

GEOLOGY FOR CIVIL ENGINEERING

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Today: Course Overview

- ✘ A few ground rules...
- ✘ Stuff about me.
- ✘ Why are we here?
- ✘ Course exams & grading.
- ✘ Prelude: What is Geology?

- **Read the textbook**

Ketin İ., Genel Jeoloji Yerbilimlerine Giriş, İTÜ Vakfı Yayınları, 2016.

Önalp A., Sert S., Geoteknik Bilgisi, Birsen Yayınevi, 2016.

Tarbuck, EJ and Lutgens, FK, Earth Science, Prentice Hall, 2011.

Cazeau C.J. and Hatchar R.D., Physical Geology: Principles, processes, and problems, New York: Harper & Row, 1976.

Alan E. Kehew, Geology for Engineers and Environmental Scientists, Prentice Hall, 3rd ed., 2006

- **Attend lectures**

- Hear topical overviews & ask questions
- Do in-class assignments & turn in & pick up HW
- Exams, quizzes & extra credit opportunities

- **In-class exercises and homework assignments (depend on your status!!!)**

- Exercises weekly & homework every other week

Required by all students:

While in lecture, please DO NOT:

- Forget to turn off cell phones
- read different documents instead of course notes
- Talk and have conversations
- Sleep uncontrollably, endangering yourself and others

Required by all students:

While in the lecture, please DO:

- Ask questions when anything is not clear
- Engage in the discussions
- Fully participate in in-class exercises
- Geology is great! Have fun with it!

WHY YOU ARE HERE

- ◆ Since you will be Civil Engineer, you should learn basics of geology
- ◆ You need a science credit to graduate
- ◆ Just curious, it seemed like it might be cool
- ◆ You have absolutely no idea

ABOUT ME

- ◆ Graduate from Department of Geological Engineering (2003)
- ◆ Research assistant (2006-2011)
- ◆ Geological Engineer (2011-2012) DSI
- ◆ Geological Engineer (2012-...)The Ministry of Forestry and Water Affairs
- ◆ Phd and section manager of Modelling department
- ◆ Research Areas
 - ◆ Geology
 - ◆ Petroleum reservoir geology
 - ◆ GIS and remote sensing
 - ◆ Hydrology
 - ◆ Groundwater
 - ◆ Water resources modelling

EXAMS & GRADING

Geology Exams:

1. There will be two Exams.

- In class, 1-hour, 100 points each
- One midterm, one final

2. Review outline

- Will be handed out before exams
- Will provide a list of topics that will be covered

3. Final Exam

- Covers last section of course, but all exams may call on basic concepts presented earlier.

EXAMS & GRADING

MAKE-UP EXAMS

- There are none! Exceptions include a health problem.

TERM PAPER OPTION

- It is optional, not decided yet

GOALS

Basic principles of **geology**, **geochemistry**, and **geophysics**. Rocks, minerals, weathering, earthquakes, mountain building, volcanoes, water, and glaciers.

