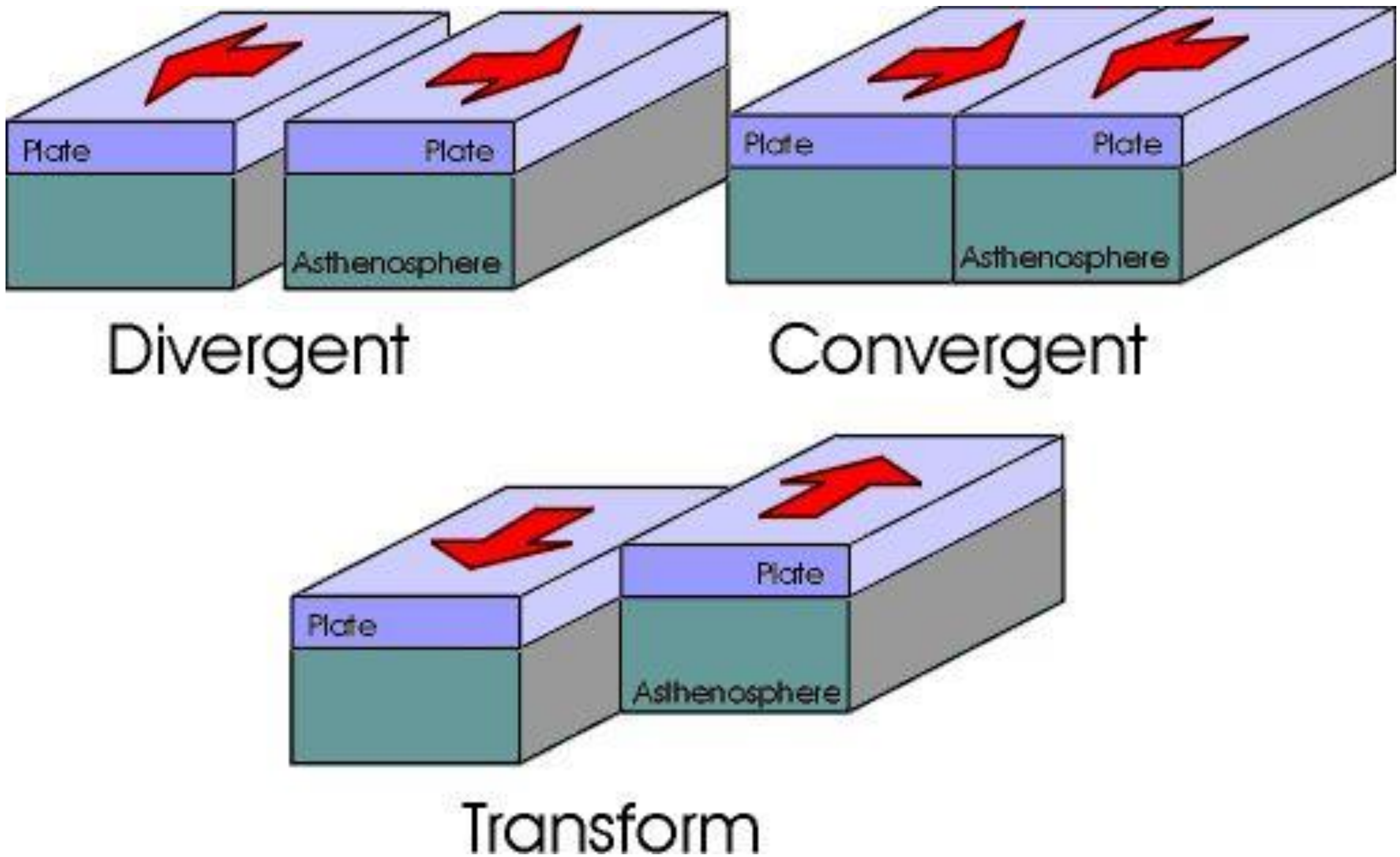


Plate
Plate
Asthenosphere
Divergent
Plate
Plate
Asthenosphere
Convergent
Plate
Plate
Asthenosphere
Transform

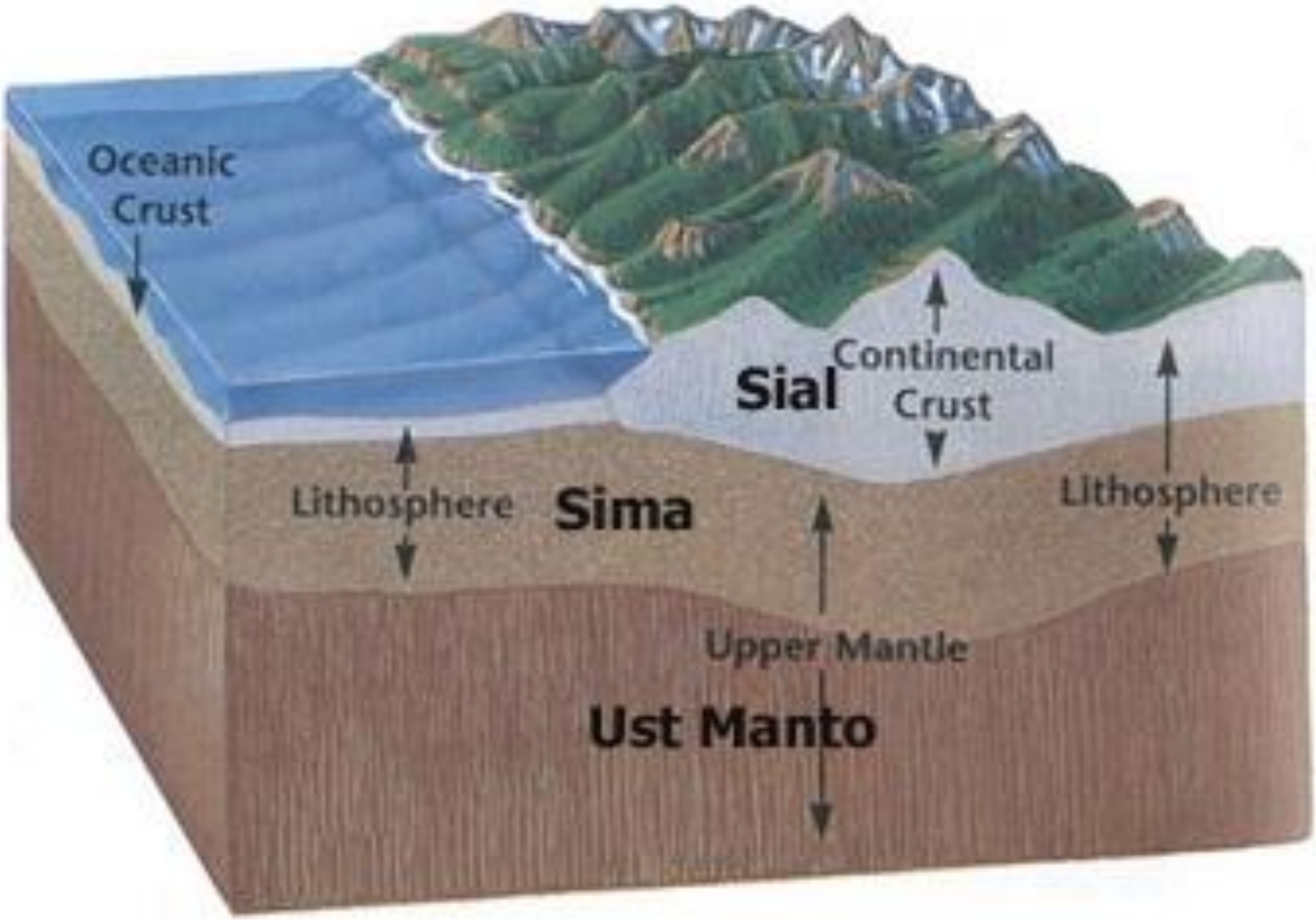
8) When moving apart, basaltic lava erupts out from the Asthenosphere creating new land.

9) When colliding each other, the heavier plate slides beneath the lighter one and by time it melts (= is consumed) in the Asthenosphere at a depth of approx. 700km.

……cont.

The oceanic crust is denser (=heavier) than the continental crust hence it is the one that sinks.

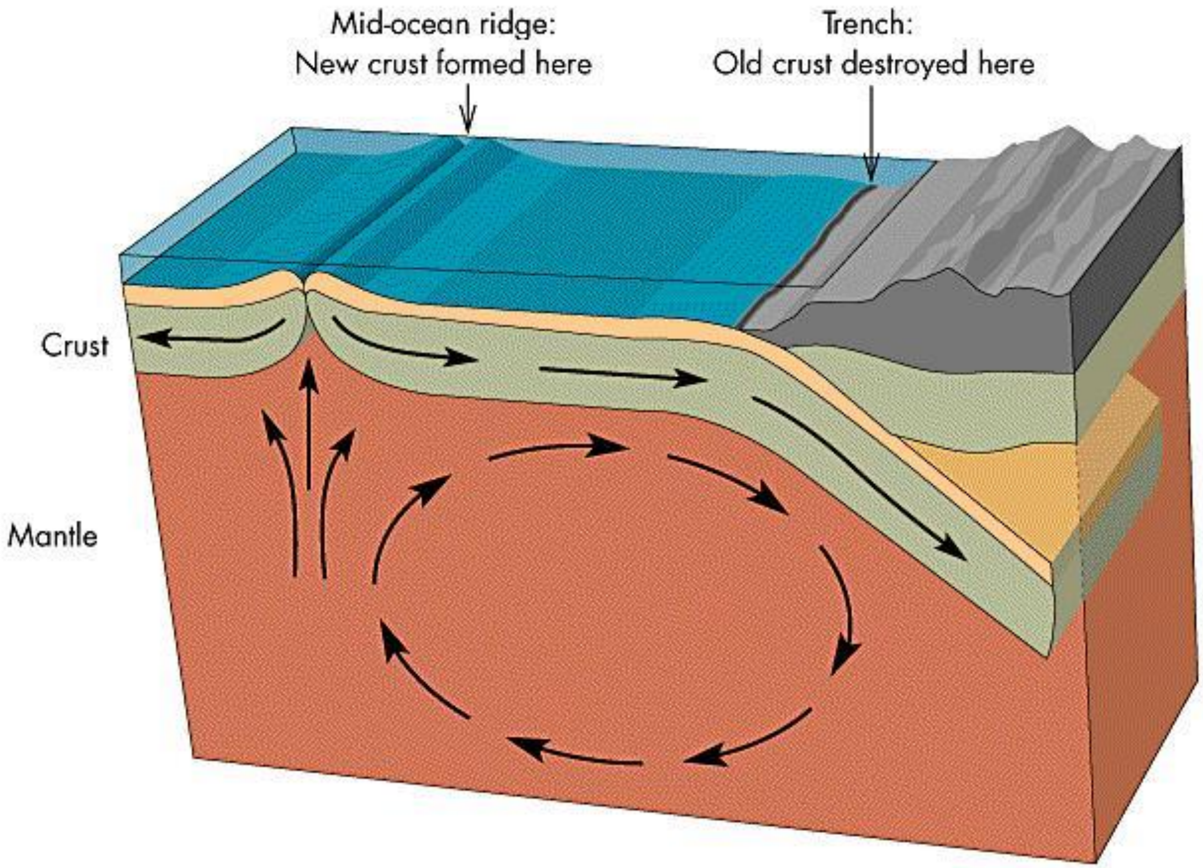
The Earths' upper solid sphere is composed of 3 layers: The lower one rich in Mg+Fe silicates called SIMA, then the middle one rich in Al silicates called SIAL and the most upper of sedimentary rocks called the EARTHS'CRUST


Oceanic
Crust
Sial
Continental
Crust
Lithosphere
Sima
Lithosphere
Upper Mantle
Ust Manto

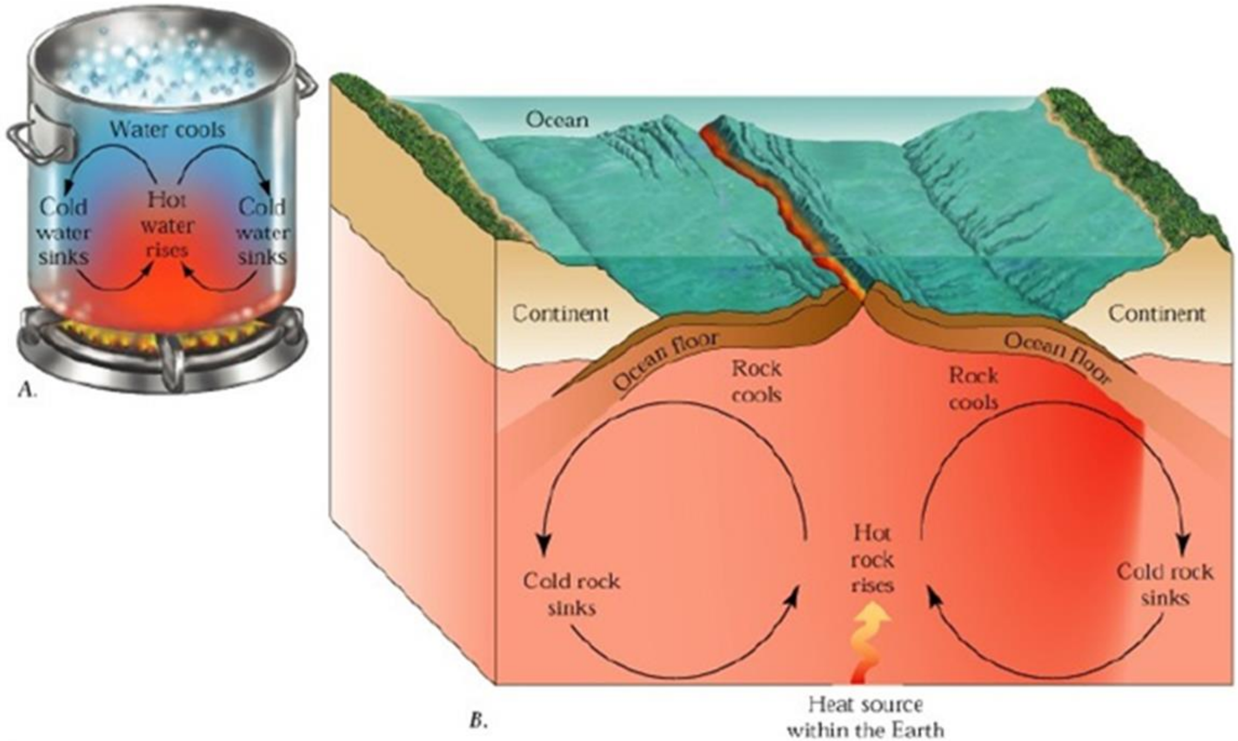
10) The driving force beyond the whole movements is the <u>Convectional Currents</u> which are created in the Asthenosphere due to atomic reactions occurring there.

11) On the boundaries of both the diverging as well as the converging plates, many and complicated geological processes and events are happening (e.g. Earthquakes, volcanism, mountain building, metamorphism, melting & partial melting, rocks' deformation/folding/faulting/doming ...) *...cont.*

The Convectional Currents



Convectional Currents

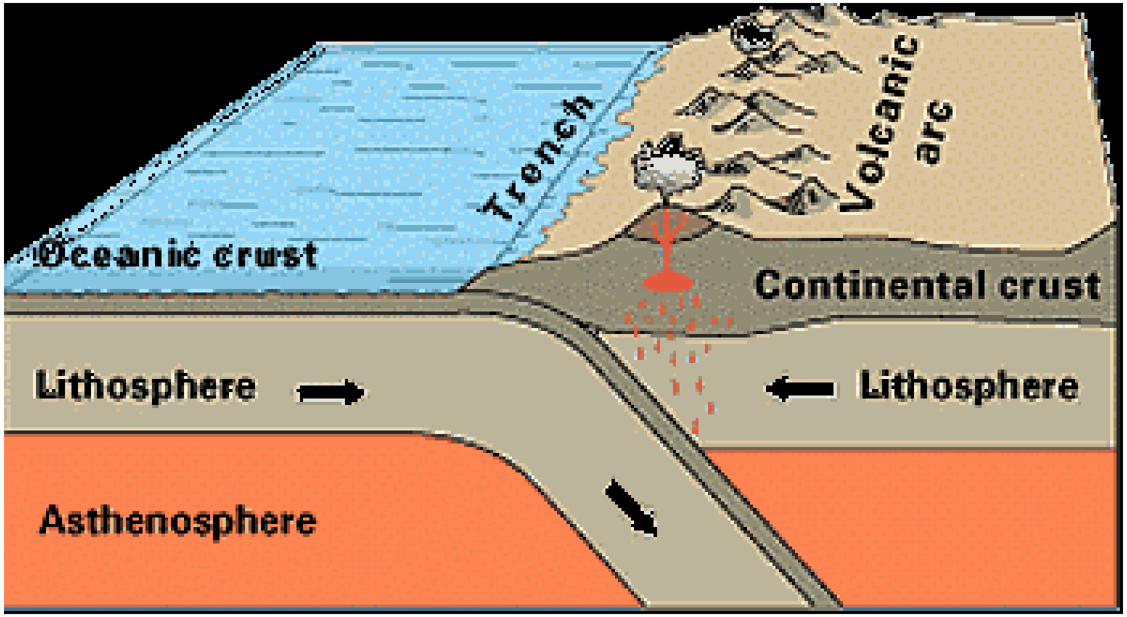


The heavier one that sinks is called the SINKING PLATE and the lighter one is called the HANGING PLATE. The zone where the two plate meet is called the SUBDUCTION ZONE.

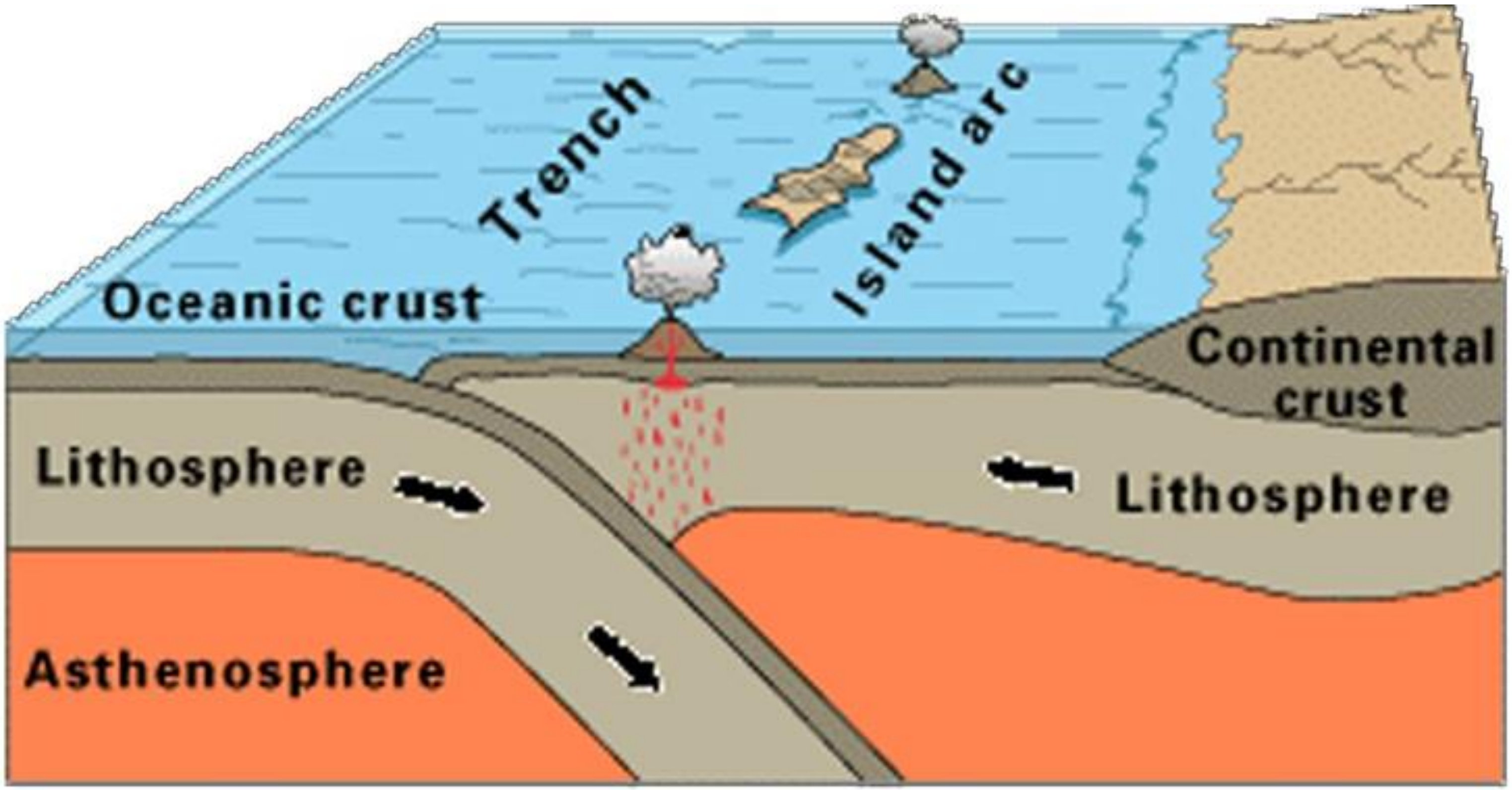
A. ON THE CONVERGENT BOUNDARIES:

The heavier plate slides below the lighter one with inclination of approx. 45°and sinks in the Asthenoshere to melt completely below approx. 700 km. Results:

a) At the meeting boundary a deep trench is formed.



......cont.