GOALS

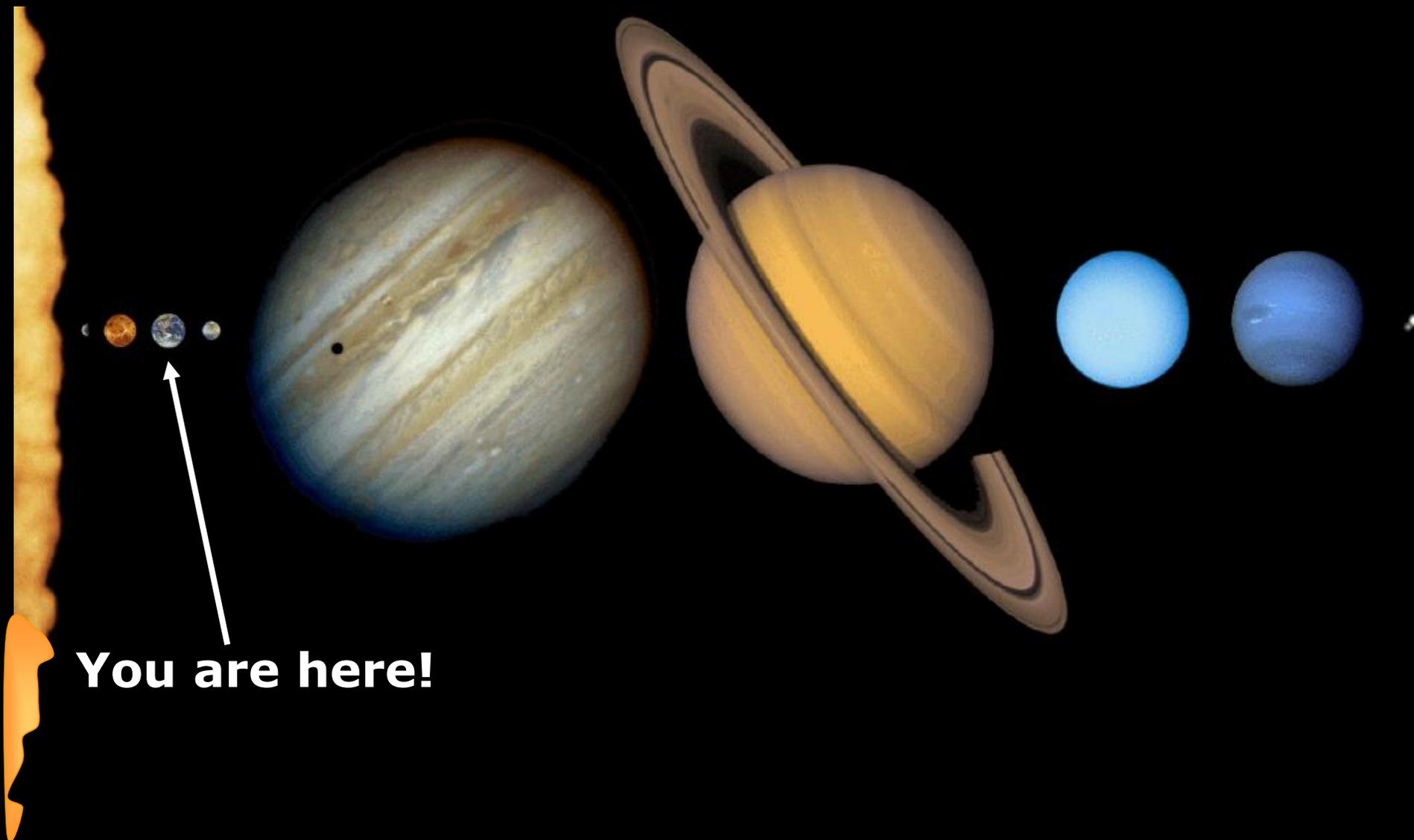
- **But also, we have these goals:**

- ◆ To develop critical thinking skills & a basic understanding of how the science works
- ◆ Become familiar with some of the observational methods, reasoning processes and analytical tools used by geologists to understand the Earth and its history
- ◆ Learn the basic scientific concepts and principles of Earth sciences.

GOALS

❖ Geology is a broad, interdisciplinary science with a rich vocabulary. The terminology we will use throughout this course will require that you learn a new language.

Geology: The study of the Earth and its systems



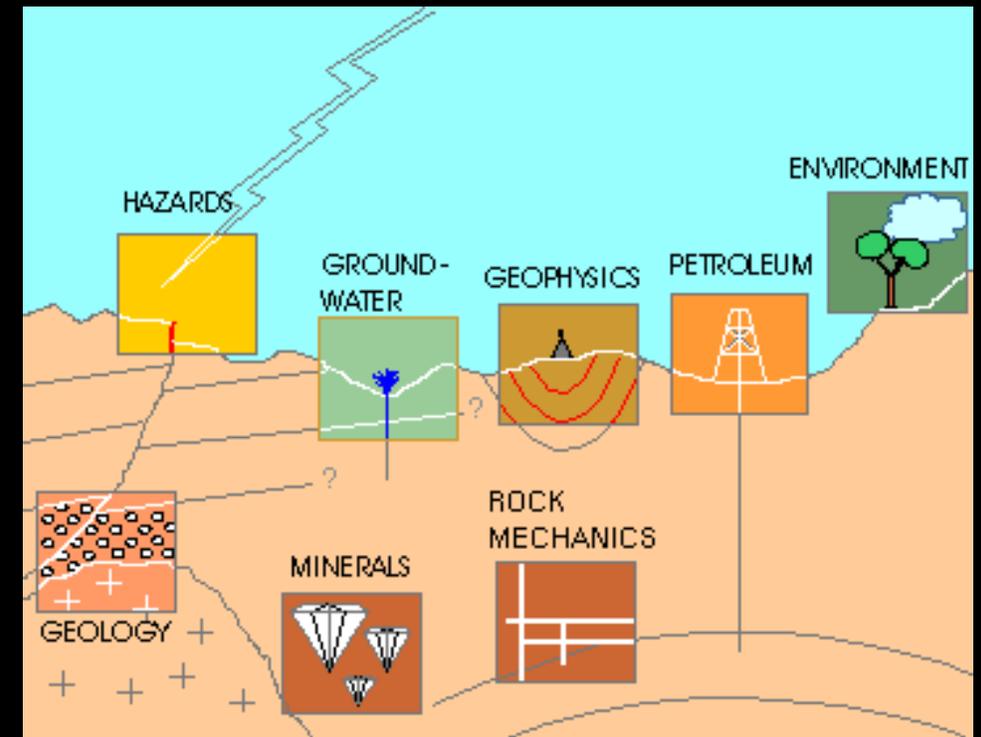
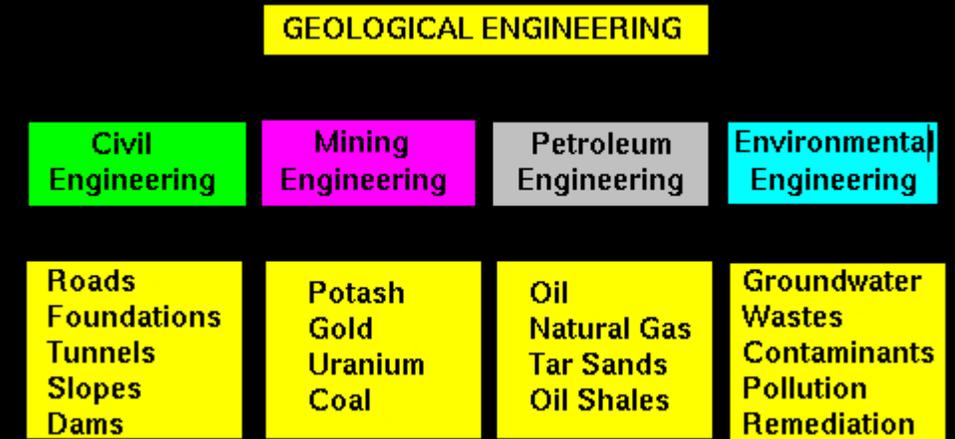
A Prelude:

- Geology; Physics, chemistry, mathematics, zoology, botany, construction, mining and other engineering.
- Geology «The history of the earth, its combination of rock, soil and water, and the science of studying evolution»
- Geological Engineering: Provides the use of geological data for practical engineering purposes.

And just what is Geology?