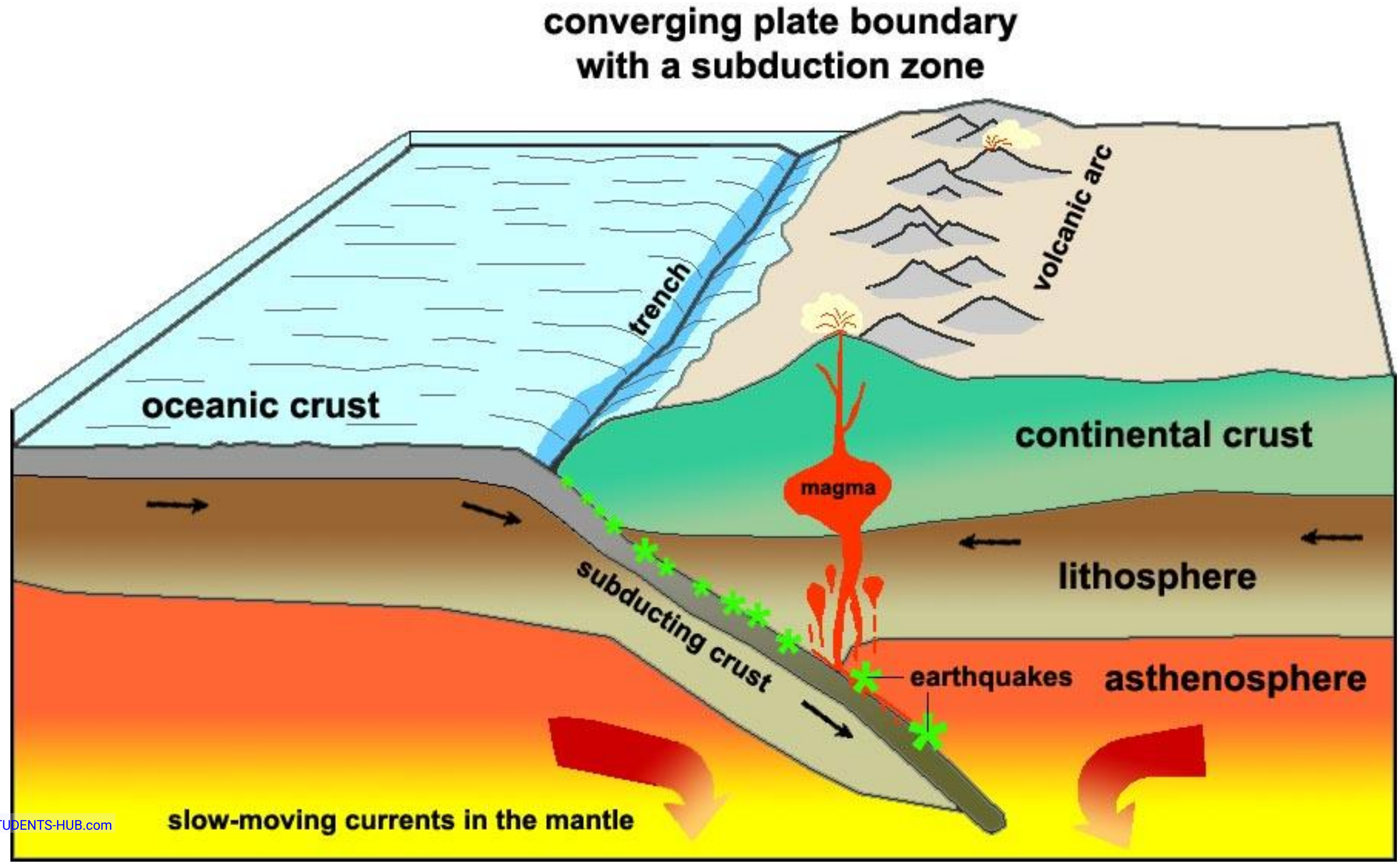


Lithospheric Plates

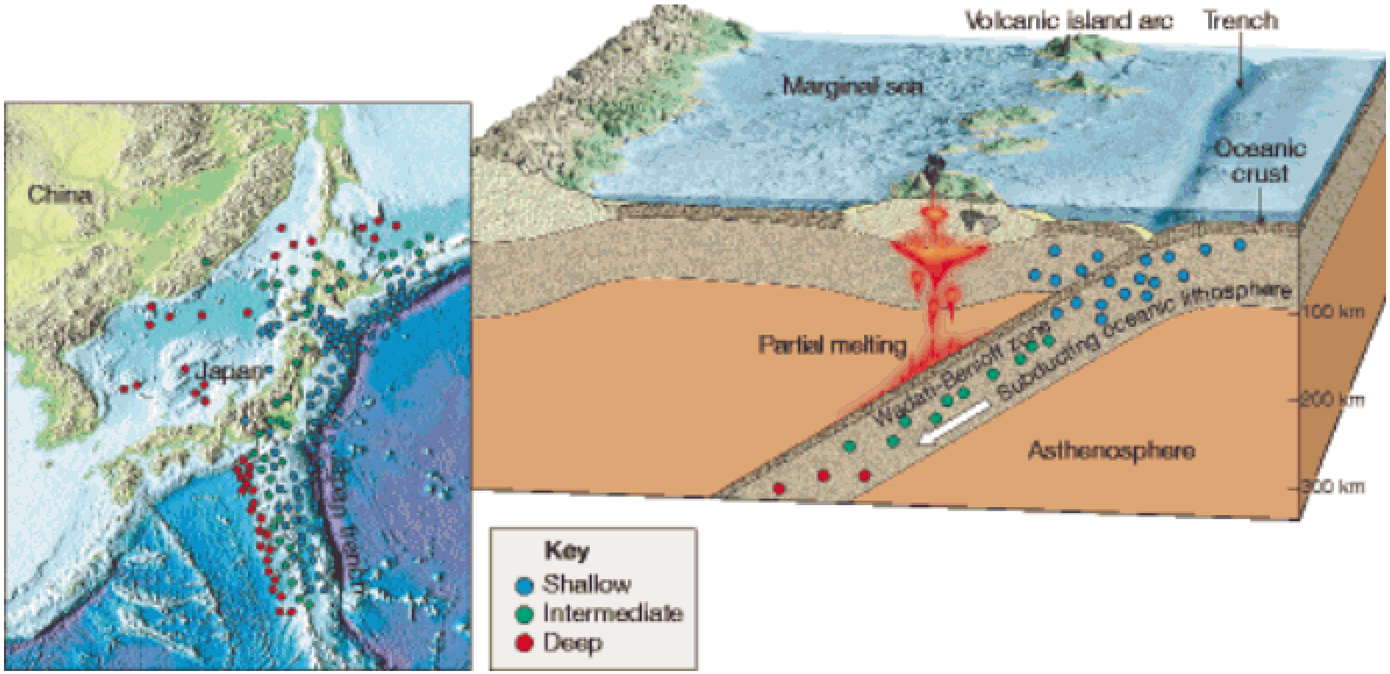
b) The minerals' components of the sinking plate, and in its way to melt in the Asthenosphere, melt in a gradual rhythmus called "PARTIAL MELTING" [that means minerals with lower melting points melt first & so on…]. This produces magma of lighter composition in weight [= granitic magma]. And due to the high pressure exerted by the collision, this magma intrudes the hanging plate to form a series of a rather rhyolitic volcanoes nearer to the convergent boundary.

c) As the sinking plate goes deeper, minerals of higher melting points (e.g. ferro-magnesian minerals) start to melt and the magma starts to be more heavier (andesitic first then basaltic). The intruding magma in form of lava over the hanging plate forms series of volcanoes called <u>"VOLCANIC ARCS".</u> They get to be basaltic (richer in Fe-Mg Minerals) in composition away from the boundary.

….. Also on the hanging plate:
The components forming the hanging plate *[which in their upper part are mainly composed of layers of sedimentary rocks],* and due to the pushing force exerted, start to fault and fold to form higher areas [THE MOUNTAINS] as Hemalaya, Alps, Andes, Anatolia, Oral …. etc.

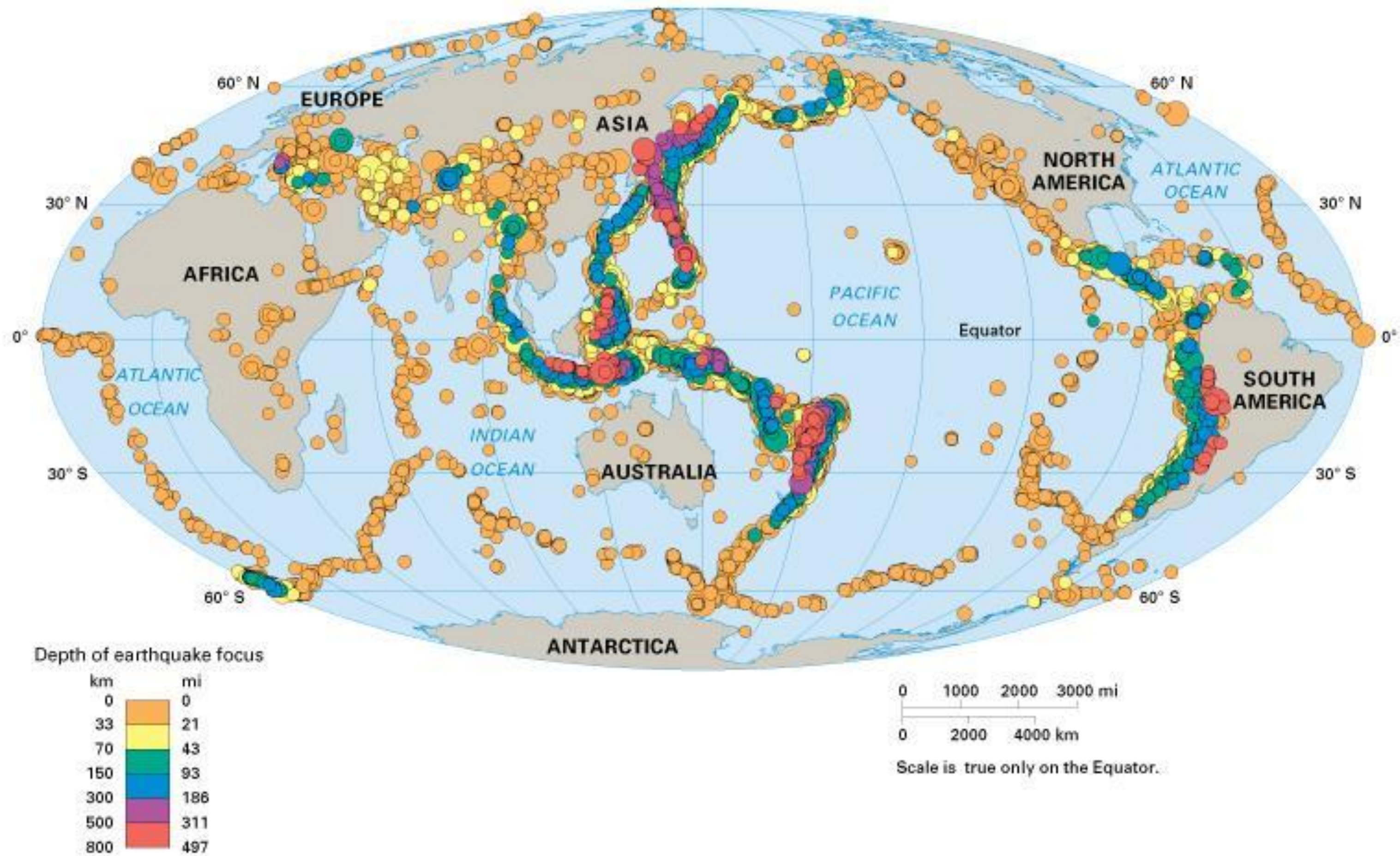

converging plate boundary
with a subduction zone
volcanic arc
trench
oceanic crust
continental crust
magma
lithosphere
subducting crust
earthquakes
asthenosphere
slow-moving currents in the mantle

Worth to mention is that the sliding of the sinking plate does not happen in a gradual manner but in abrupt way leading to release of immense energy in form of EARTHQUACKES.
The nearer the release of this energy to the boundary of convergence the more intensive is the Earthquake.

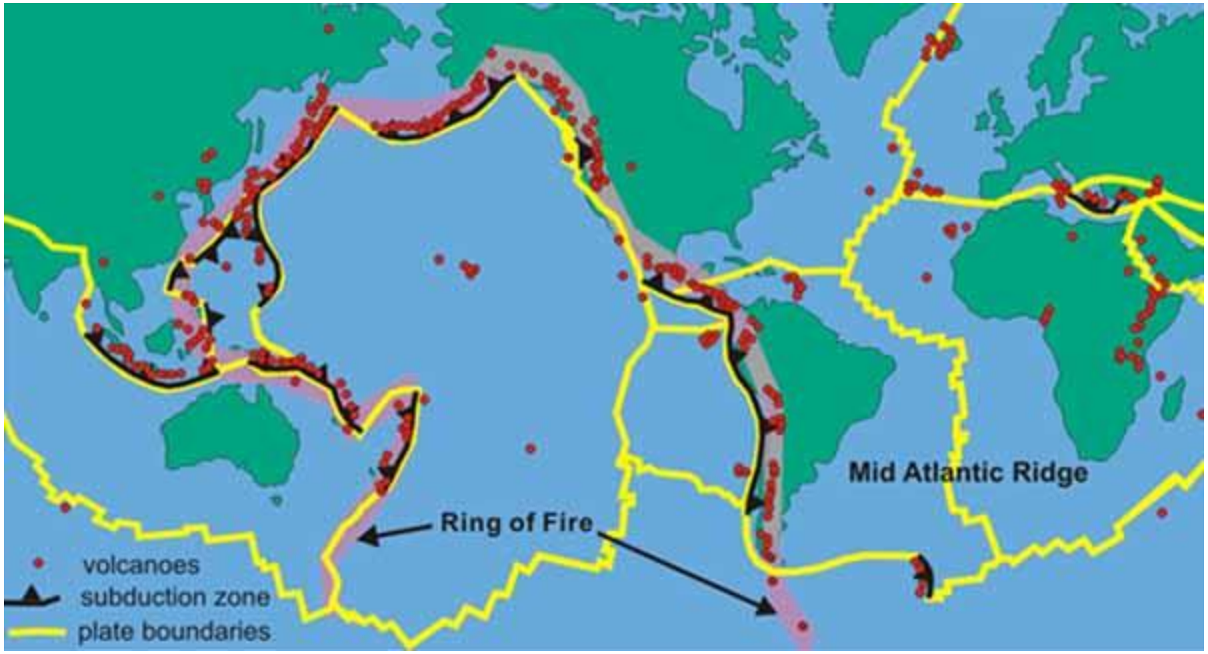


China
Japan
Japan trench
Volcanic island arc
Trench
Marginal sea
Oceanic crust
Subducting oceanic lithosphere
Wadati-Benioff zone
Partial melting
Asthenosphere
100 km
200 km
300 km
Key
Shallow
Intermediate
Deep

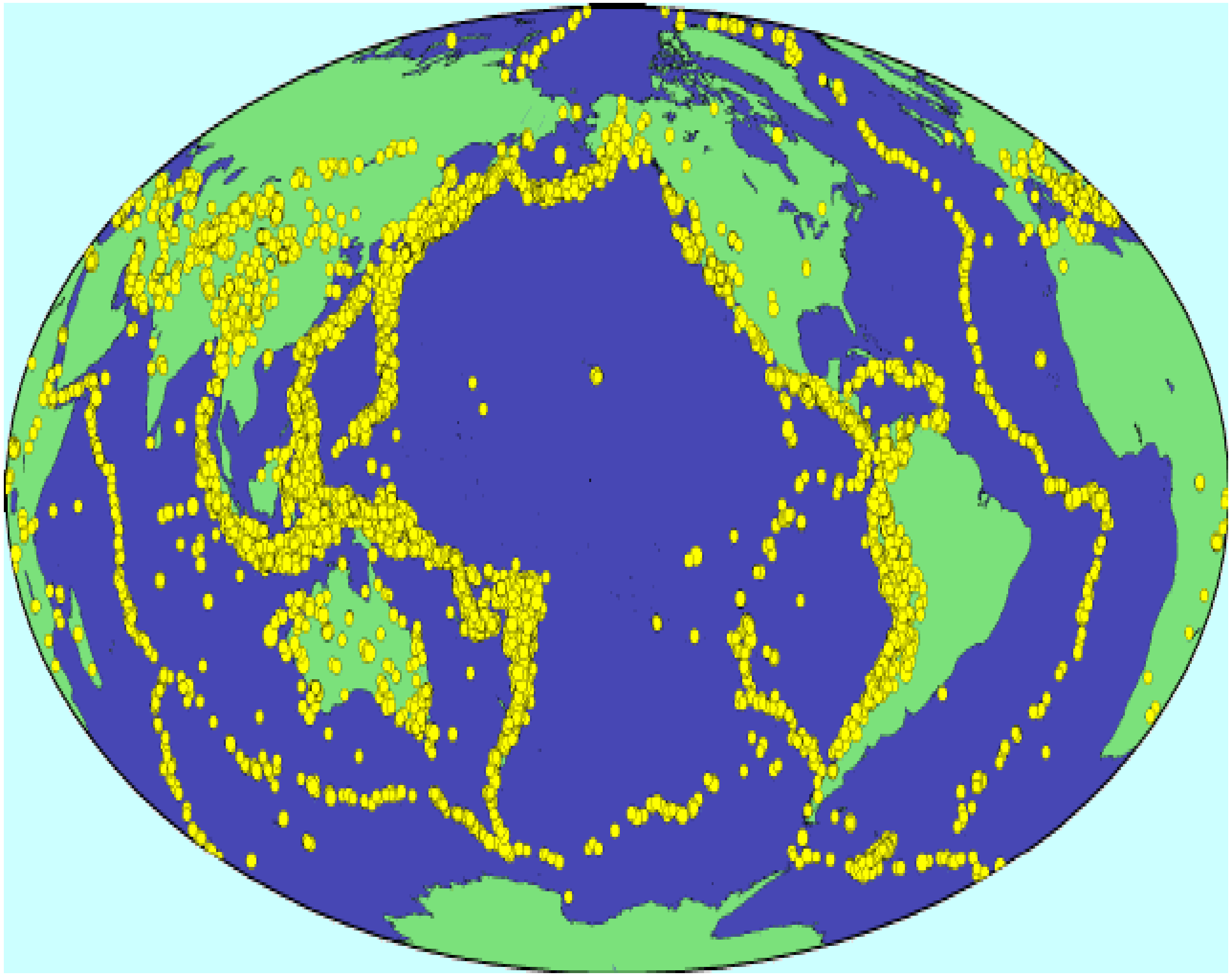
Global seismic centres in 1975–99:
earthquakes of magnitude 5.5 and greater



Circle size is proportional to earthquake magnitude.



Mid Atlantic Ridge
Ring of Fire
volcanoes
subduction zone
plate boundaries



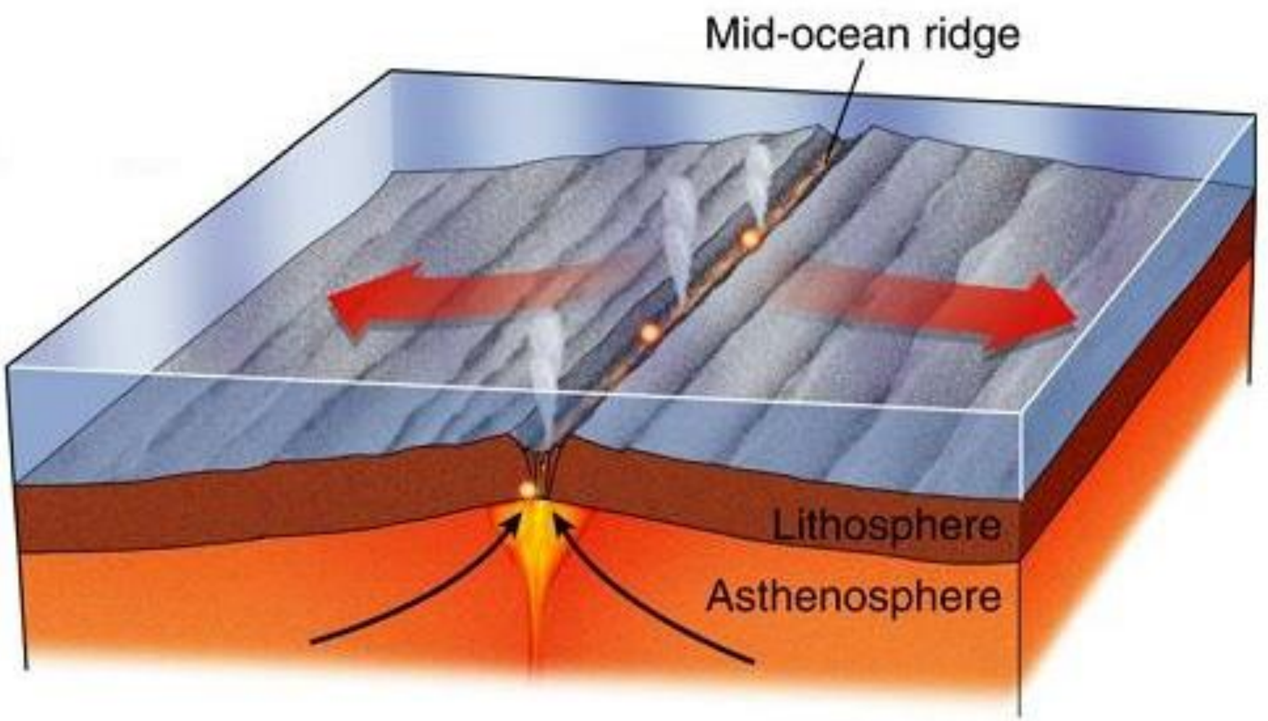
2. On the Divergent Boundaries:

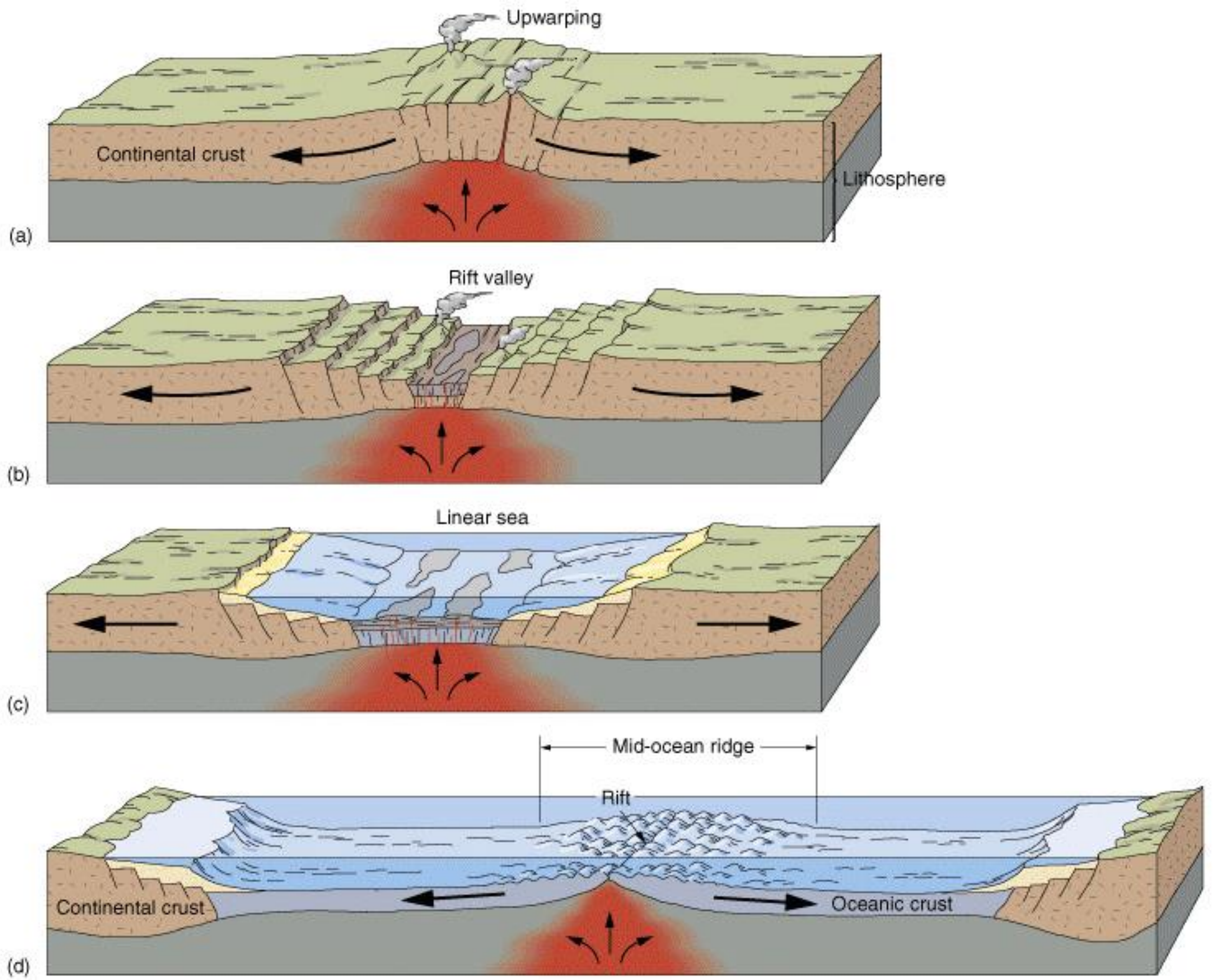
1) **At first, and due to the convectional currents power, immense tensile stress leads to the breaking of one plate into two plates.**
2) **This breaking resembles an injury in mans' skin in that the injury itself is deeper than the areas around on both sides & is called a RIFT. The areas around are subjected to inflation and rise above the areas far around. This inflated area on both sides of the rift is called a RIDGE.**