The relationship between Geological Engineering and other engineering sciences

- **Civil Engineering (safe and economical construction of buildings)**
- **Mining Engineering (safety and economical factors in mining deposition operating and development)**
- **Petroleum Engineering (Economic design for extracting petroleum and obtaining petroleum products)**
- **Geophysical Engineering (earth physical properties and its engineering applications)**
- **Architecture (project designing)**
- **City and Regional Planners**



Geology Branches

➤ General geology

- Structural geology
- Sedimentology-Sedimentary petrography
- Stratigraphy

➤ Mineralogy-Petrography

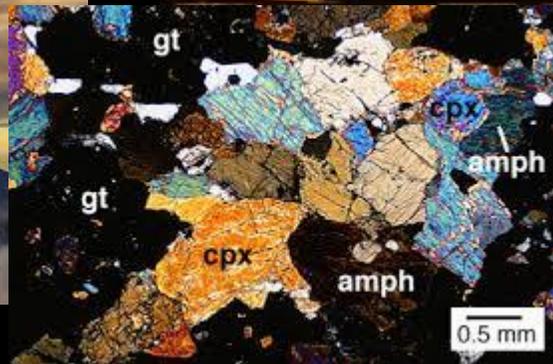
- Mineralogy
- Petrography

➤ Ore deposits-Geochemistry

- Mineral deposits
- Geochemistry
- Petroleum Geology

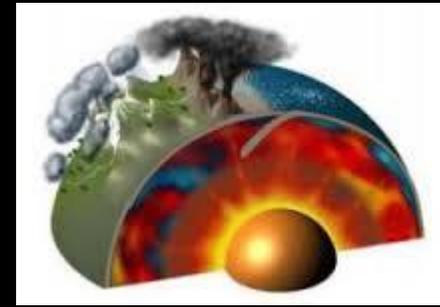
➤ Applied Geology

- Engineering Geology
- Hidrogeology
- Mathematical Geology

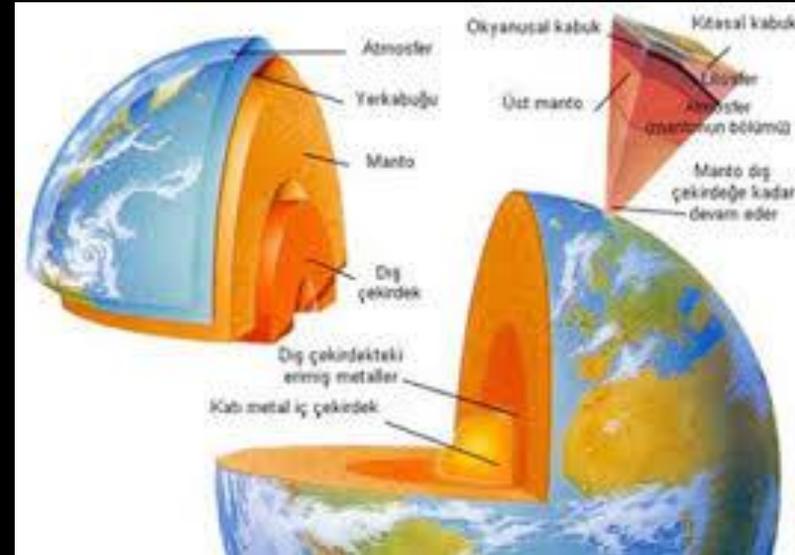
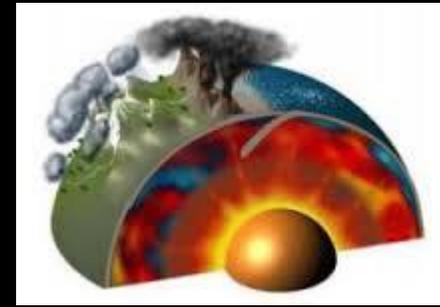


- ❖ The world's origin and geological processes
- ❖ Mineral types, rocks and rock formations, distribution and characteristics
- ❖ internal and external geological processes that affect the properties of earth materials
- ❖ Geological structures
- ❖ Surface and groundwater movements and related properties
- ❖ Deformation types and structural properties, geological time concept
- ❖ Use of topographical-geological maps
- ❖ The basic concepts of engineering geology