3- The rift, as well as its ridge are running nonlinear and irregular.
4) Along the rift, basaltic magma intrudes out in form of lava pushing the two plates apart forming a new crust *[this extruded lava resembles the blood that flows out of the injury].*

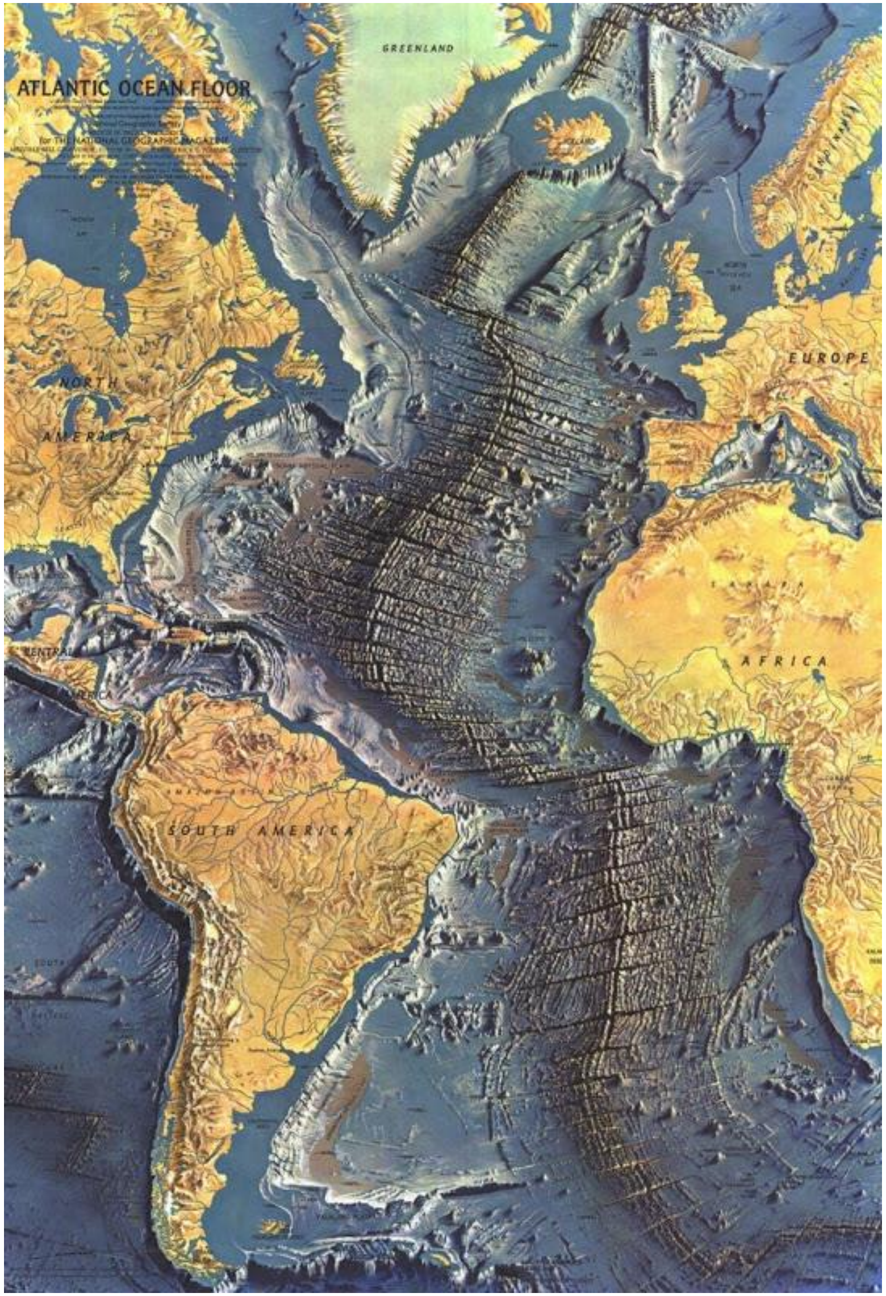
5- The divergence of the two plates is a continuous action but the extrusion of lava happens sometimes in pulses creating Earthquakes of medium scale.

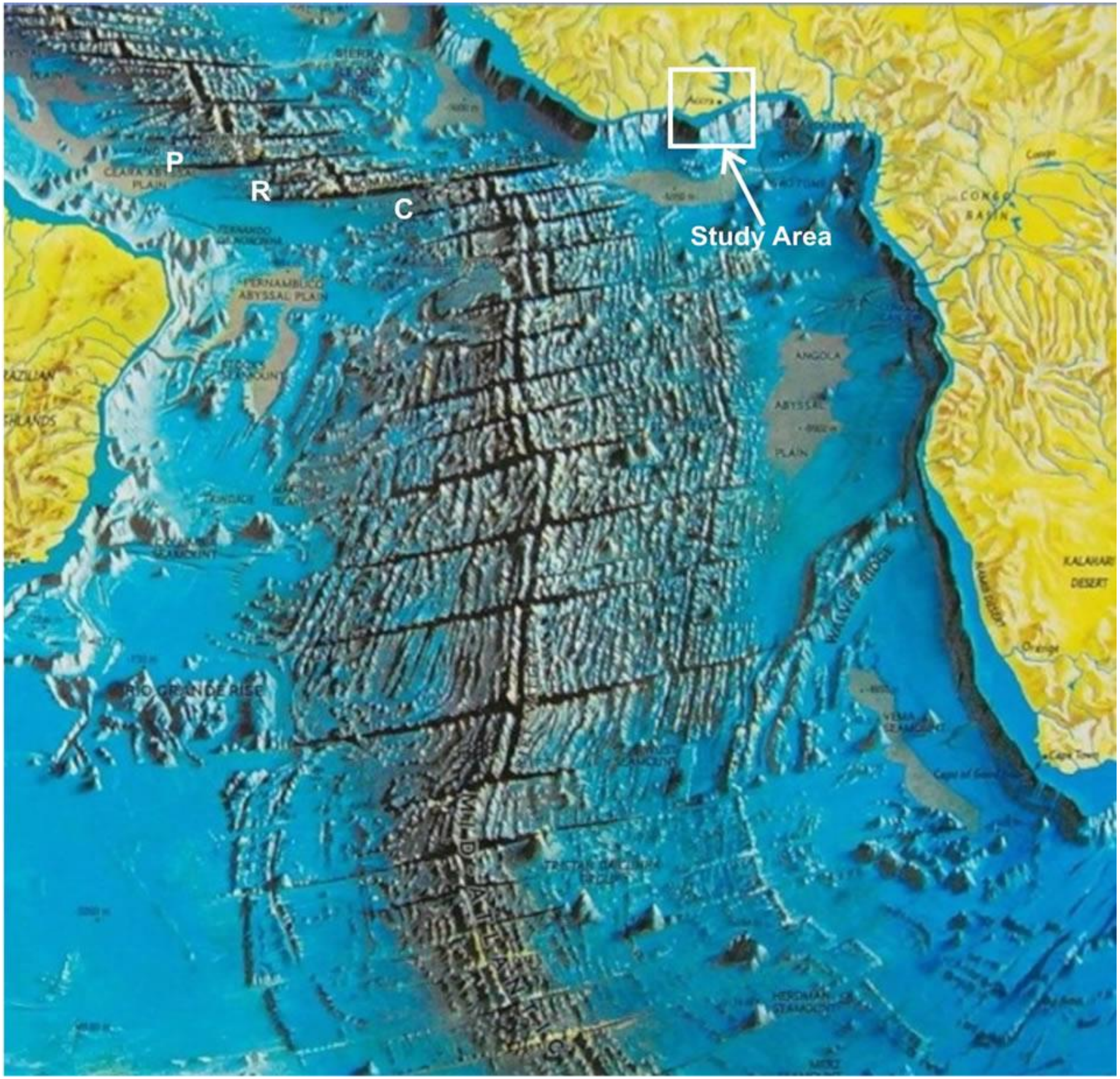
6- By time the rift deepens more and more and sea water intrudes the area forming a longitudinal sea that with time becomes an ocean; examples: the Atlantic Ocean & the Red Sea….

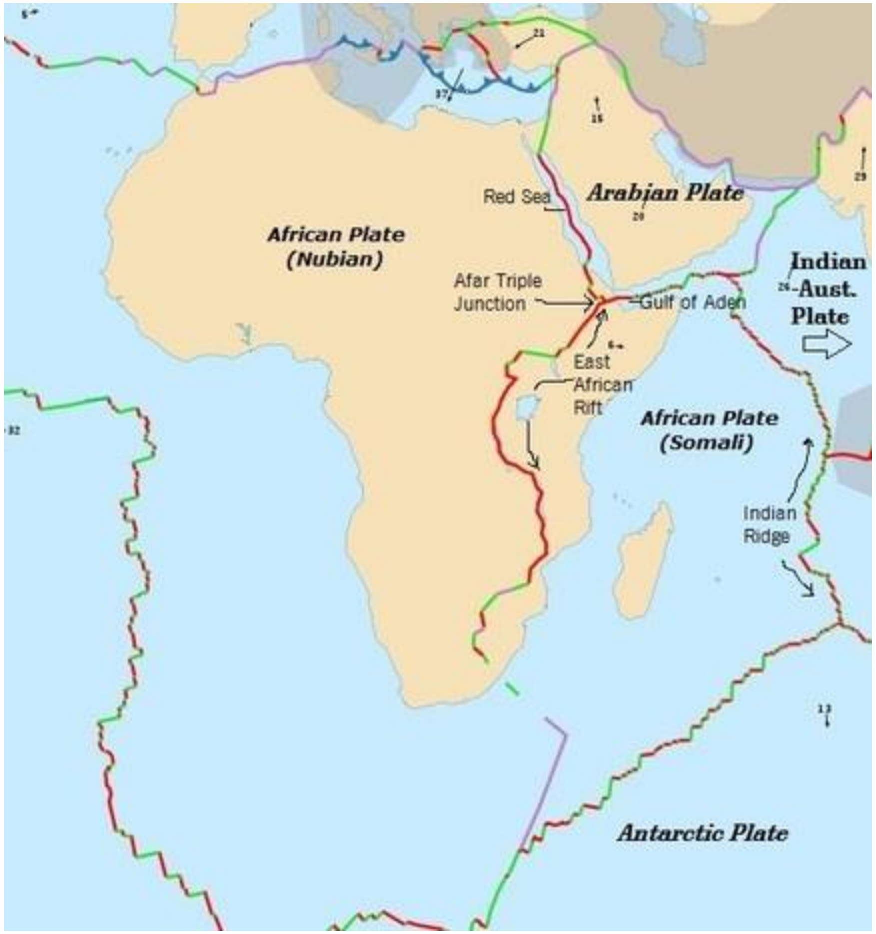

Mid-ocean ridge
Lithosphere
Asthenosphere

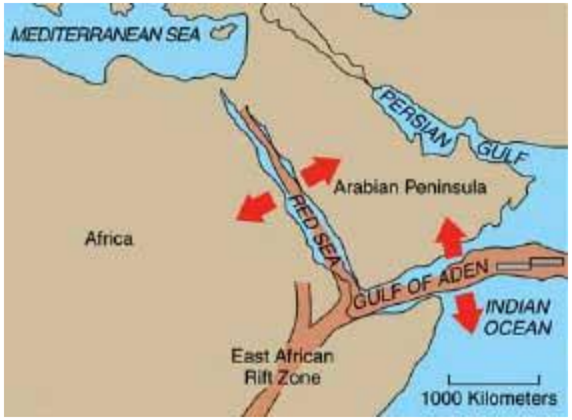

Upwarping
Continental crust
Lithosphere
(a)
Rift valley
(b)
Linear sea
(c)
Mid-ocean ridge
Rift
Continental crust
Oceanic crust
(d)

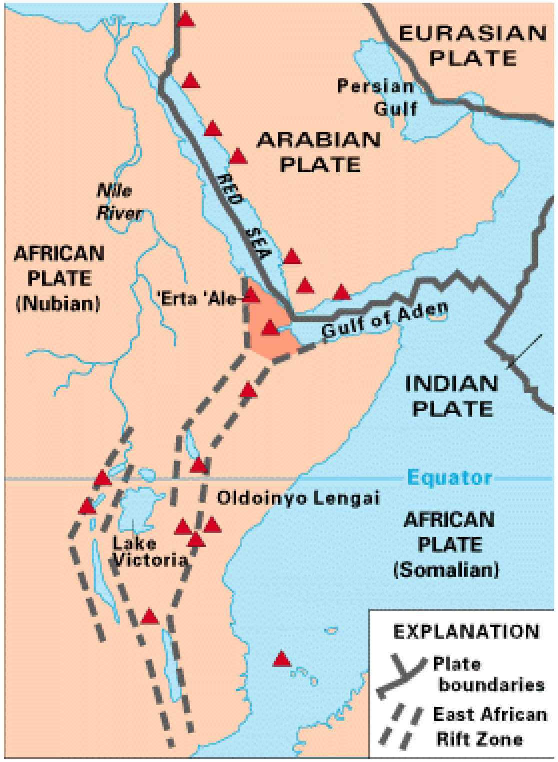
شكل 33
تكوين الحيد المحيطي


ATLANTIC OCEAN FLOOR
GREENLAND
EUROPE
NORTH
AMERICA
AFRICA
SOUTH AMERICA

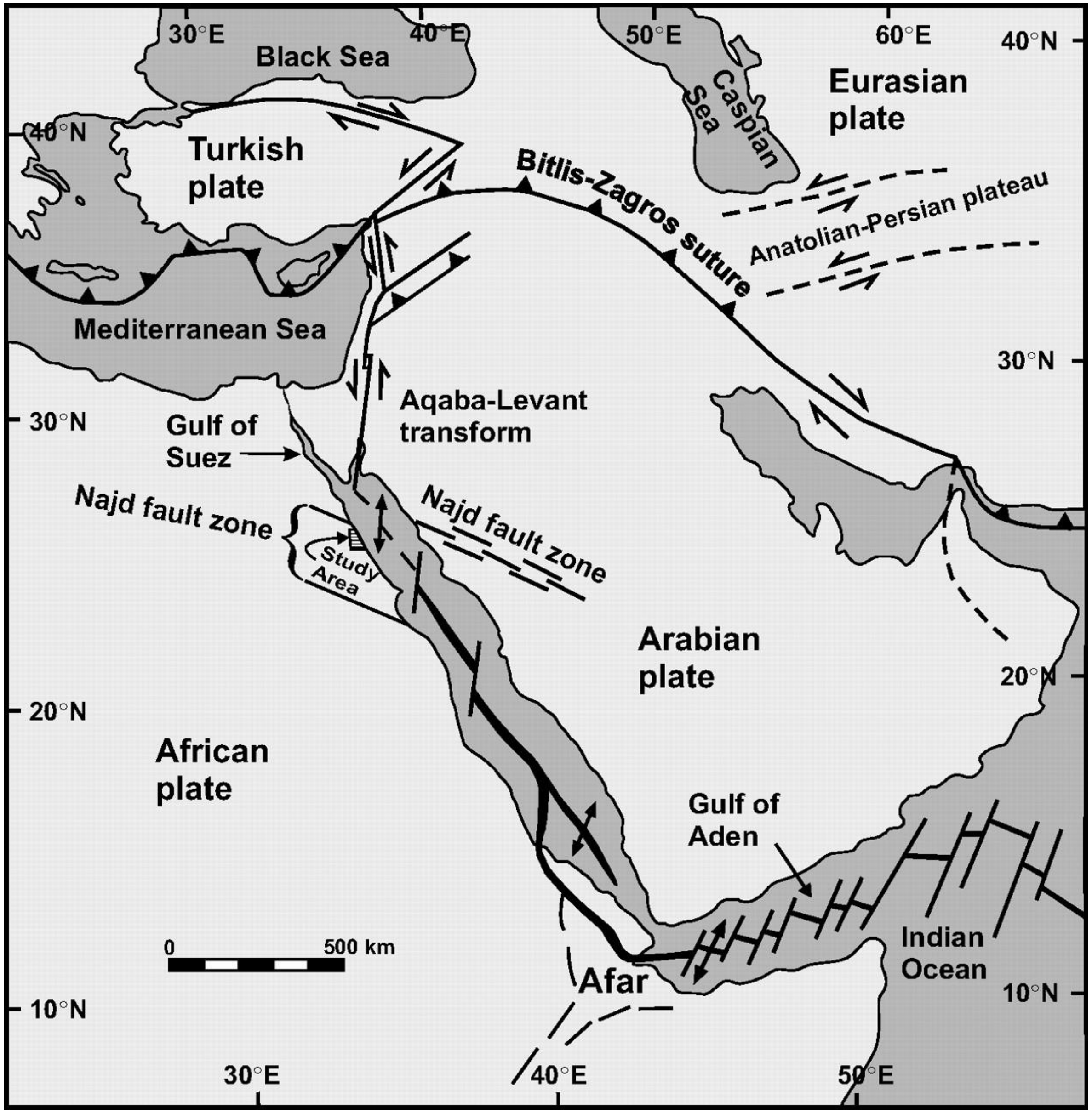

P
R
C
Study Area
PERNAMBUCO ABYSSAL PLAIN
ANGOLA
ABYSSAL
PLAIN
CONGO
BASIN
KALAHARI
DESERT
RIO GRANDE RISE
WALVIS RIDGE
Cape Town
Accra

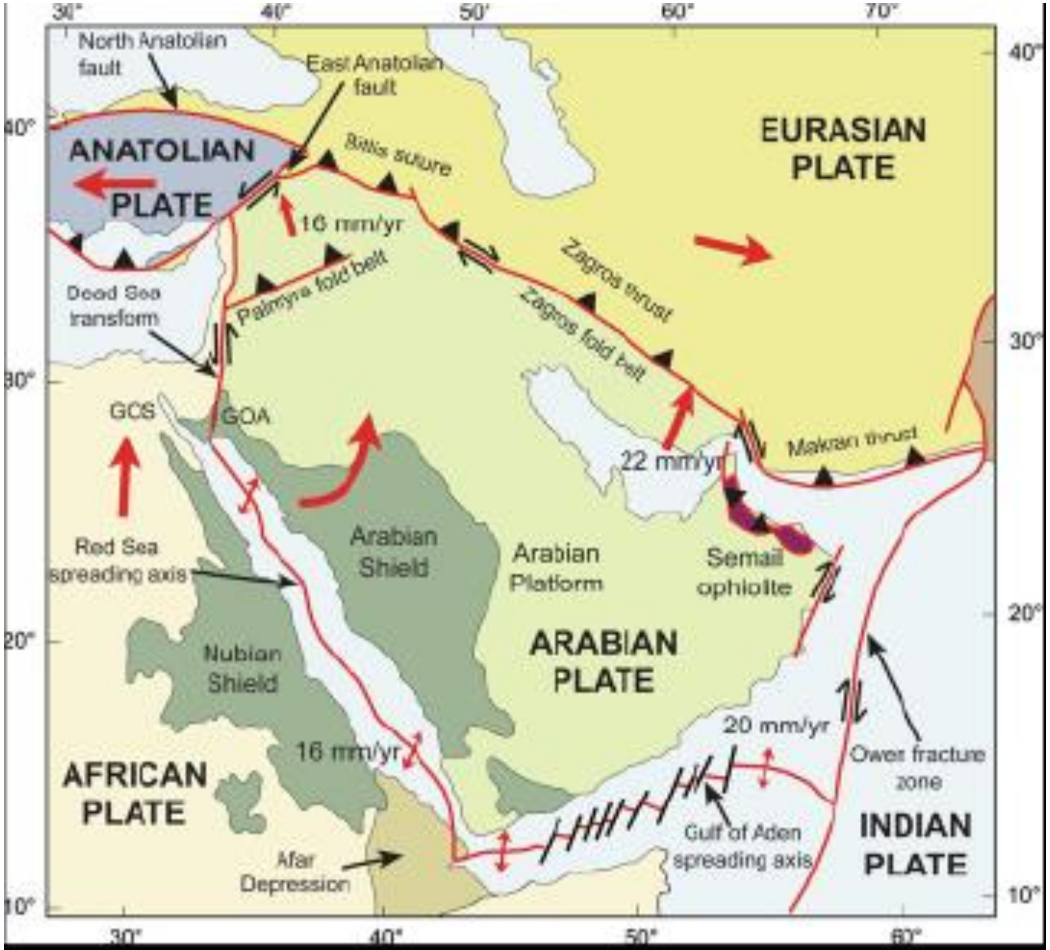

Red Sea
Arabian Plate
African Plate
(Nubian)
Afar Triple
Junction
Gulf of Aden
Indian
-Aust.
Plate
East
African
Rift
African Plate
(Somali)
Indian
Ridge
Antarctic Plate


MEDITERRANEAN SEA
PERSIAN
GULF
Arabian Peninsula
Africa
RED SEA
GULF OF ADEN
INDIAN
OCEAN
East African
Rift Zone
1000 Kilometers


EURASIAN
PLATE
Persian
Gulf
ARABIAN
PLATE
Nile
River
RED
SEA
AFRICAN
PLATE
(Nubian)
'Erta 'Ale
Gulf of Aden
INDIAN
PLATE
Equator
Oldoinyo Lengai
Lake
Victoria
AFRICAN
PLATE
(Somalian)
EXPLANATION
Plate
boundaries
East African
Rift Zone


N
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat
Google earth
Imagery Date: 4/9/2013 19°20'54.71" N 37°03'31.94" E elev 1302 ft eye alt 2485.16 mi


30°E
40°E
50°E
60°E
40°N
Black Sea
Caspian Sea
Eurasian plate
40°N
Turkish plate
Bitlis-Zagros suture
Anatolian-Persian plateau
Mediterranean Sea
30°N
Aqaba-Levant transform
30°N
Gulf of Suez
Najd fault zone
Najd fault zone
Study Area
Arabian plate
20°N
20°N
African plate
Gulf of Aden
0
500 km
Indian Ocean
Afar
10°N
10°N
30°E
40°E
50°E