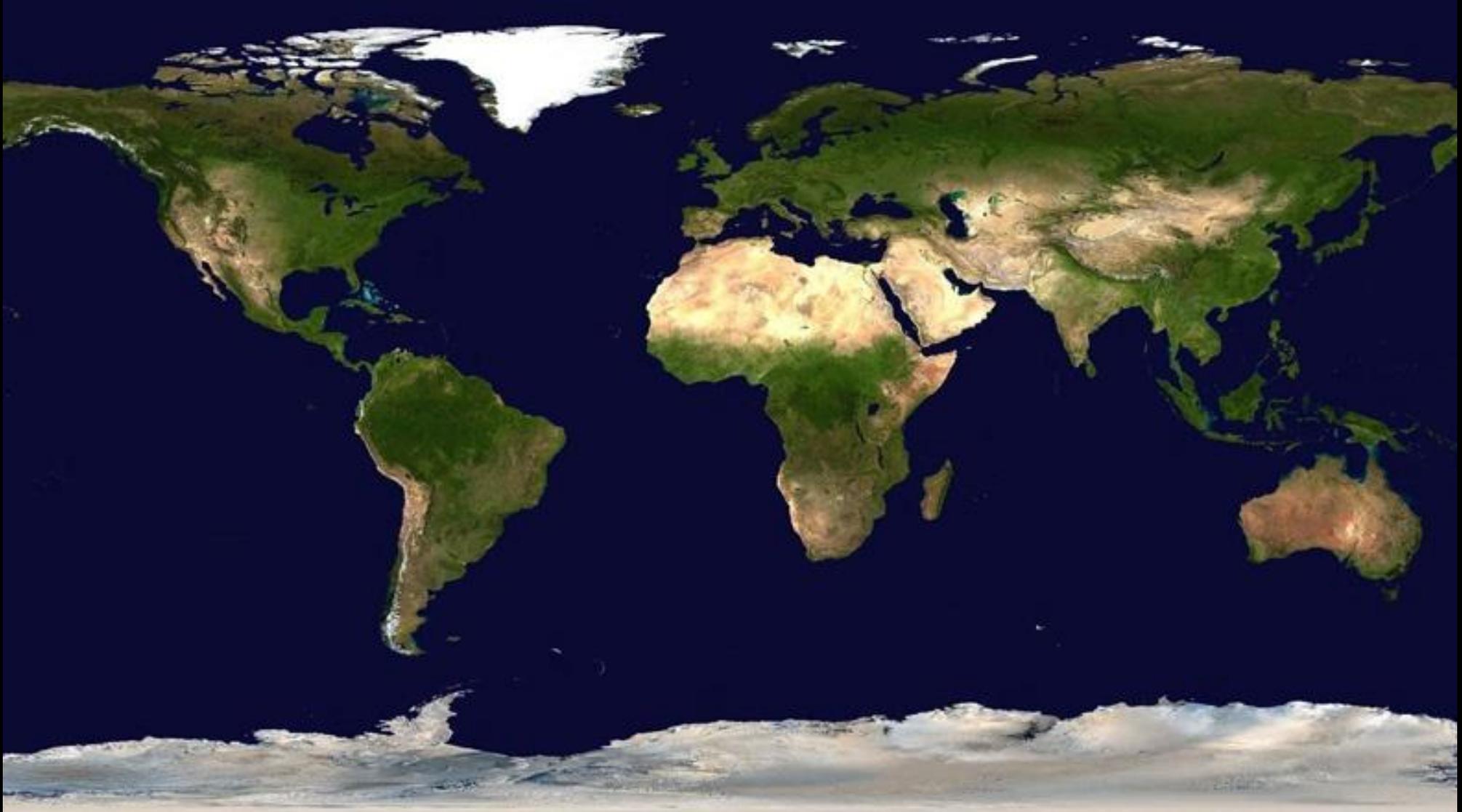
How old is the world and how did it?



Layers of the earth



How continents are formed?



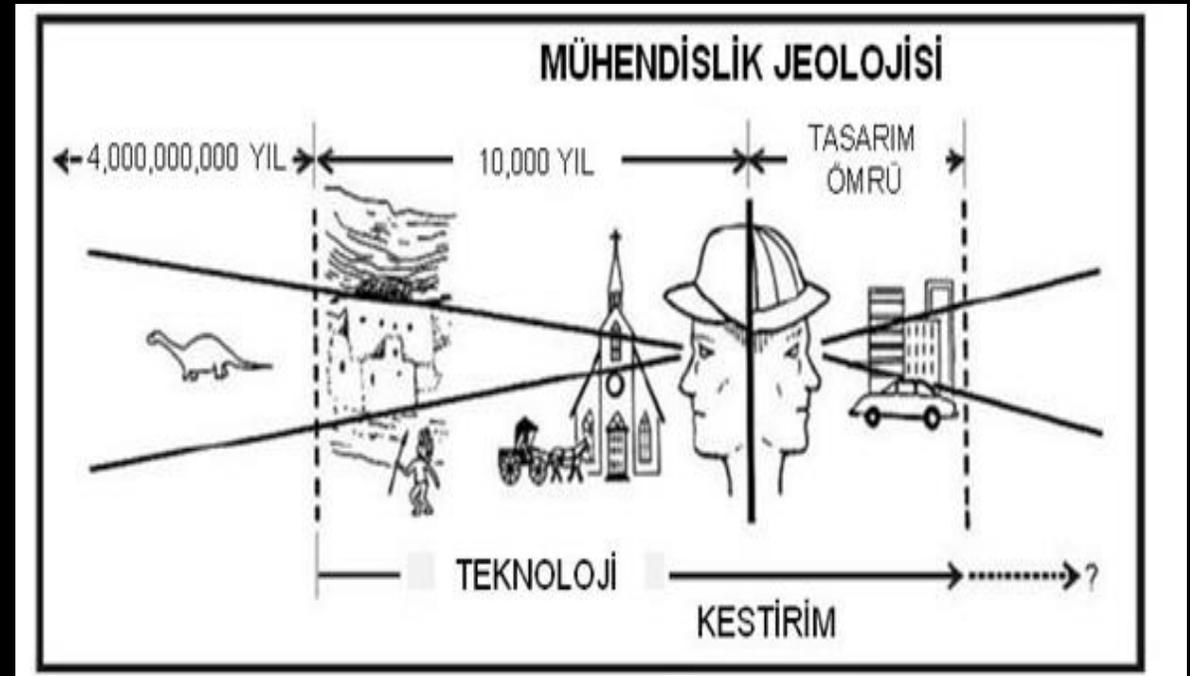
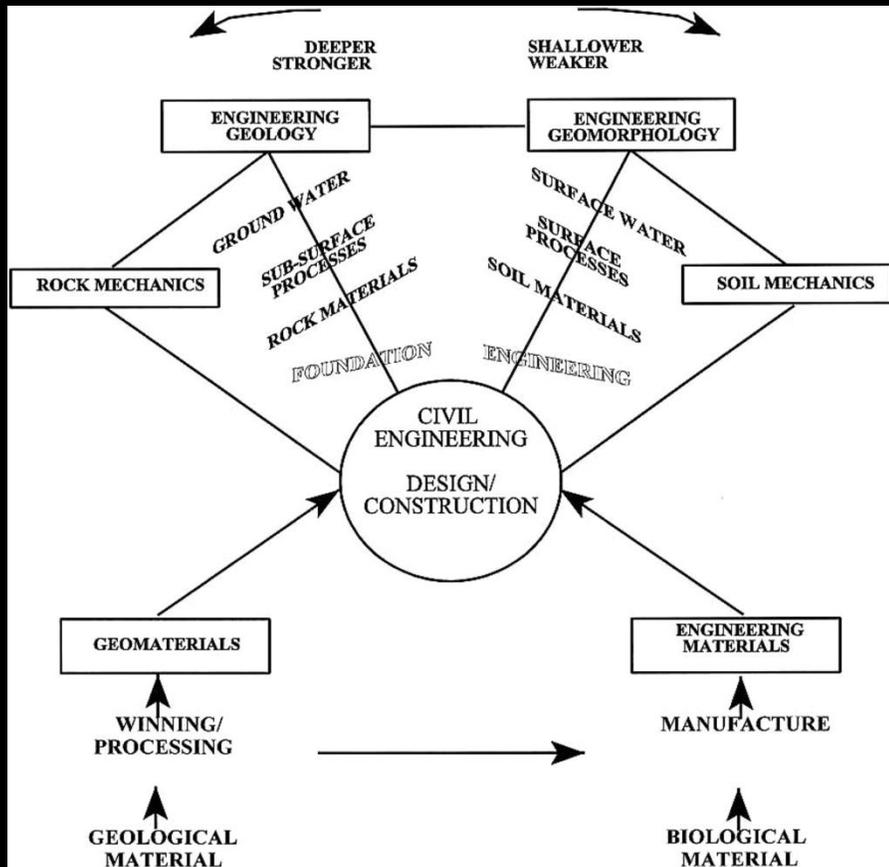
How the mountains are formed and eroded?