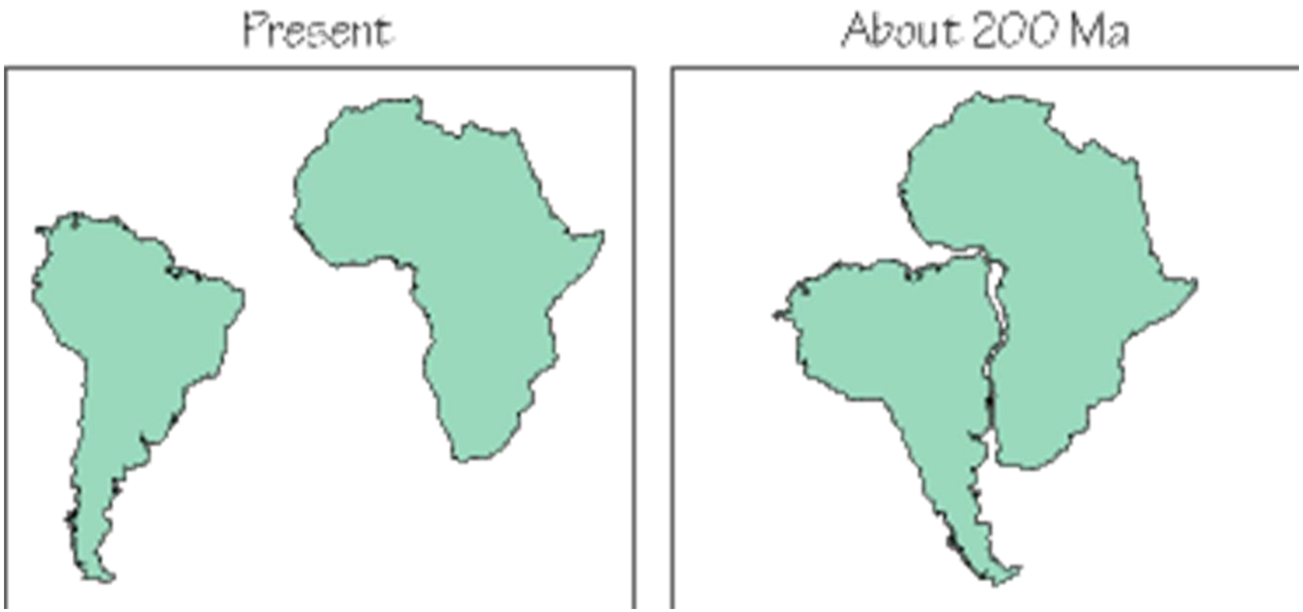


30°
40°
50°
60°
70°
North Anatolian fault
East Anatolian fault
Bitlis suture
EURASIAN PLATE
ANATOLIAN PLATE
16 mm/yr
Palmyra fold belt
Dead Sea transform
Zagros thrust
Zagros fold belt
GCS
GOA
22 mm/yr
Makran thrust
Red Sea spreading axis
Arabian Shield
Arabian Platform
Semail ophiolite
ARABIAN PLATE
Nubian Shield
20 mm/yr
16 mm/yr
Owen fracture zone
AFRICAN PLATE
Gulf of Aden spreading axis
INDIAN PLATE
Afar Depression
40°
30°
20°
10°

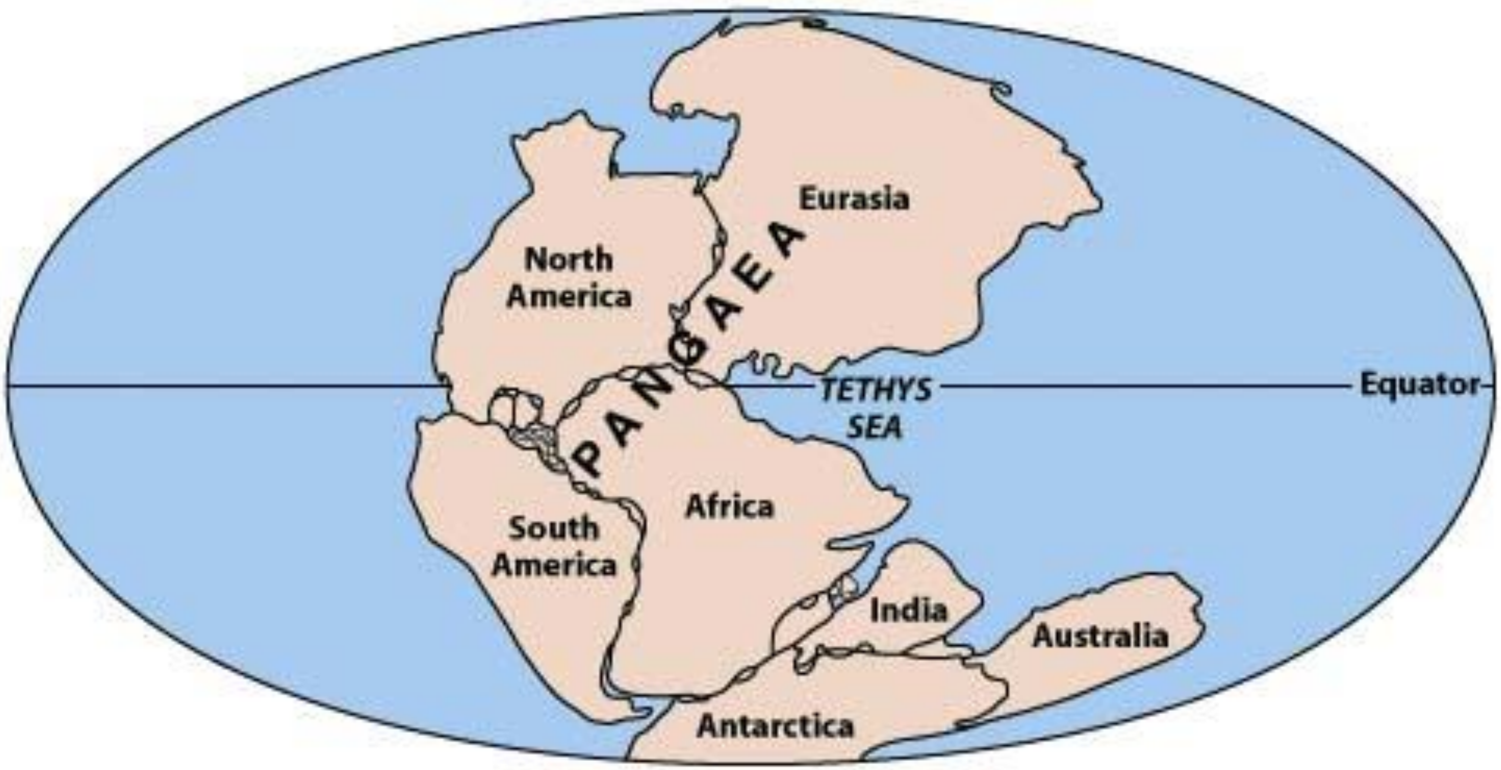
EVIDENCES PRO PLATE TECTONIC THEORY

1) The fitting between the eastern coast line of South America/North America and the western coast line of Africa/ Europe. Max. fitting at -800m below

Sea level.

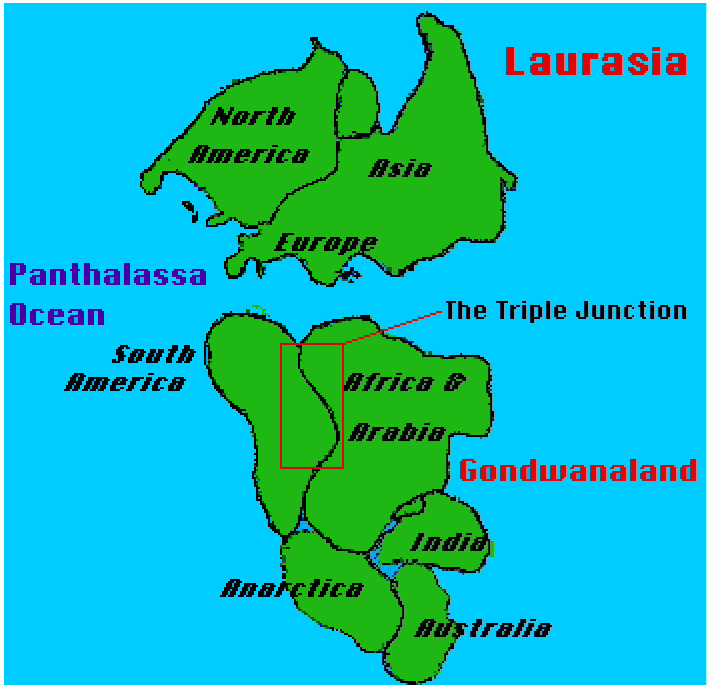


Earth before 300 Million Years ago

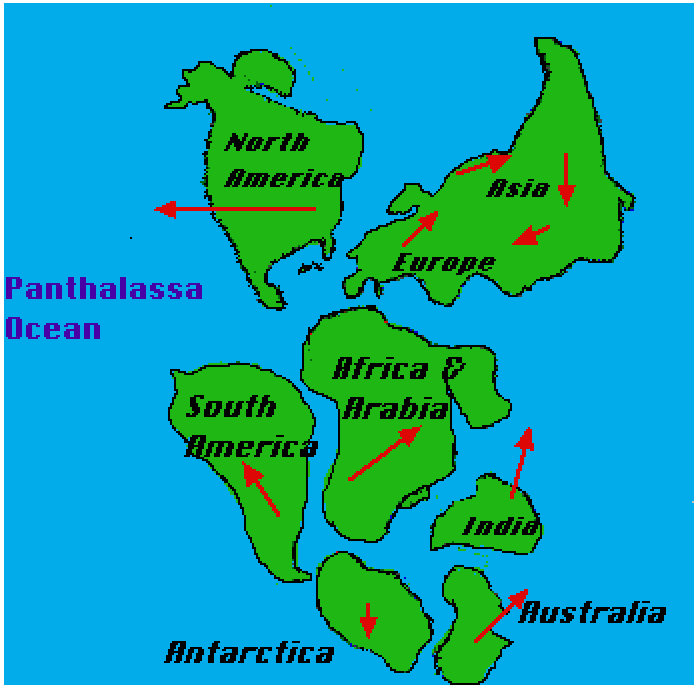


Prior to this splitting [before 250 Million years ago], scientists say: The whole land was one continent called "PANGEA" surrounded by water of the super ocean named "TETHYS"

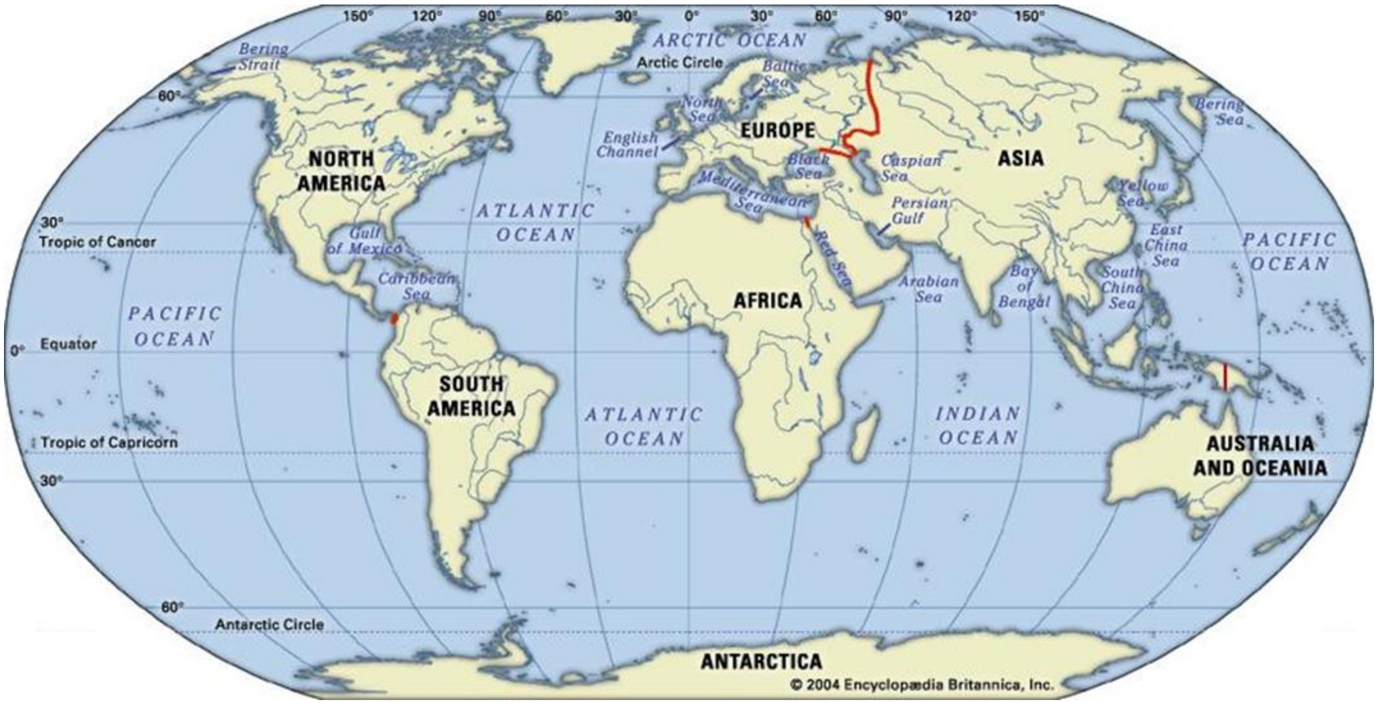
180 Million years ago: The splitting and drifting away from each other continued with time



135 Million years ago

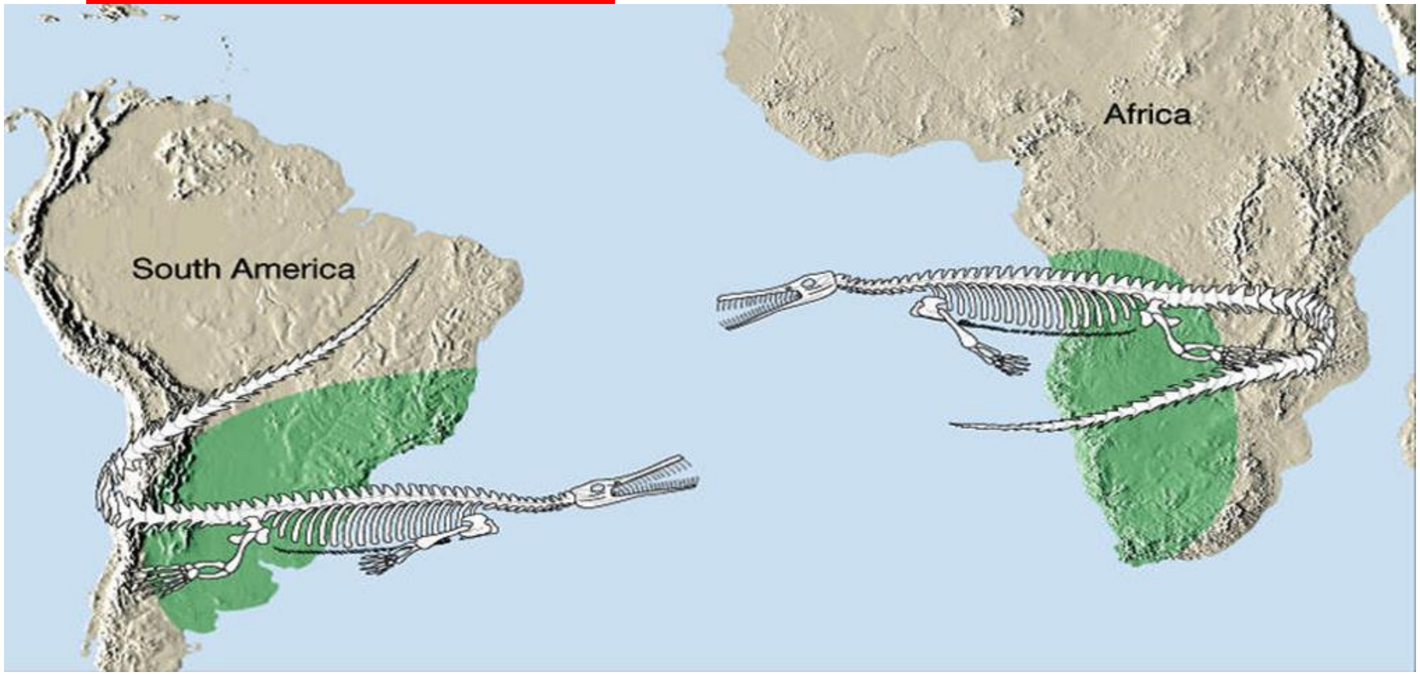


Nowadays Earth: Land & Sea



2- Fossil Evidence:

- **Remains of many similar terrestrial fossil species were found in old rocks on eastern coast of South America & western coast of Africa; especially that of the in fresh water lived *Mesosaurus sp*.**



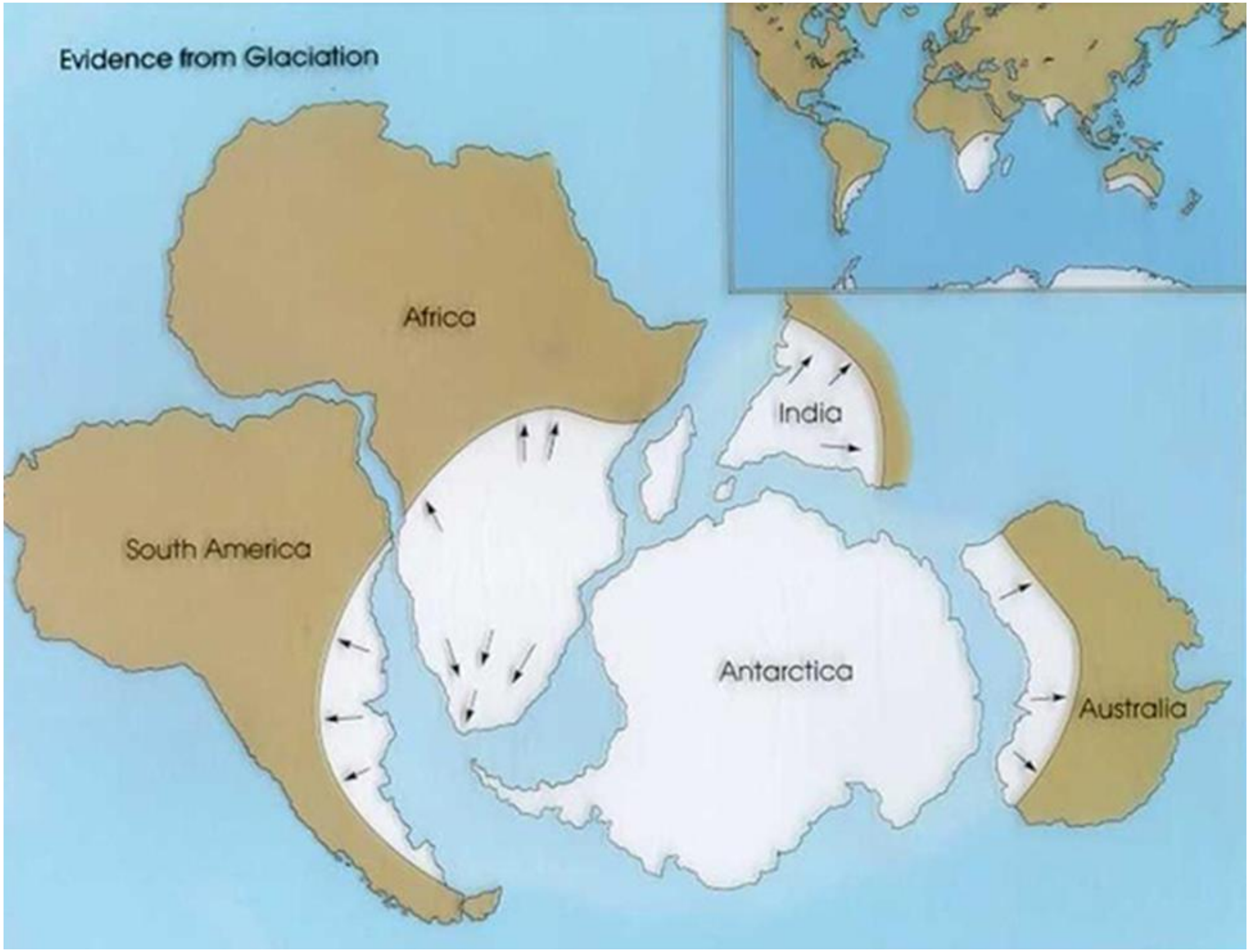
3- Rock types and successions evidence

- **On both sides of the Atlantic Ocean, similar rock types with their detailed components and approx. similar thicknesses were found:**

Rock Evidence

Rock units of similar type and age line up when continents are reassembled into Pangaea. This alignment has aided in the discovery of important mineral resources across continental boundaries.

4. Environmental evidence: Rock types indicate certain environmental conditions under which they were deposited or formed; these paleo-environments were found similar in southern parts of many continents. One significant rock type is the rock "TILL" which indicates glaciation climate.


Evidence from Glaciation
Africa
South America
India
Antarctica
Australia

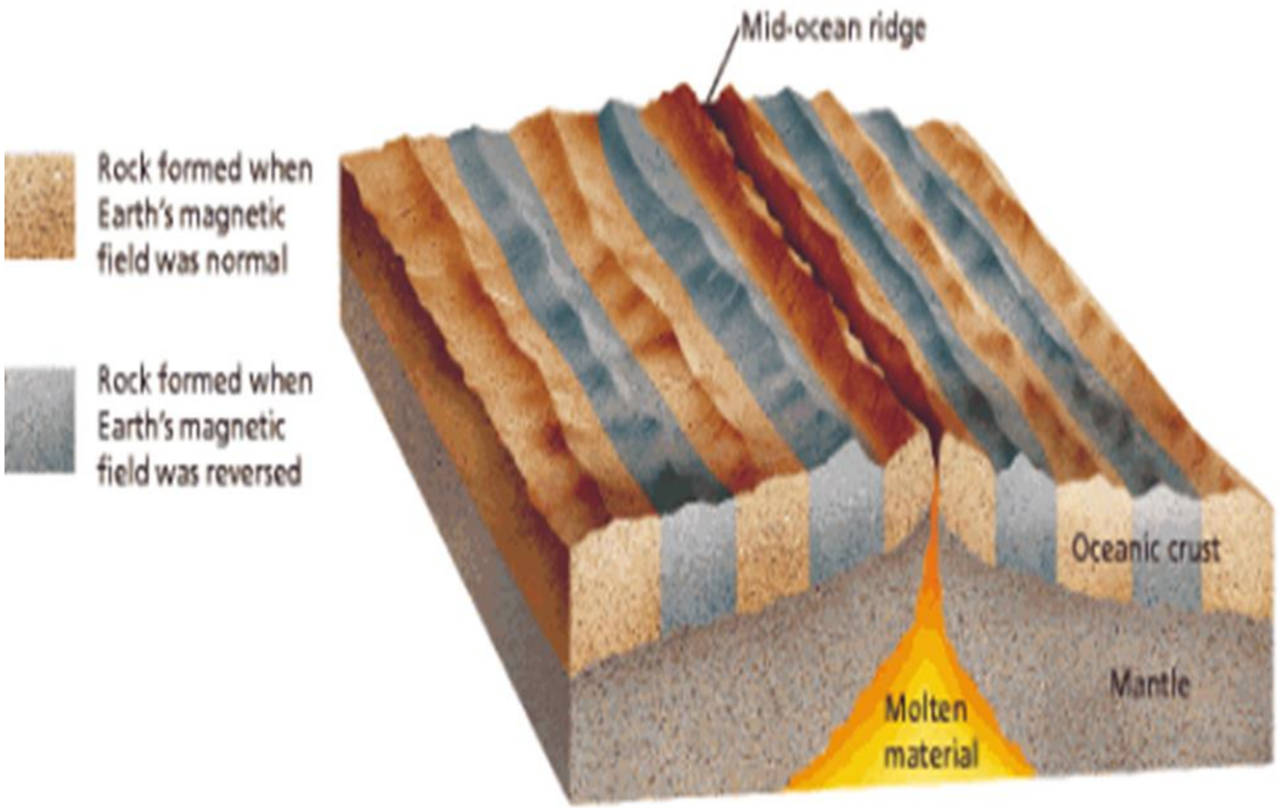
5- Paleomagnetism Evidence: As a scientific fact; our Earth nowadays has a + North magnetic pole and a – South magnetic pole with certain intensity. This was not the case always. Scientists detected that our Earths' magnetic intensity had lost > 5% of its intensity in the last century and the loss is going on until the intensity will reach a zero Gauss.