Geology and Civil Engineering Relationship

Civil engineering works are carried out either on site or within the site.

For this reason, erosional and geological process which cause the stability of the rocks and ground and their changes are important for civil engineering



Geology and Civil Engineering Relationship

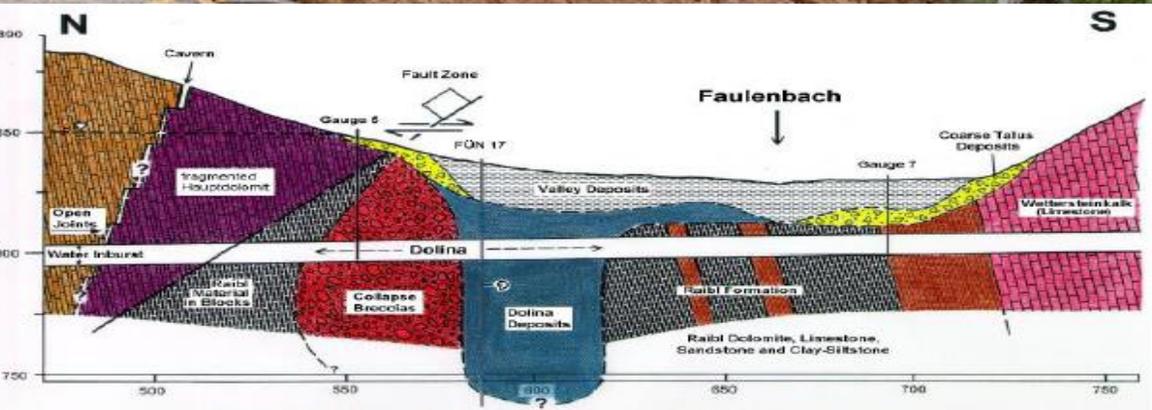
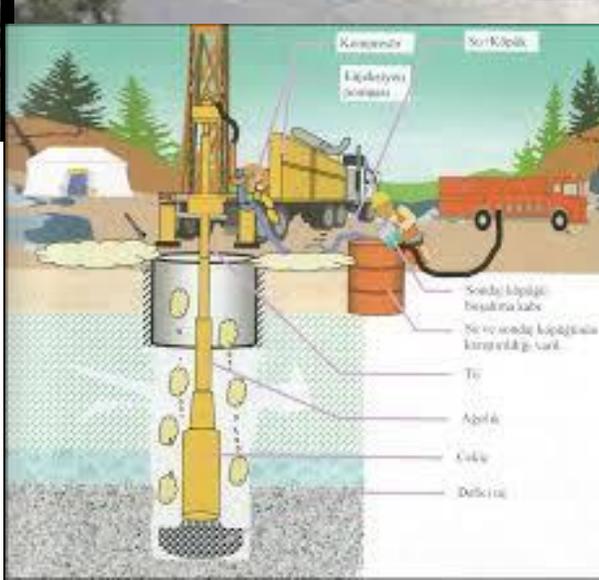


Figure 3 : Detailed geological section through the Faulenbach valley.