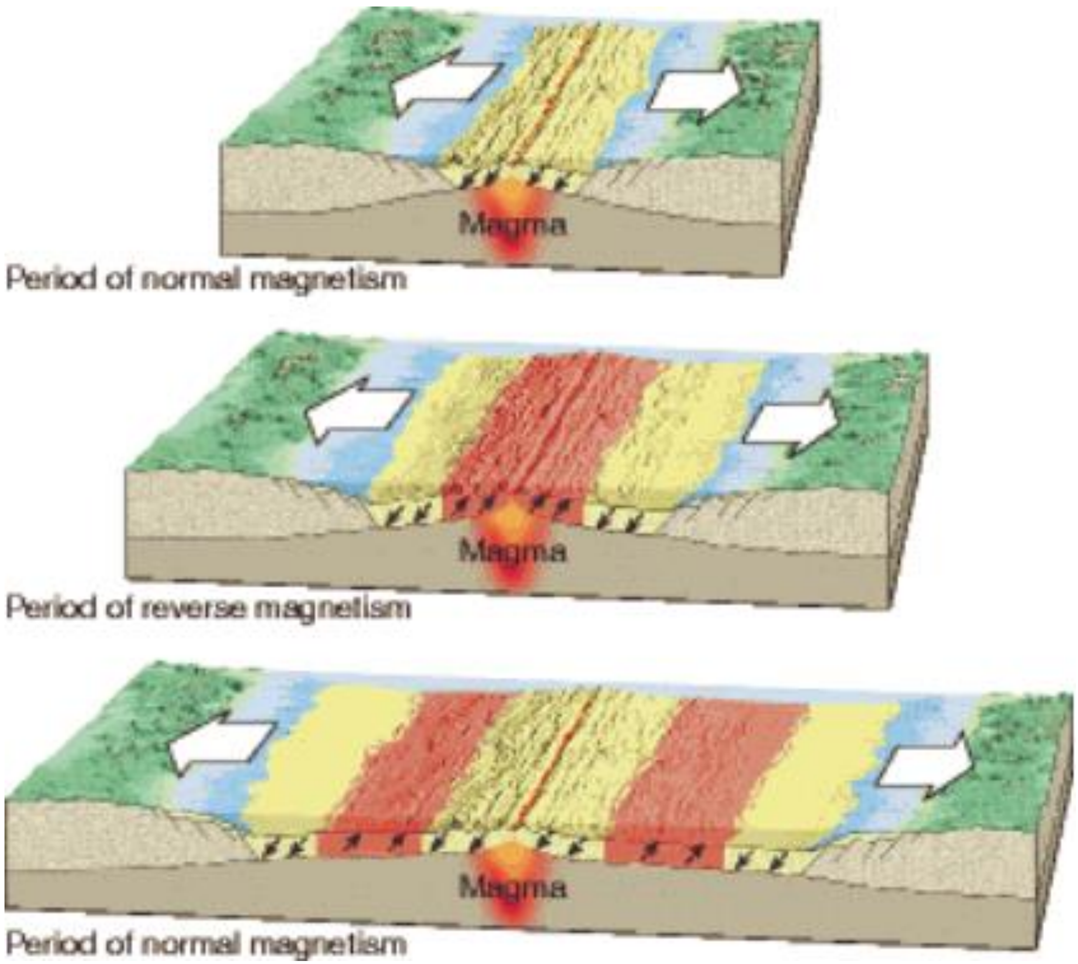
Then the intensity of both poles will start to grow up but with changing sign; the – will regrow as + and the + will regrow as – like a balance game. This phenomenon is called Magnetic Reversals

What has this to do with Plate Tectonics?

Answer: **Nowadays we have many active volcanoes that extrude basaltic magma rich in ferrous minerals. These minerals once start to quench on Earth surface and below 770 C^o?** ***[The degree above which magnet looses its magnetism],*** **they arrange themselves parallel to the recent magnetic field [+ North & - South].**

As we know, the most areas that extrude basaltic lava are the rift areas. So going apart from any rift on both sides, we meet basaltic flows symmetrical in their polarity, arrangement and age on both sides.


Mid-ocean ridge
Rock formed when Earth's magnetic field was normal
Rock formed when Earth's magnetic field was reversed
Oceanic crust
Mantle
Molten material


Magma
Period of normal magnetism
Magma
Period of reverse magnetism
Magma
Period of normal magnetism

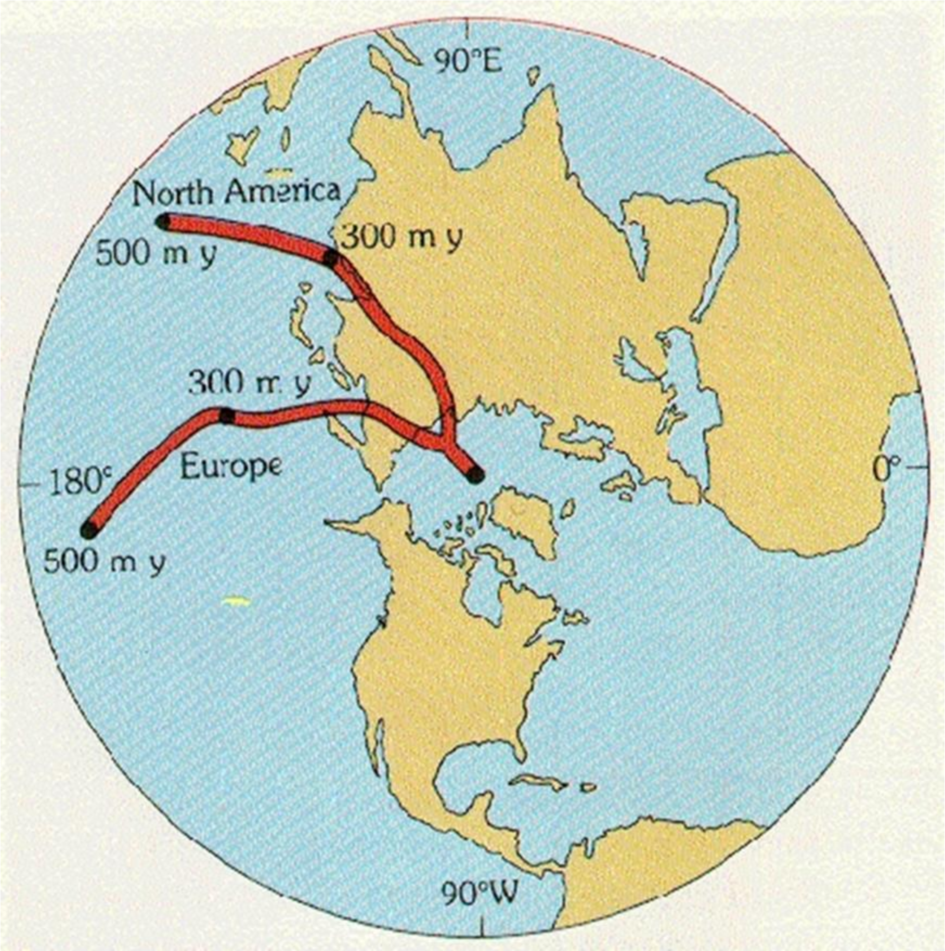
Polar Wandering Phenomenon:

Magnetic poles are stationary always. When ferrous minerals in basalts were extruded in old times, these minerals arranged themselves in accordance with the Earths' polarity at that time. Observing many extrusions on Earth surface of same age but with different directions' orientations means only one thing:

"The poles were not wandering but the plates did".

Also studying the directions' orientation of ferrous minerals in basaltic extrusions of different ages over one plate; scientists found that each extrusion shows certain direction different from the other. This observation also means that this plate on which all these basaltic extrusions occurred itself has been moving thru time not the Earths' poles.

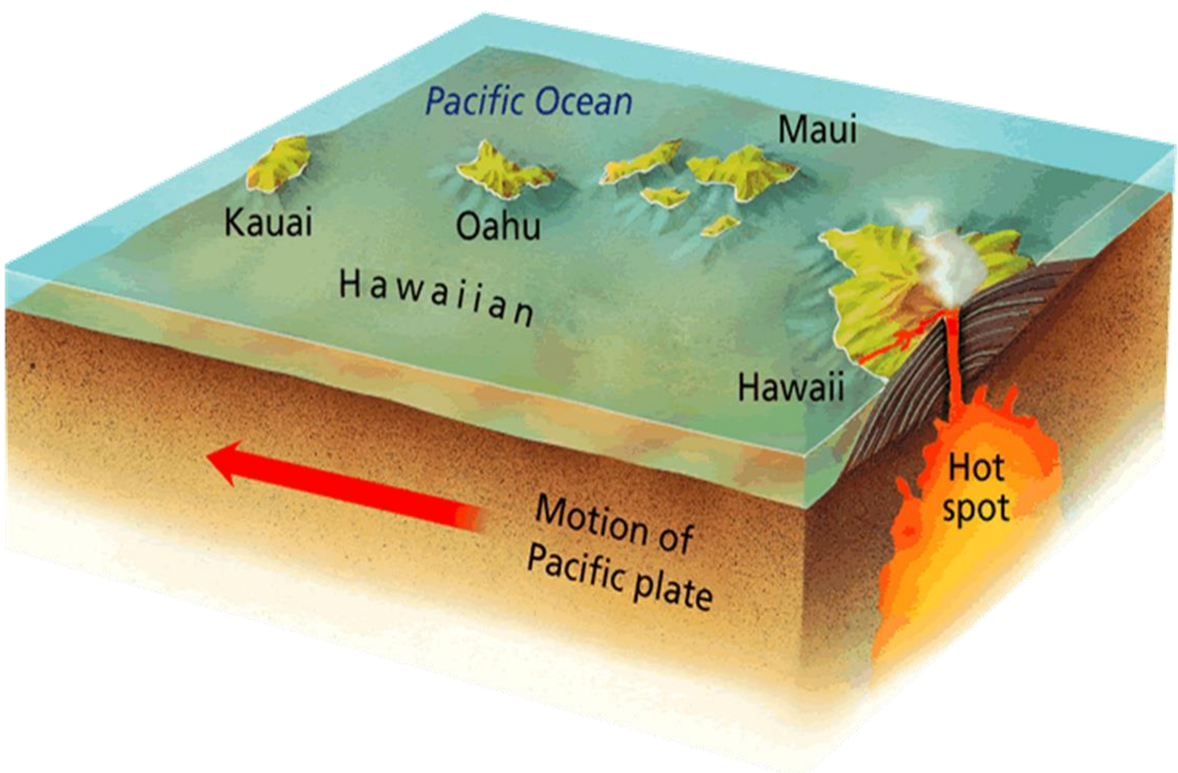
POLAR WANDERING↓

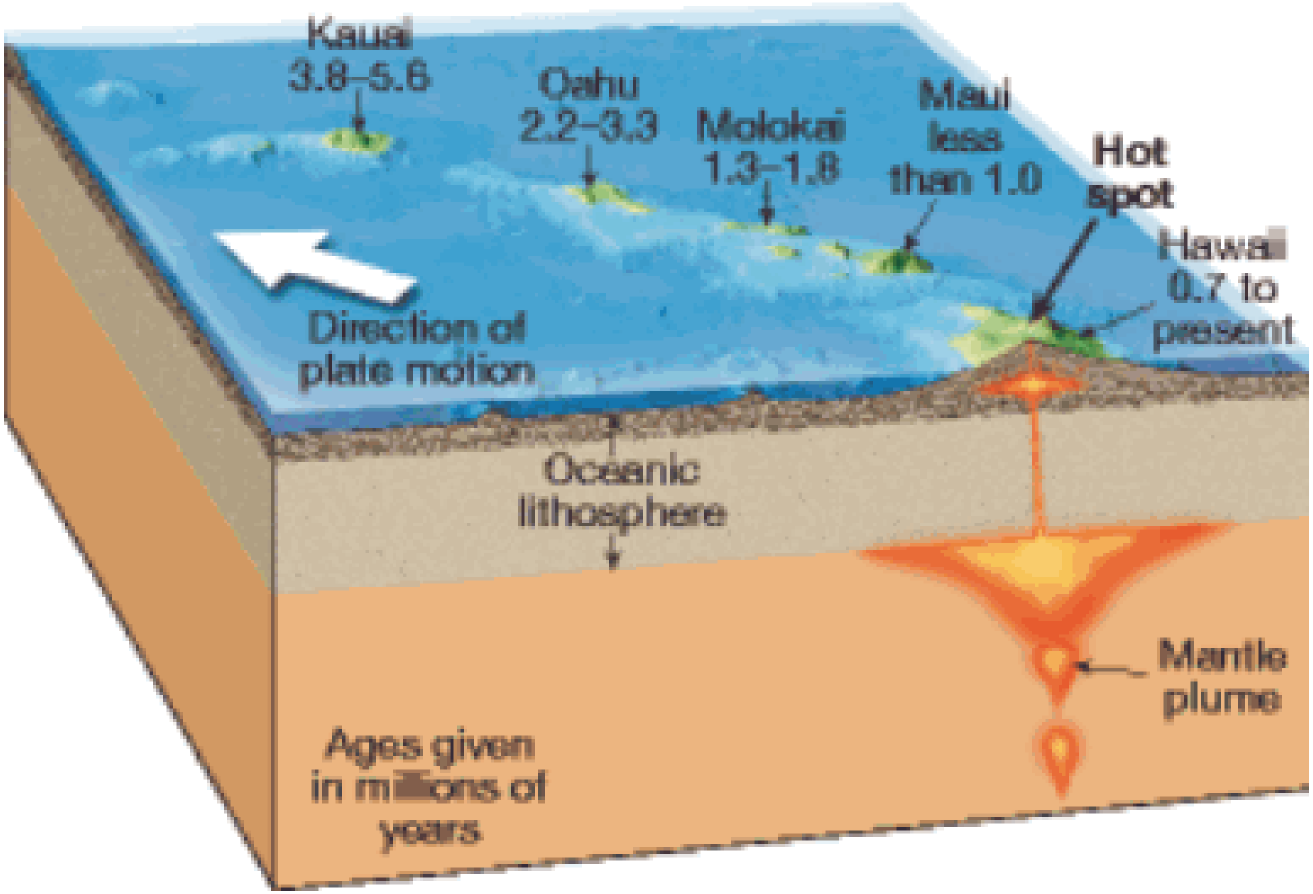


6- Evidences from Deep Sea Drilling Project (Glomar Challenger Driller):

On both sides of the Mid-Atlantic Ridge, Geologists dug many deep boreholes and picked rock cores out of them. On both sides of the rift they found there is symmetry in rock successions, ages and features (e.g. microfossil content, rock types, thicknesses…)

7. Evidence from Hot Spots: What is a HS?. It is a stationary "zone" within the Asthenosphere that extrudes basalt in pulses on the moving Lithosphere every certain period of time. Example: Hawaii Archipelago.



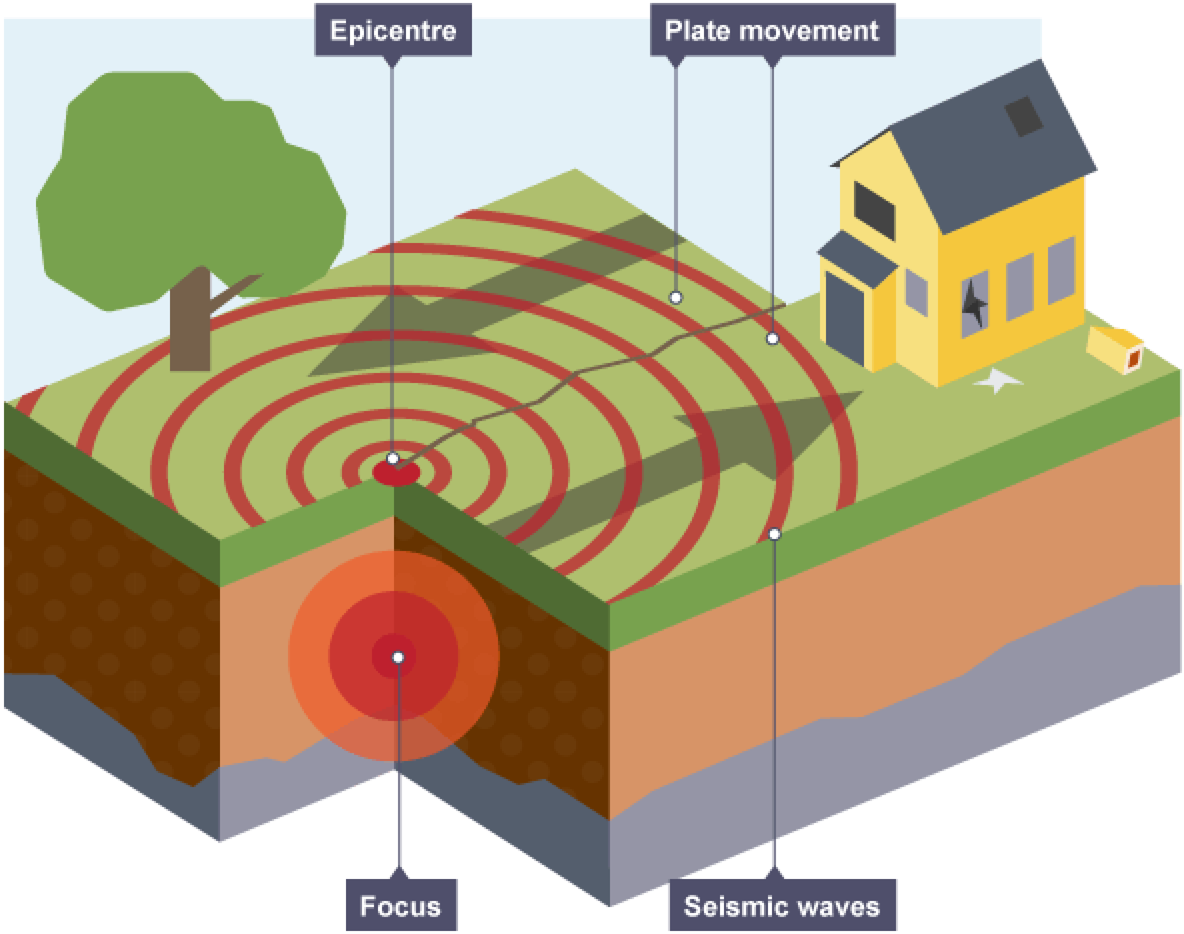

Kauai
3.8–5.6
Oahu
2.2–3.3
Molokai
1.3–1.8
Maui
less
than 1.0
Hot
spot
Hawaii
0.7 to
present
Direction of
plate motion
Oceanic
lithosphere
Mantle
plume
Ages given
in millions of
years

EARTHQUAKES

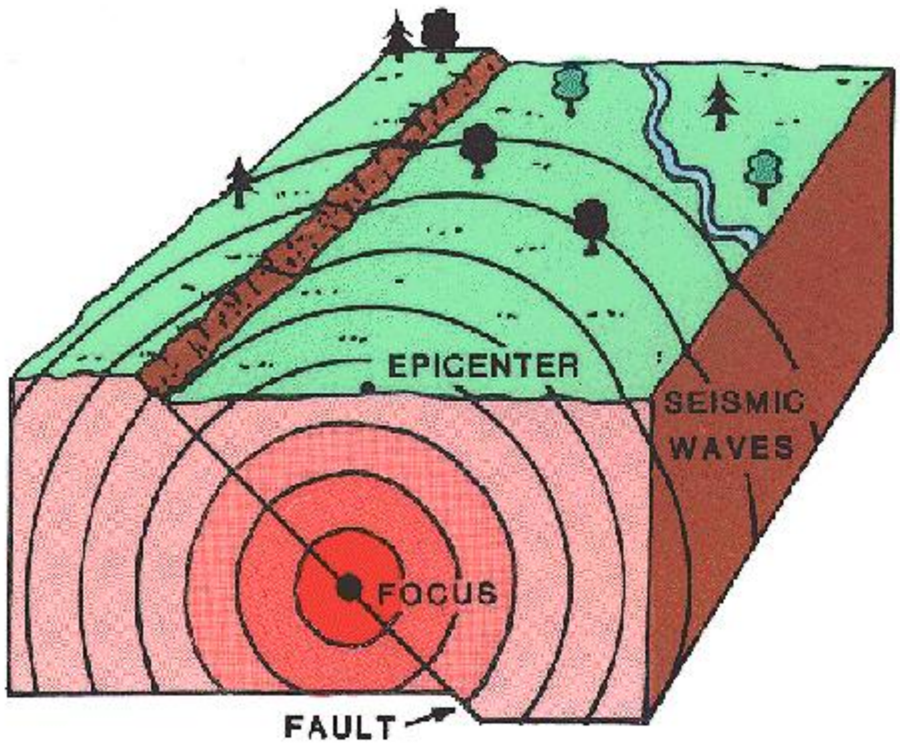
What is an EQ?

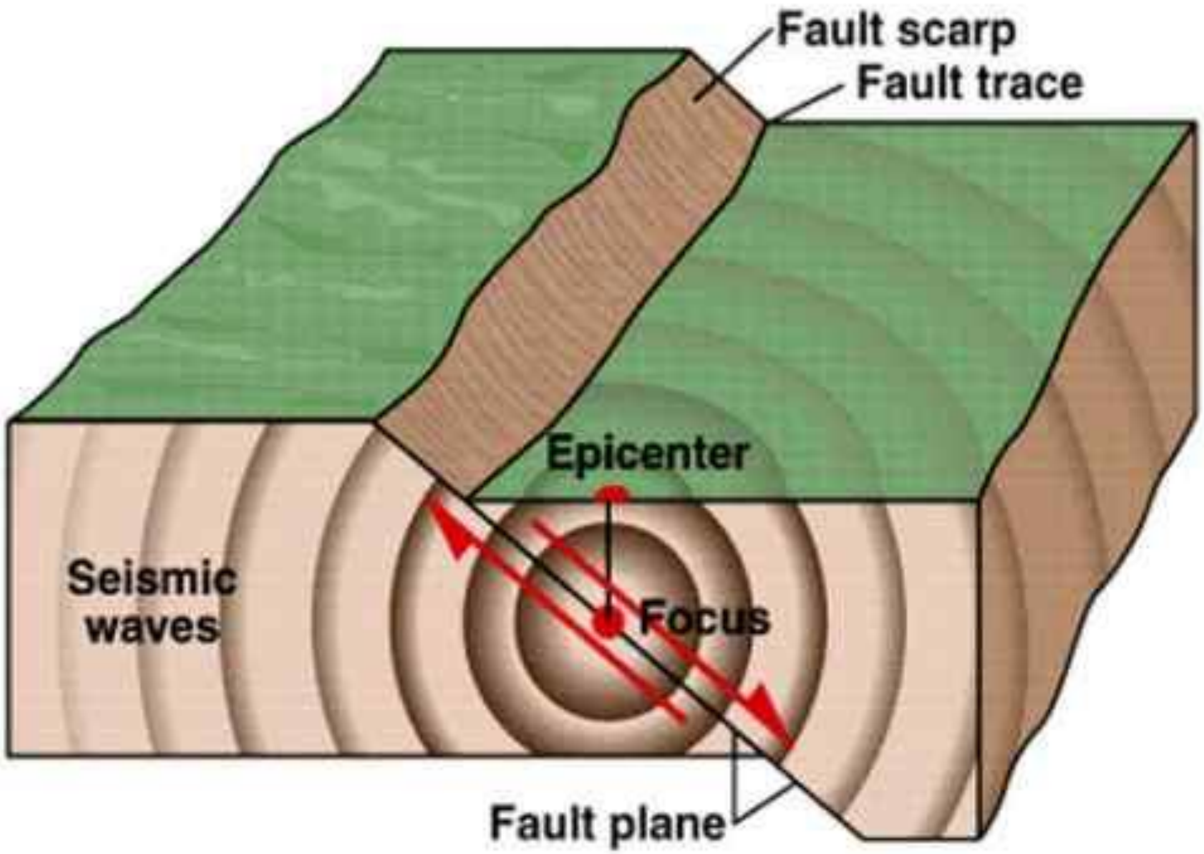
EQ is the vibration of the surface of the Earth, resulting from the sudden release of energy in the Earth's crust.

This energy radiates as waves called “SEISMIC WAVES” in all directions from a certain source in the Earths’ interior called “FOCUS”. The energy is dissipated in all directions and the nearest point on the surface that the energy first reaches is called the “EPICENTER”.



Epicentre
Plate movement
Focus
Seismic waves


EPICENTER
SEISMIC
WAVES
FOCUS
FAULT


Fault scarp
Fault trace
Epicenter
Seismic waves
Focus
Fault plane

1) As we learned in PLATE TECTONICS, our Earth is unstable dynamic planet,
2) so most EQs occur as a result of this PLATE TECTONICS.
3) Every year about 30,000 EQs happen but rare are perceptible & considered.
4) Atomic explosions, volcanic eruptions, heavy traffic do cause vibrations [EQs] but all these are considered weak. *[triggers for mass wasting]*
5) Every place on Earth have/had experienced EQ.

Earthquakes Recorded Over the Last 7 Days

Displaying 1000 earthquakes

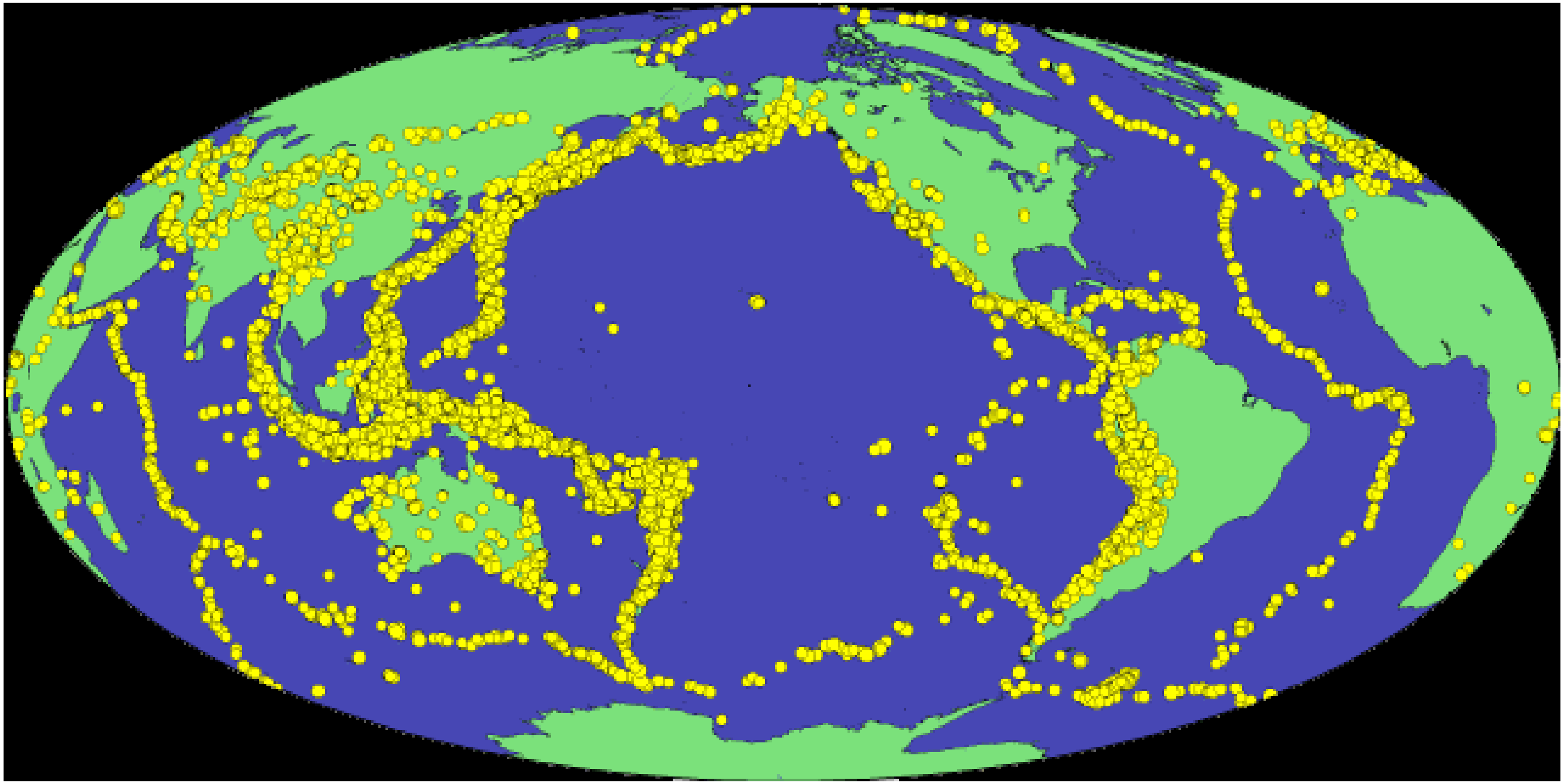
Where to expect EQs?

95% of the Energy released in the World is concentrated in few relatively narrow zones like:

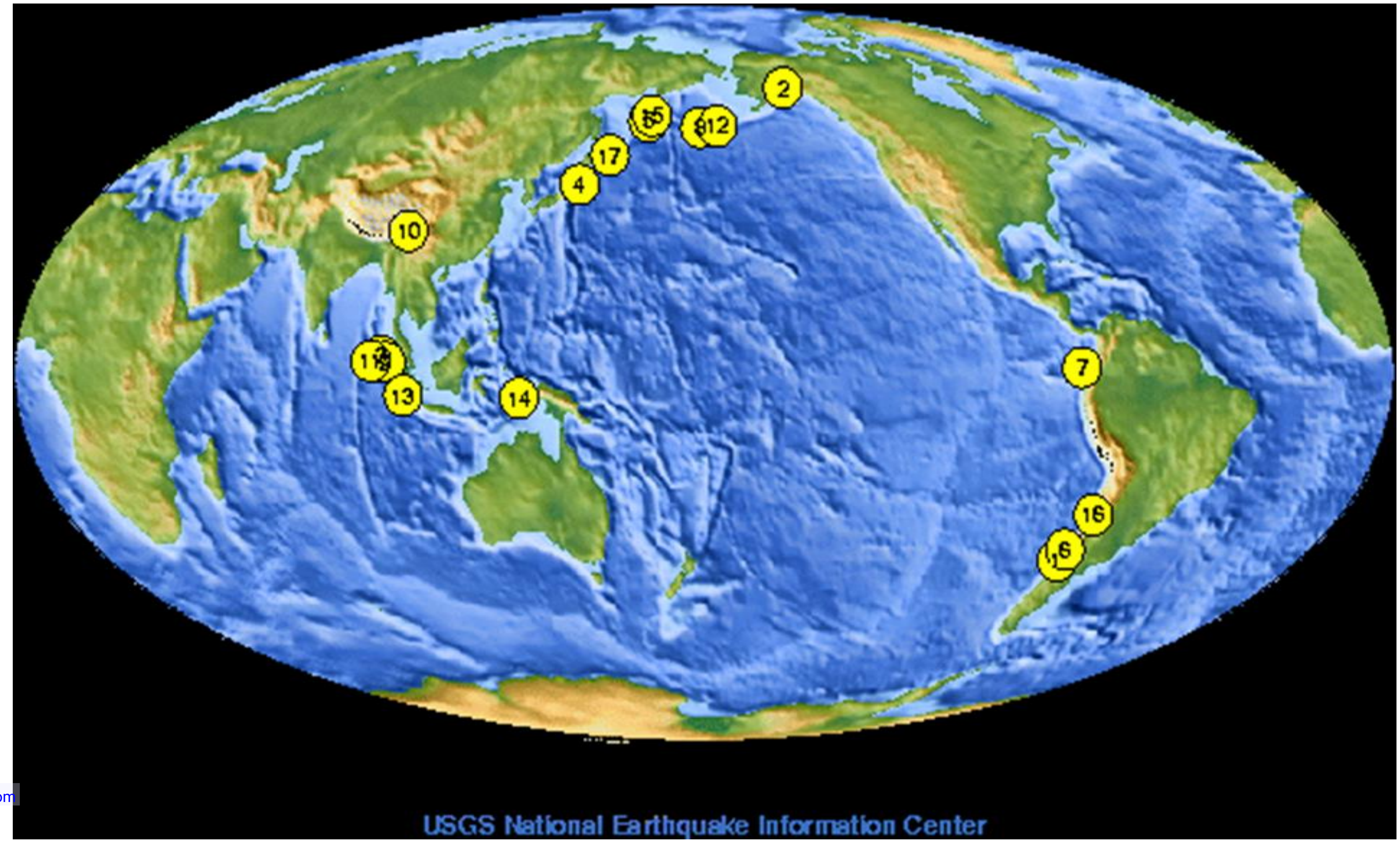
1) Circum-Pacific Fire Belt.

2) Mountain Range from Iran to Himalaya.

3) Along the Mid-Oceanic Ridges; around the Rifts.



Major EQs in the latest 5 years



6) Most of the motion of plates is along faults' surfaces.
7) These mobile plates interact with the neighboring plates straining and deforming the rocks until the frictional resistance exceeds the cohesion force that holds the rocks together, then the plates slide against each other releasing the stored Energy that causes the EQ

Earthquake Waves:

1) The science that studies EQs, their different wave types, recordings, impacts, mitigation measures, prediction … etc is called "Seismology".

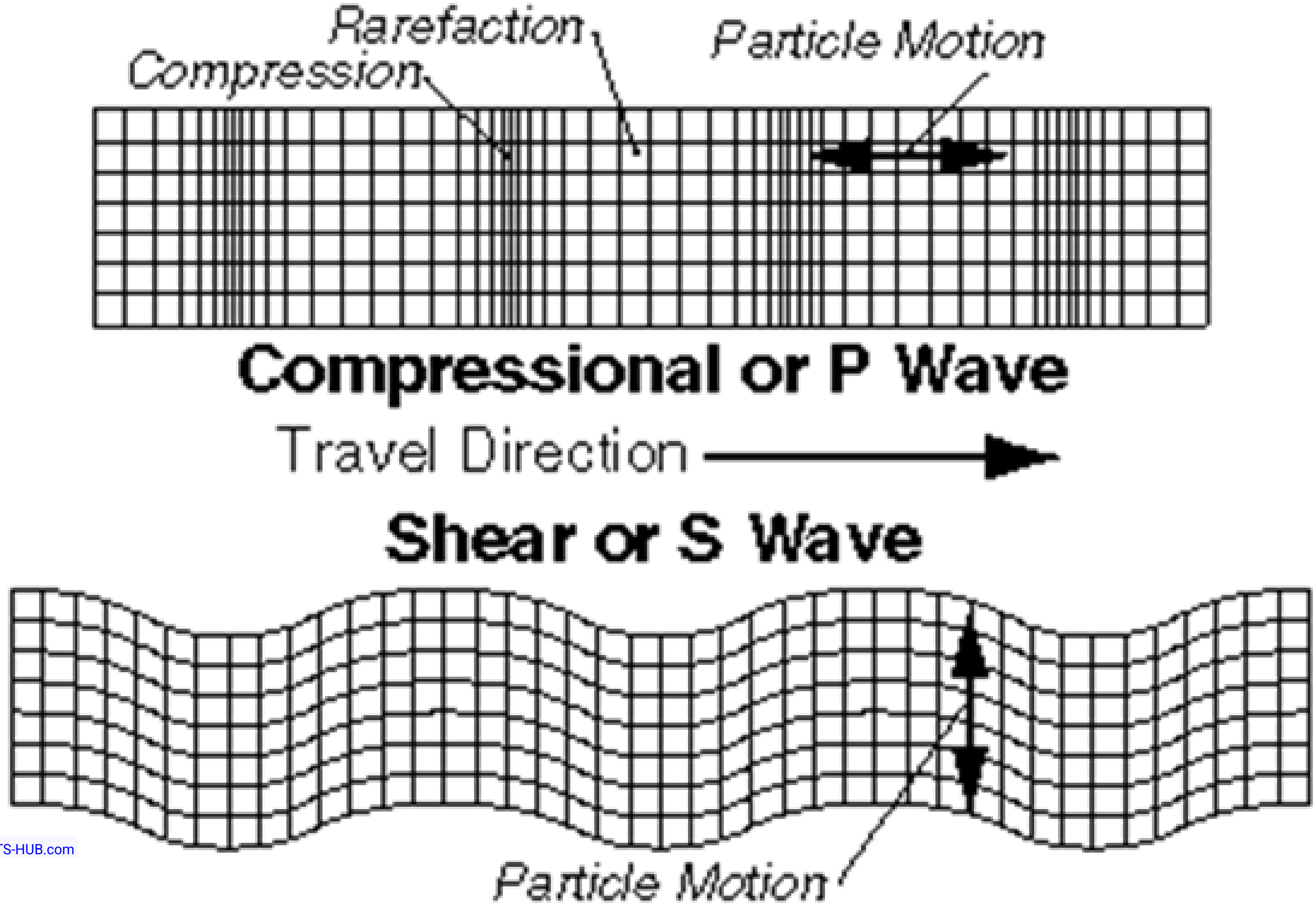
2) The instrument that detects and records these waves is called "Seismograph".

3) The sheet on which these records are kept is called "seismogram".

4) There are many types of seismic waves that originate from the focus of an EQ and propagate in all directions, what interests us here are only 2 types: The primary (P)- waves & the secondary (S)- waves.

- P-Waves: Compress the rocks' material/s in their direction of travelling causing change in the volume of the matter they pass thru.
- S-Waves: Shake the rock particles at right angle to their travel direction causing change of the rocks' shape.
- Liquid and gas <u>don't</u> transmit S-waves.

In any solid material, P-Waves velocity is about 1.7 times the velocity of the S-Waves ***(in granite the P waves velocity = 6km/sec., for S waves it is 3.5km/sec),*** **so P-Waves arrive to the seismograph earlier than the S-waves. So any seismograph can tell us how far an EQs' epicenter is.**

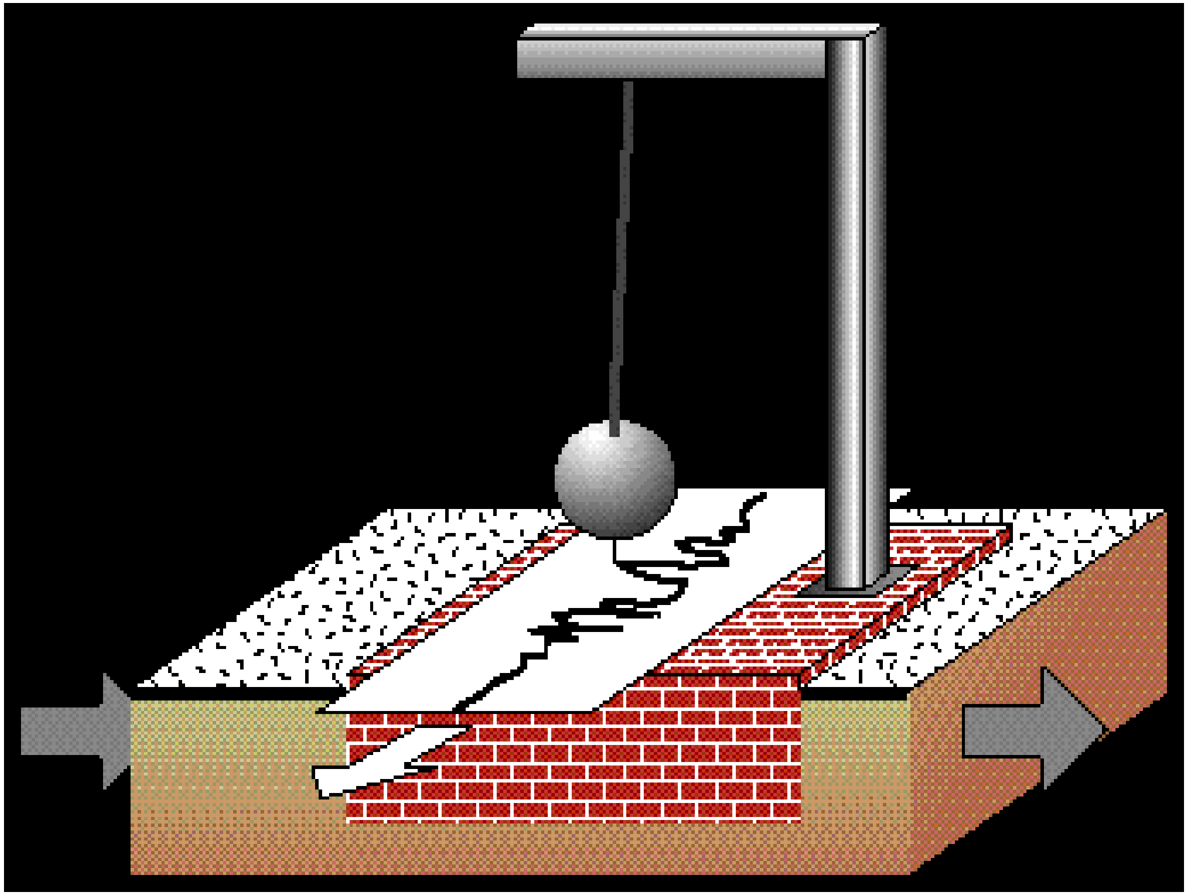

Rarefaction
Compression
Particle Motion
Compressional or P Wave
Travel Direction
Shear or S Wave
Particle Motion

Detection of an Earthquake

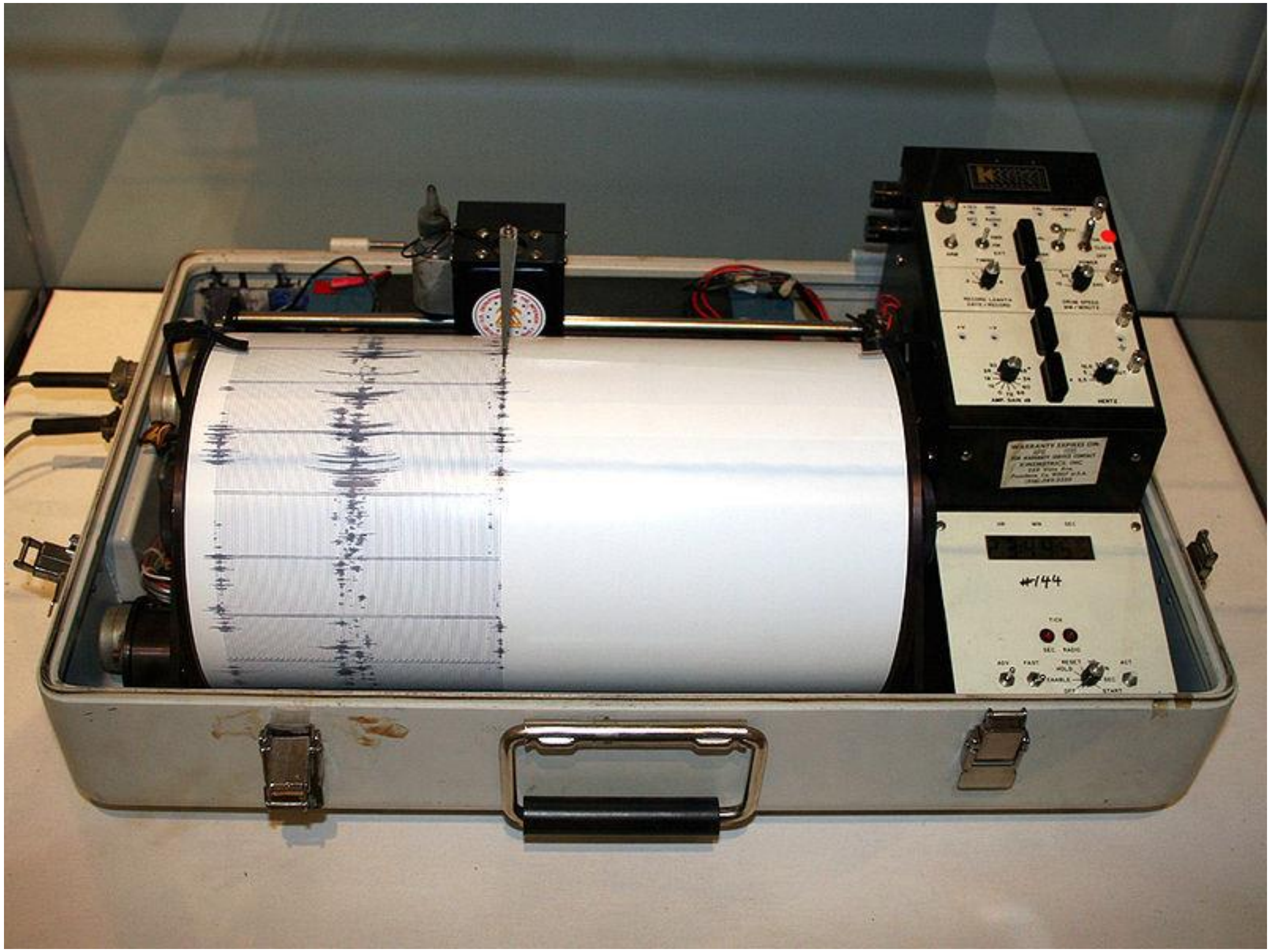
- **EQ can be detected by an instrument called "SEISMOGRAPH" that records the seismic waves on a paper called "SEISMOGRAM". All these are found in a place called "SEISMIC RECORDING STATION". In history, there were some seismograph models and nowadays there are many modern sophisticated models.**

Old Chinese Seismograph

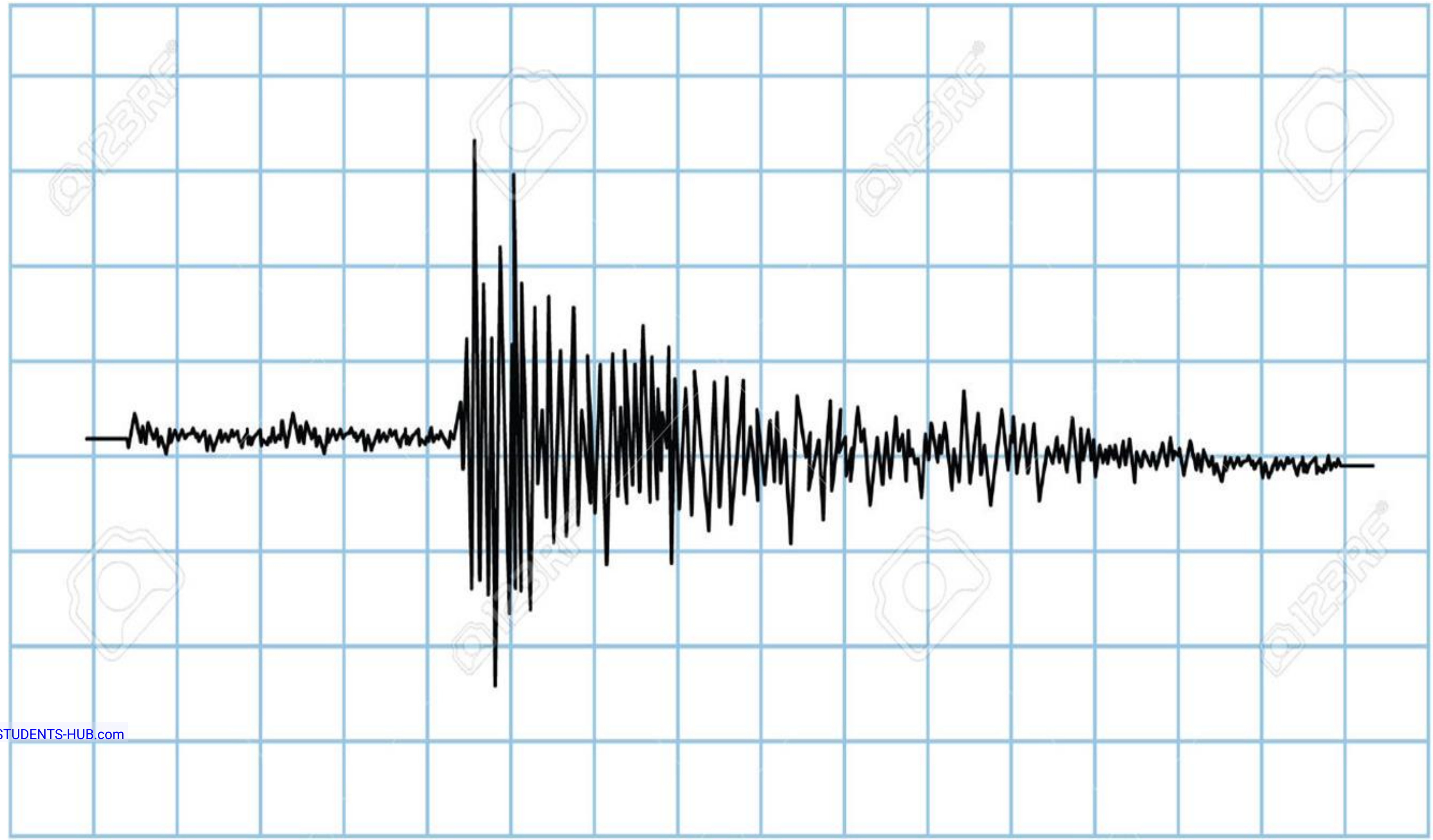
Seismographs



Modern Seismograph

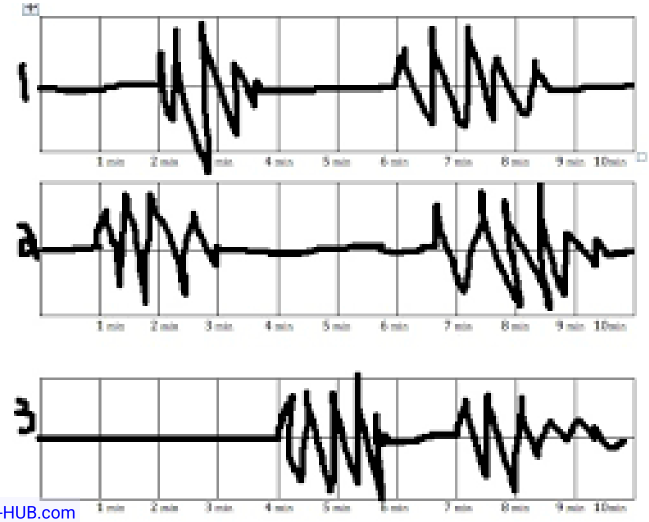


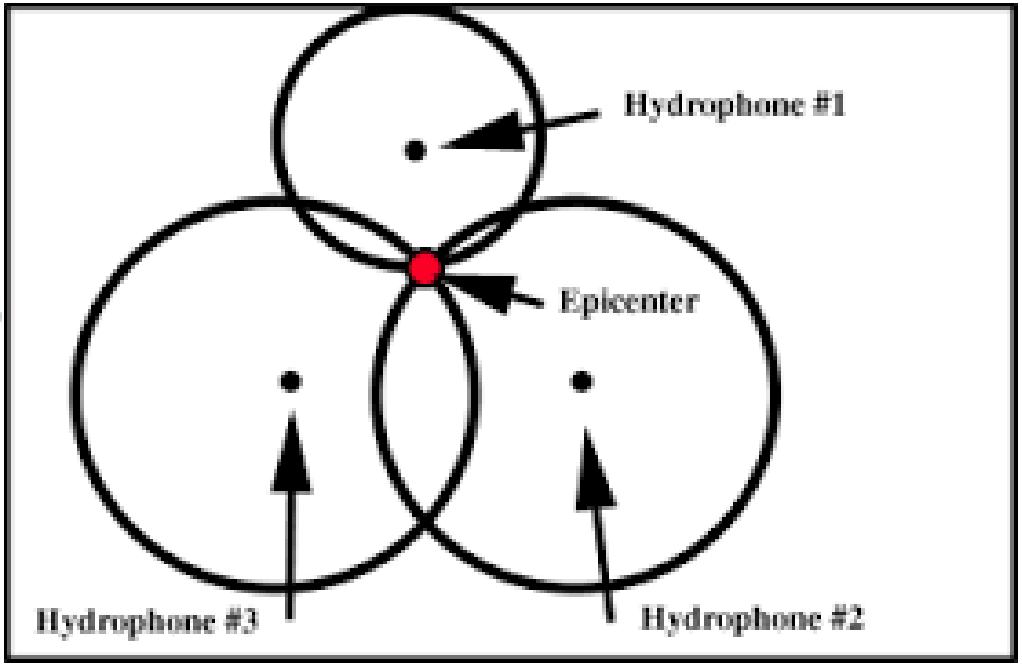
Seismogram:↓



How to know the exact location of the Epicenter of a certain EQ?

- **At least 3 seismogram readings from 3 seismic stations should be known**






0 200 400 600 800 1000 1200 1400 mi
0 200 400 600 800 1000 1200 1400 1600 1800 2000 km
Seattle
1,800 km
Chicago
San Francisco
Denver
New York
1,300 km
800 km
Houston
Miami

EQ intensity & magnitude?

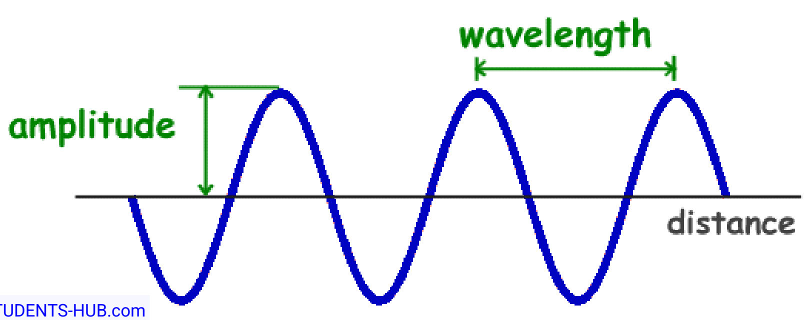
- The effect of an EQ on the Earths' surface is called the intensity.
- Based on the amount of damage caused to the various types of structures on Earths' surface, Mercalli put his scale in 1902 [The MERCALLI SCALE].

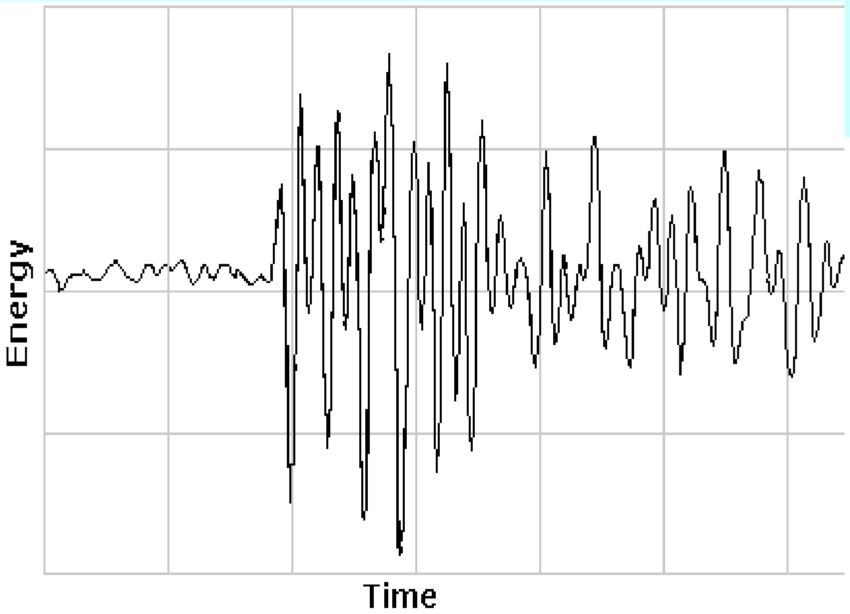
Modified Mercalli Scale

I.	Not felt.
II.	Felt by persons at rest, on upper floors, or favorably placed.
III.	Felt indoors. Vibration like passing of light trucks.
IV.	Vibration like passing of heavy trucks.
V.	Felt outdoors. Small unstable objects displaced or upset.
VI.	Felt by all. Furniture moved. Weak plaster/masonry cracks.
VII.	Difficult to stand. Damage to masonry and chimneys.
VIII.	Partial collapse of masonry. Frame houses moved.
IX.	Masonry seriously damaged or destroyed.
X.	Many buildings and bridges destroyed.
XI.	Rails bent greatly. Pipelines severely damaged.
XII.	Damage nearly total.

The modern scale is **RICHTER SCALE**:

1- It is used to describe earthquake magnitude which is determined by measuring the amplitude of the largest wave recorded on the seismograph.

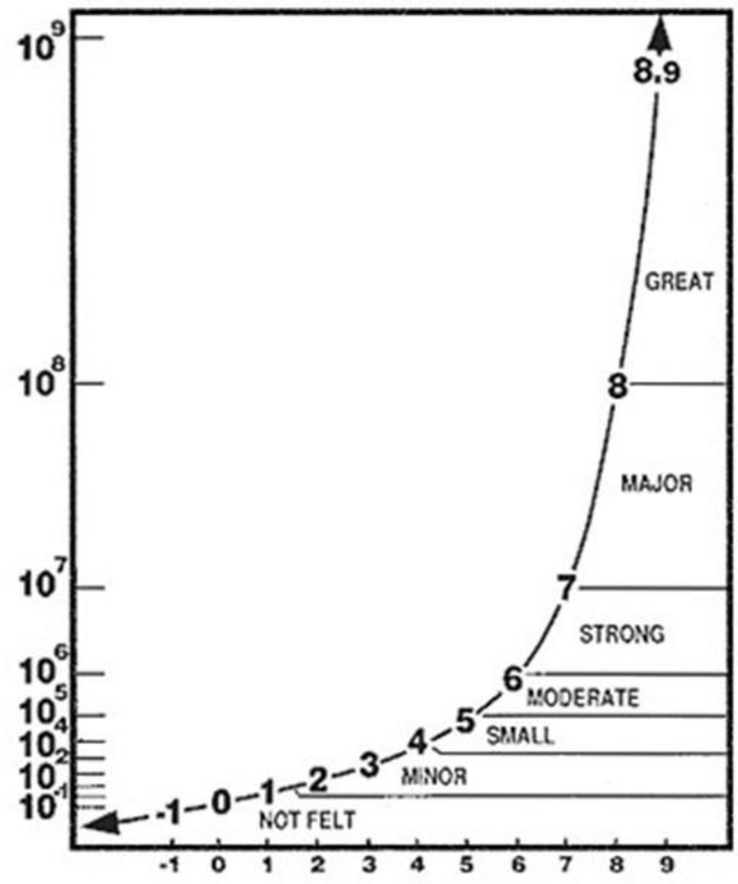




2- Magnitude is expressed in terms of logarithm scale; this means each unit increases on Richter scale means the Energy released equals 30 times the one before; e.g. Energy released by EQ of 6 degrees on Richter scale = 30 times the Energy released by an EQ of 5 degrees.

RICHTER SCALE

Magnitude	Intensity of the tremors(shakes)
Less than 2.0	Micro
2.0–2.9	Minor
3.0–3.9	
4.0–4.9	Light
5.0–5.9	Moderate
6.0–6.9	Strong
7.0–7.9	Major
8.0–8.9	Great
9.0 and greater	



Factors That Contribute to the Destructiveness of an Earthquake

1) Location: Populated or not.

2) Depth: The deeper the weaker.

3) Magnitude or intensity: Proportional

4) Duration of the EQ & its Before and After shocks: Most EQ tremors last in 1 minute.

5) Distance from the epicenter: The most affected areas are those within the 20- 50kms around the epicenter.

6) Local geological conditions: Clay ground acts as amplifier.

7) Construction Design: Height to base area ratio.

8) Materials of the construction: Effect of AMPLIFICATION.

9) Infrastructures: EC, gas, water, sewer, …

Relationship between amplification and the Soil & Rock Types:

The soil and rock types are classified into 6 categories in order to determine their amplification effects:

Type A, hard rock (igneous rock).

Type B, rock (volcanic rock).

Type C, very dense soil and soft rock (sandstone).

Type D, stiff soil (mud).

Type E, soft soil (artificial fill).

Type F, soils requiring site-specific evaluations.

Type A has the less amplification, while Type E has more amplification.

Other DANGERS CAUSED BY EQs:

Fire due to EQ: Due to vibrations gas pipe lines may break and cause fire. Sometimes fire risk is greater than the whole other damages.

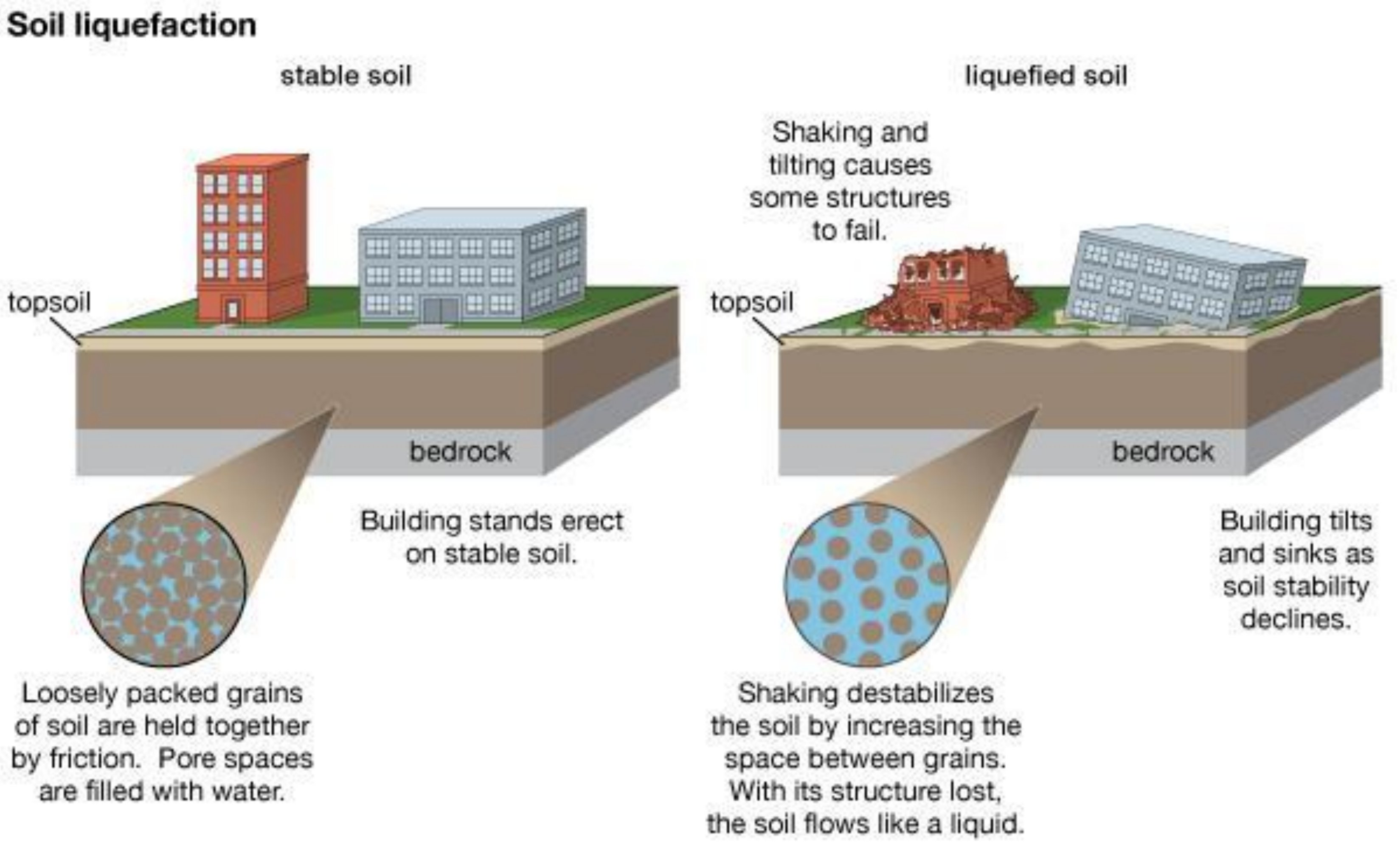
Fire due to earthquake. Photo by M. Rymer, USGS

Dams' Collapse due to EQs


circle of blue

Important

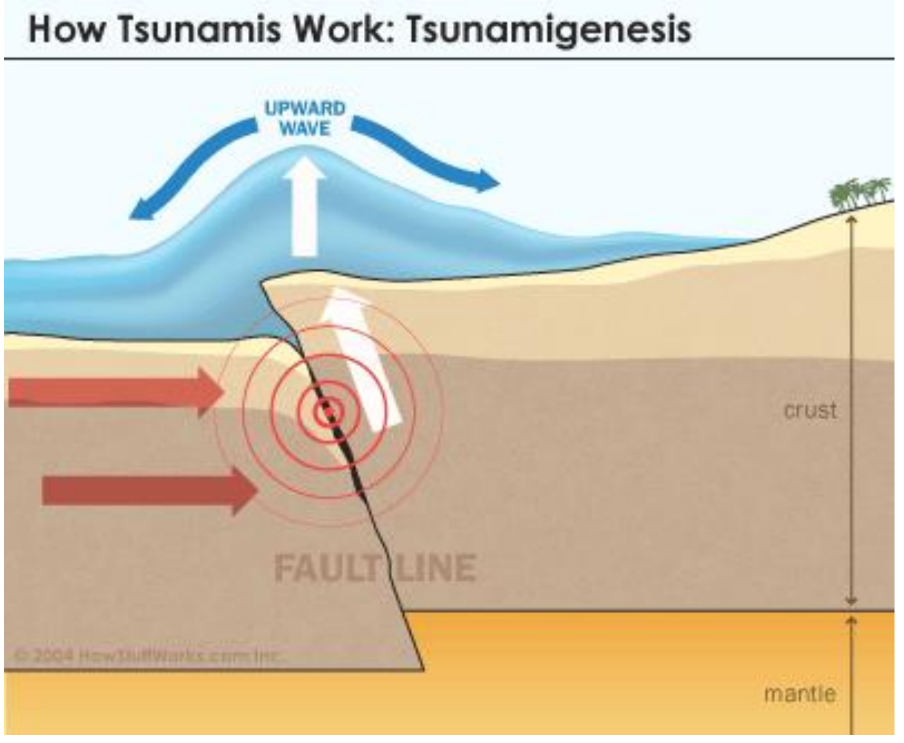
In areas where unconsolidated materials are saturated with water, EQ can generate a phenomenon called LIQUIFACTION, in which the soil turns into fluid that is not capable of supporting buildings or other structures so they collapse.


Soil liquefaction
stable soil
liquefied soil
topsoil
bedrock
Building stands erect on stable soil.
Loosely packed grains of soil are held together by friction. Pore spaces are filled with water.
Shaking and tilting causes some structures to fail.
topsoil
bedrock
Building tilts and sinks as soil stability declines.
Shaking destabilizes the soil by increasing the space between grains. With its structure lost, the soil flows like a liquid.

TSUNAMI

What is a Tsunami?

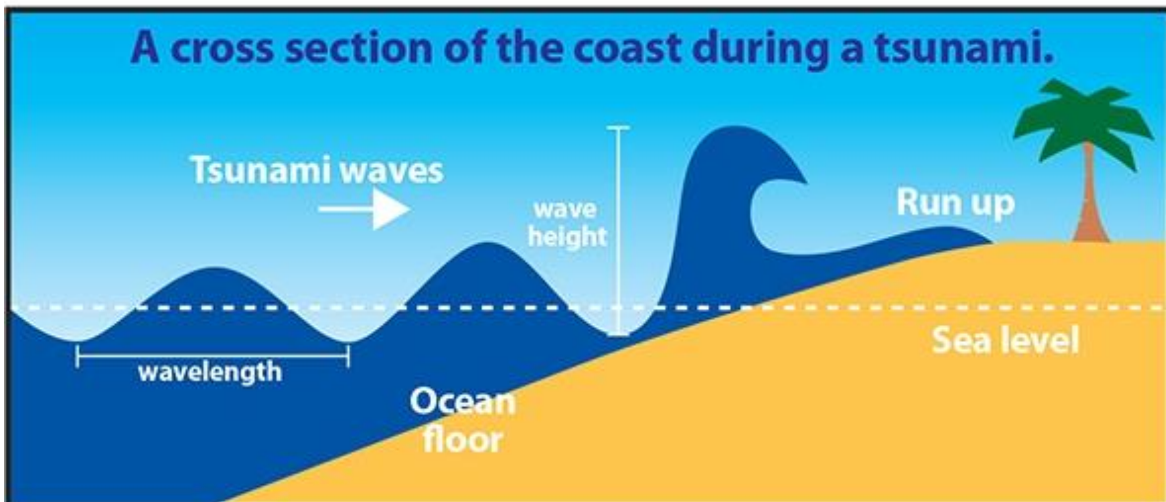
It is a “seismic sea waves” results due to vertical displacement of the ocean floor during an EQ.



Speed of waves = 500-950kms/hr.

Height far in the sea <1m, coming nearer to coast reach = 30m

When the crest of these waves approaches shore, it appears like a rapid rise in sea level with turbulence and chaotic surface.



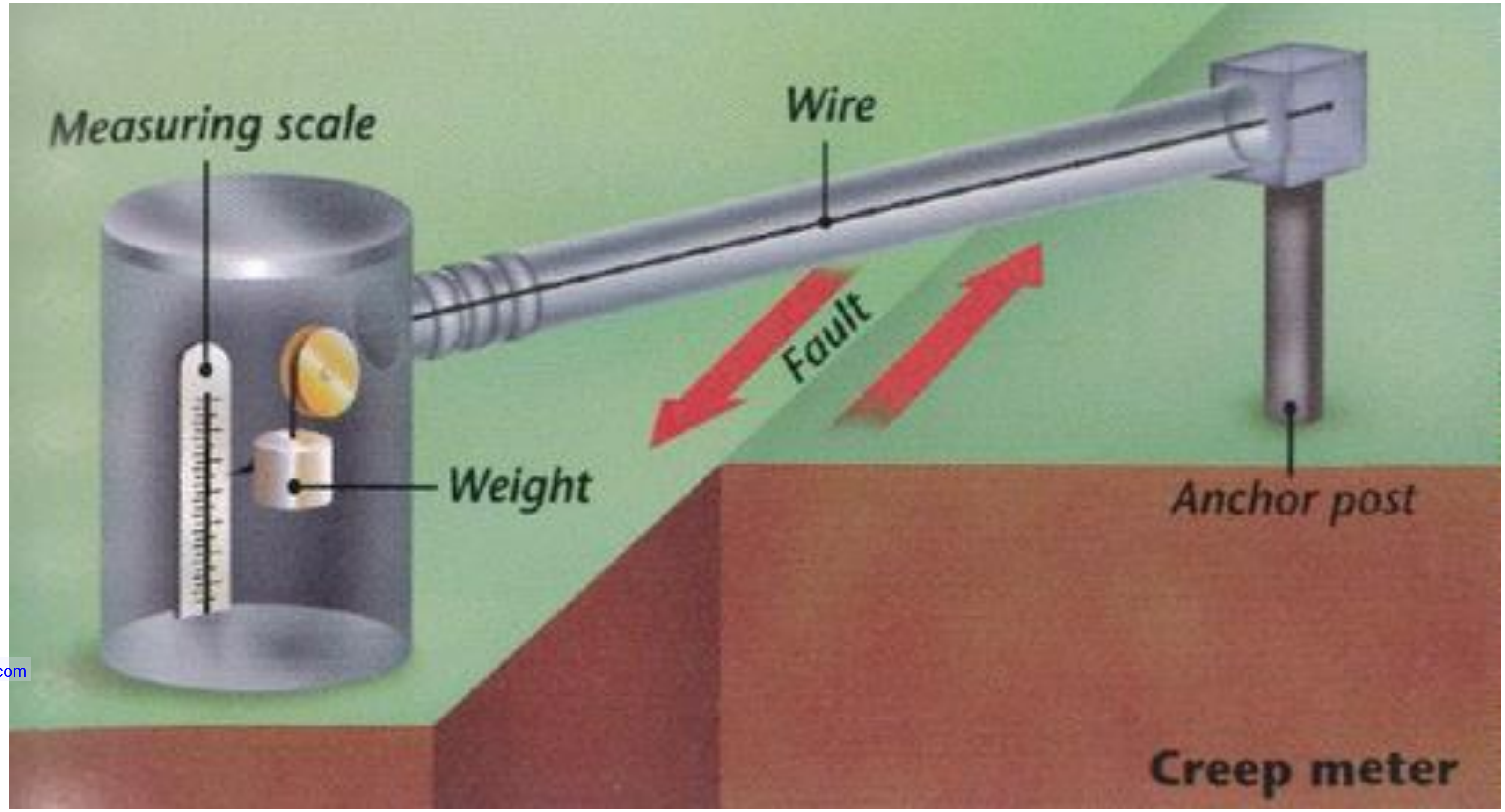

© EPA

Trigging landslides, mudflows, land subsidence or uplifting ....

Faulting: Displacement of Earth masses apart along the fault plane: Tensile form.

Faulting

Instruments like creepmeters, tiltmeters and borehole strainmeters are used to measure the accumulation and releasing of strain.



Wed. 11th Jan. 2017: New Zealand 's 7.8 magnitude earthquake lifted the seabed 2metres.

EQs & The Earth Interior:

Most of our knowledge about the Earths’ interior comes from the study of P & S waves that travel thru the Earth since the time required for P & S waves to travel thru the Earth depends on the properties of the rock materials encountered.

ACCORDINGLY, EARTH IS DIVIDED INTO 4 MAJOR LAYERS *(from surface downwards):*

1) The crust: Very thin outer layer.

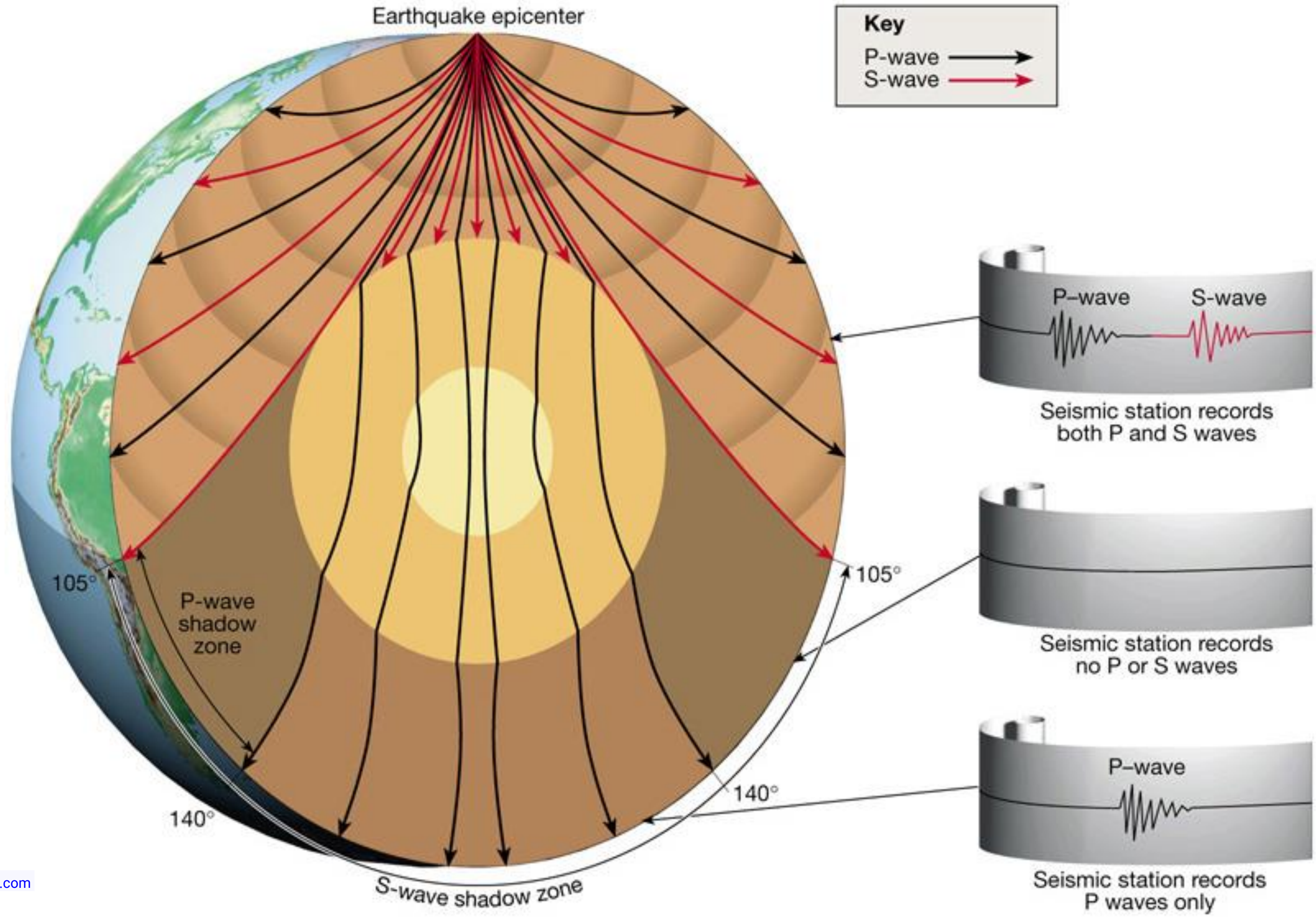
2) Mantle: Rocky layer of 2885 km thick. *[only the uppermost 700kms Asthenosphere is highly viscous and composed of basaltic composition).*

3) Outer Core: Liquid like of 2270 km thick.

4) Inner Core: Solid metallic of 1216 km thick.

In 1909 a Yugoslavian geologist Andrija Mohorovicic studied the seismic records and discovered that the velocity of the seismic waves increases abruptly below a depth of 50 km. This boundary separates the crust from the underlying mantle is later on named MOHO DISCONTIUITY.

Years later, another major boundary was discovered, based on the observation that P waves die out at about 105° from an EQ then reappears again at 140° . This belt where direct seismic waves are absent is about 35° wide and is known as SHADOW ZONE.

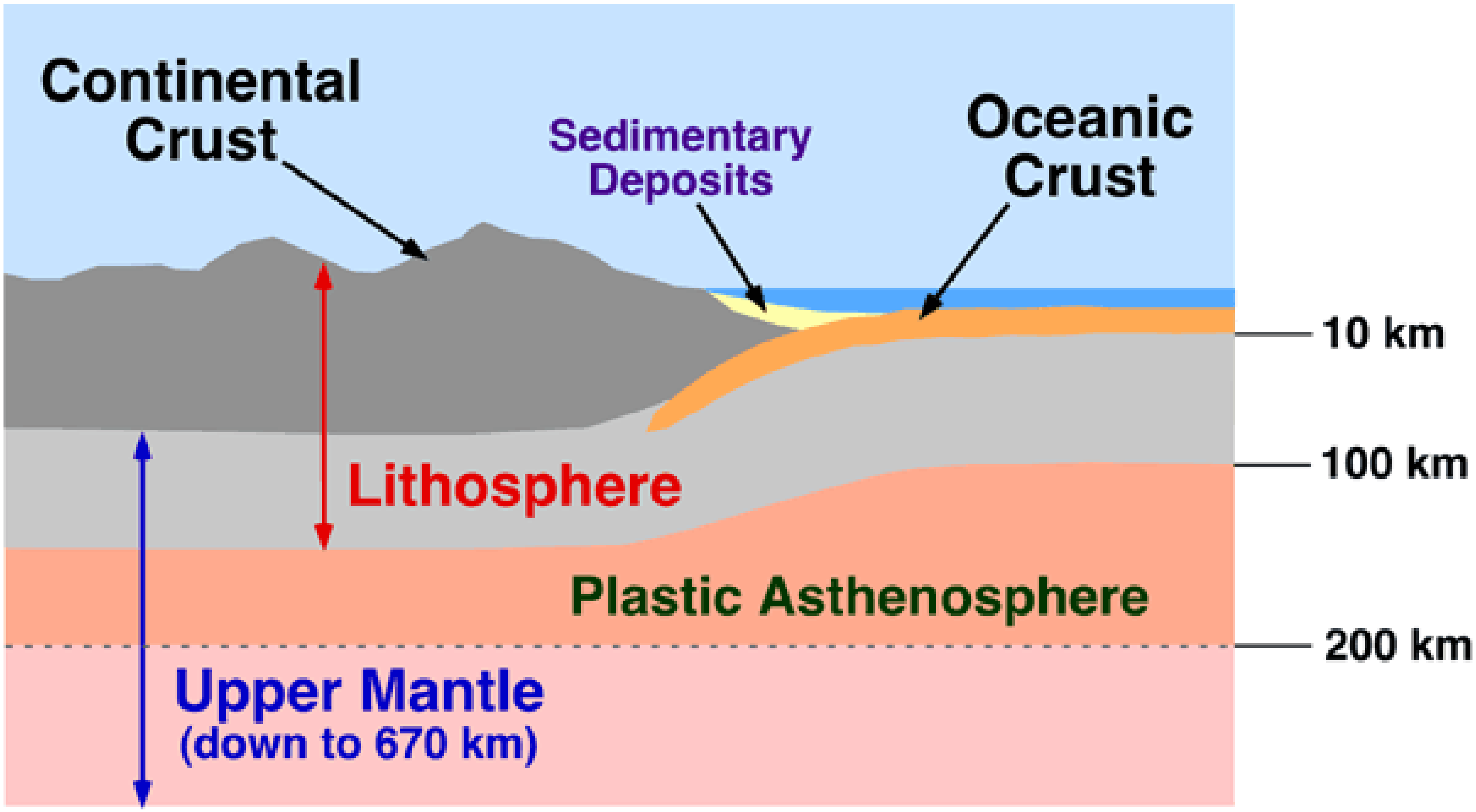


Earthquake epicenter
Key
P-wave
S-wave
P–wave
S-wave
Seismic station records both P and S waves
Seismic station records no P or S waves
P–wave
Seismic station records P waves only
105°
105°
P-wave shadow zone
140°
140°
S-wave shadow zone

This shadow zone can be explained as: As p waves bend reaching the core, then this means the core should be composed of material different from that of the mantle. And as the S waves could not propagate thru the core; this means at least the upper part of the core is liquid.

This conclusion was supported by the observation that the P waves velocity decreases by 40% as they enter the core ***[as melting reduces the elasticity of the rocks leading to the draining of the P waves propagation]*** **and again it increases when it enters the inner core** **[solid].**

Asthenosphere, which is located at depths between 100-700km, the velocity of the S waves decrease a lot; this indicates that this layer consists of hot weak rock (dough like character).


Continental Crust
Sedimentary Deposits
Oceanic Crust
10 km
Lithosphere
100 km
Plastic Asthenosphere
200 km
Upper Mantle
(down to 670 km)


معلومة مع هل تعلم :
هل تعلم ؟
في عام 1975 قامت آلاف الكلاب البرية بمهاجمة
مدينة هايتنشغ الصينية وبدأت تنبح بشكل هيستيري
مما جعل السلطات تخليِ المدينة من سكانها البالغة 90 ألف
نسمة من أجل سلامتهم، وبعد ساعات من الحادثة وقع زلزال
هائل دمر المدينة بأكملها ليكتشف السكان حينها أن الكلاب
كانت تريد حمايتهم فقط.
معا نرتقي و نتقدم...
www.facebook.com/HalTalm

PEAK GROUND ACCELERATION (PGA)

During an earthquake when the ground is shaking, it also experiences acceleration. The **peak acceleration** is the largest increase in velocity recorded by a particular station during an earthquake.

In areas of soft soil the PGA is greater than in areas with rigid rocks.

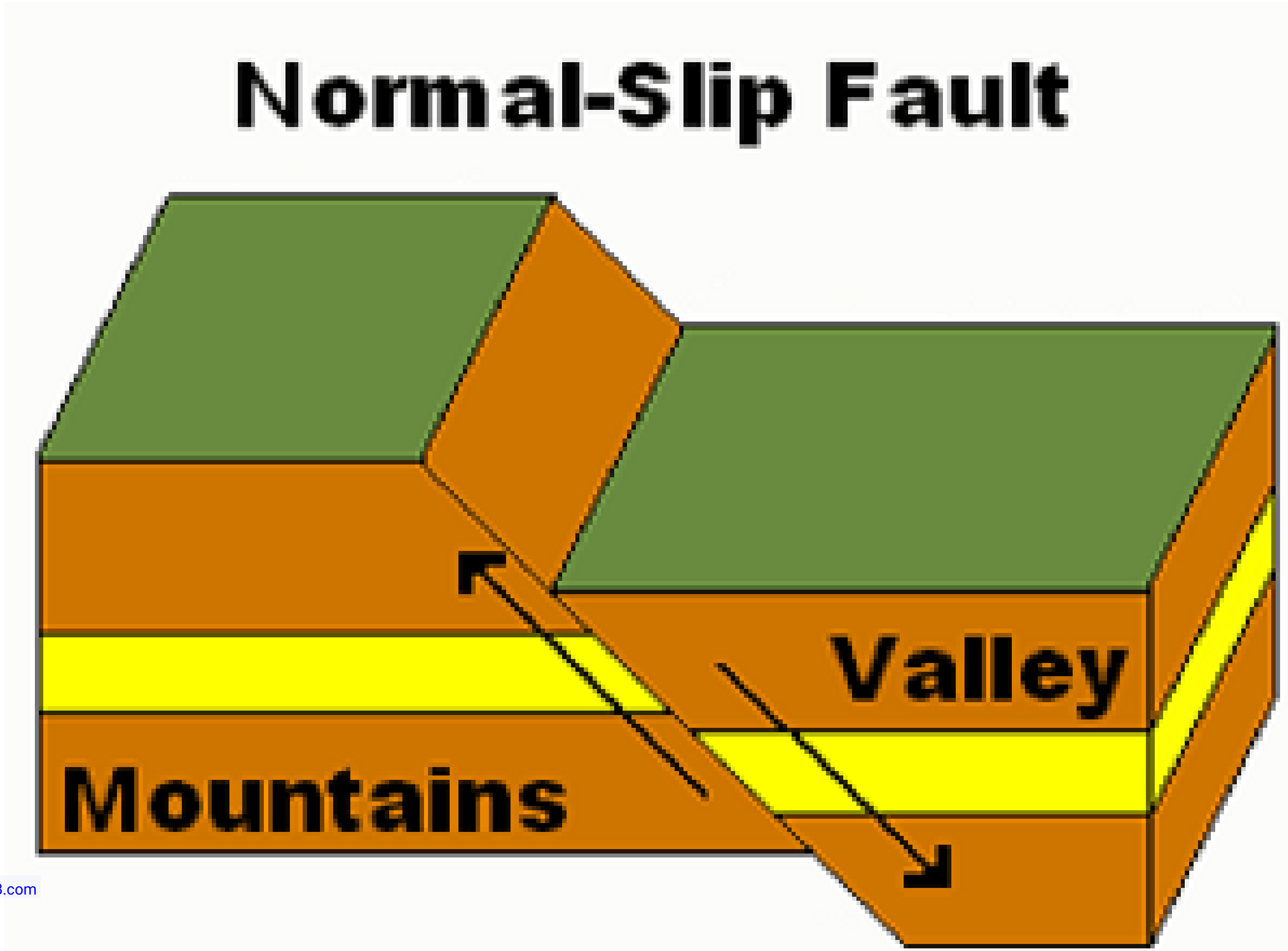
Constructional codes: PGA scale starts from 0.1g up [0.1g means very rigid rocks]. The more the PGA for a soil the more the risk for the constructions built on. This means the civil engineer should count for more reinforcing his structure *[this means more cost].* In Japan civil engineers count for +10% load for 0.1g increment in the PGA.

In Palestine the Engineers' Union coded the Palestinian areas according to their PGA values as follows:

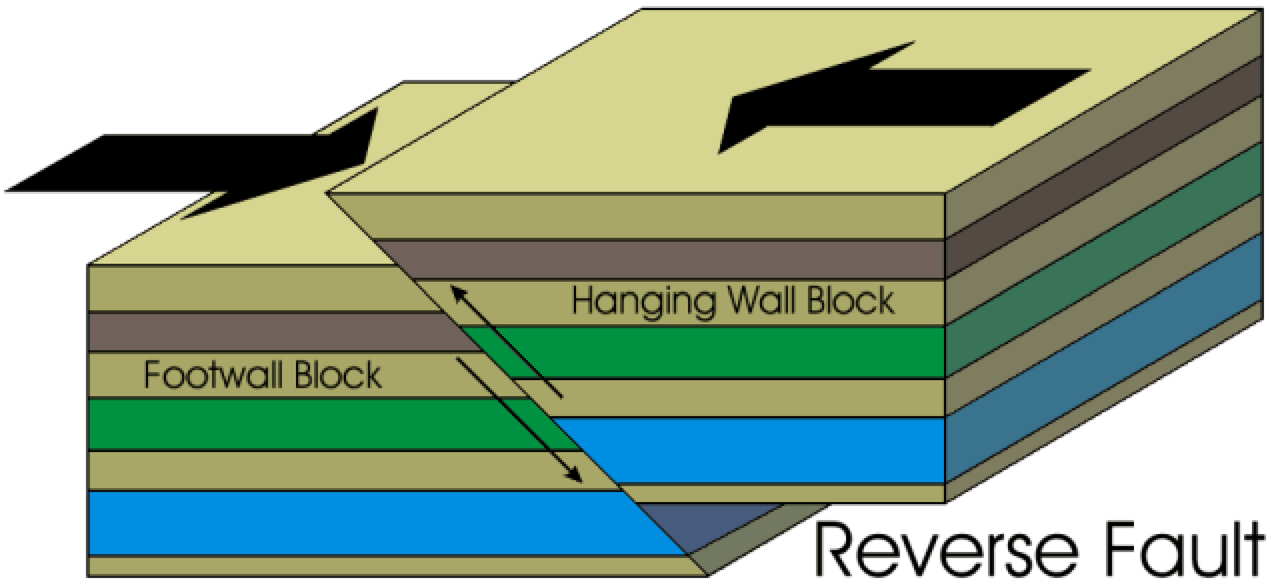
1- Jericho [including Ghor areas]: 0.3g.

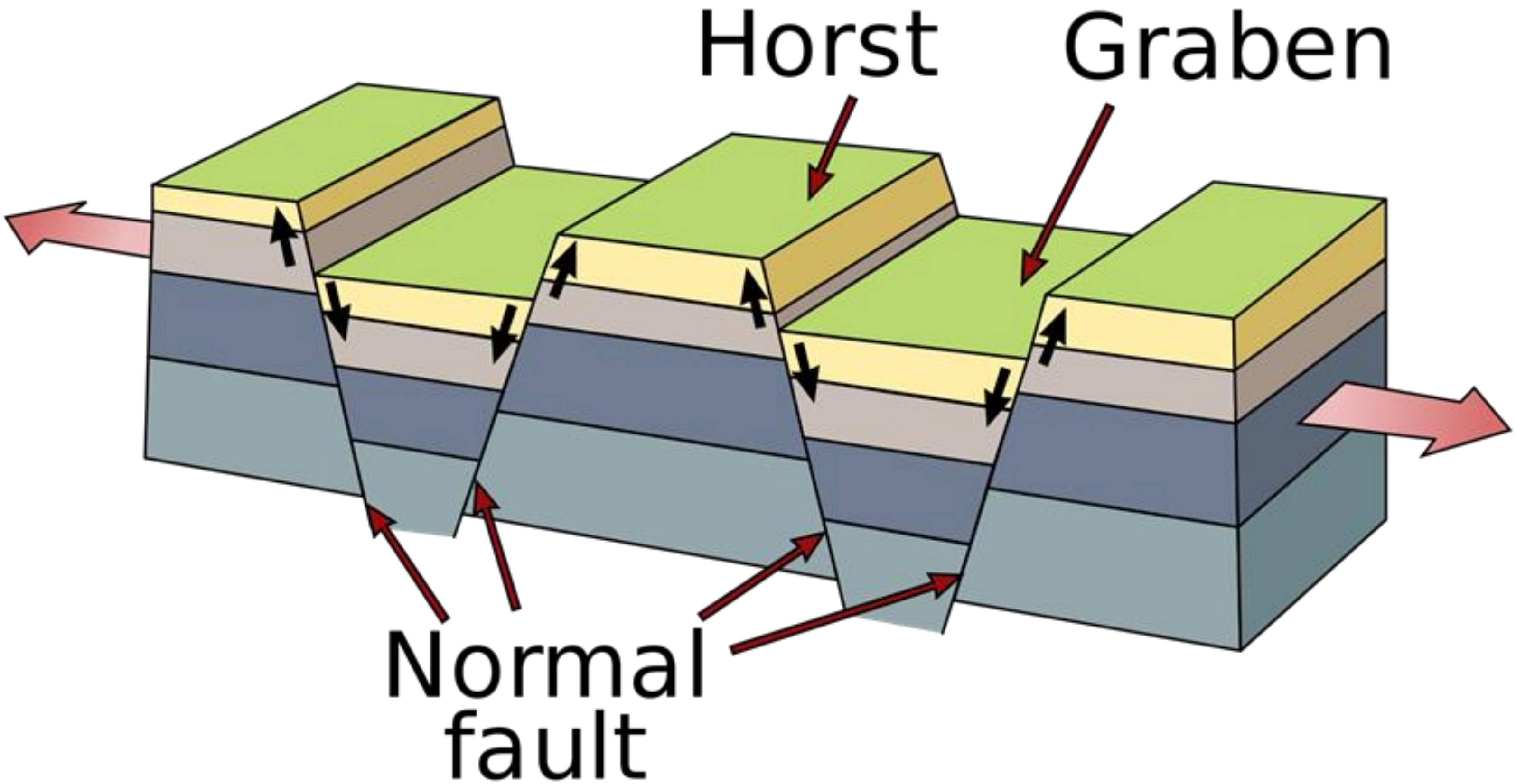
2- Mountainous areas [middle land]: 0.15g

3- Southern areas: 0.2g


Normal-Slip Fault
Valley
Mountains

Reverse Fault




Horst
Graben
Normal
fault

Transverse Fault