Geology and Civil Engineering Relationship

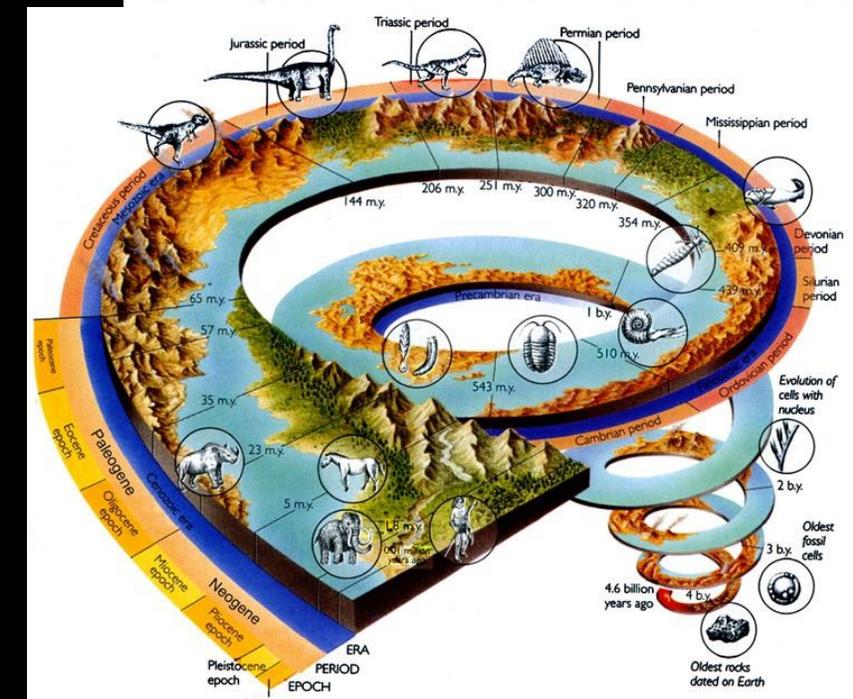
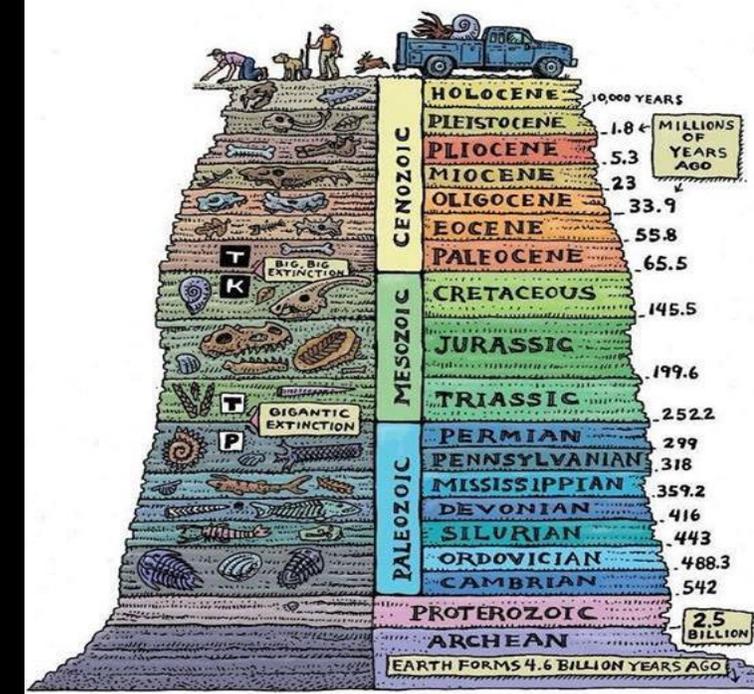
- Where is a geologically safe and economical engineering structure built?
- How to choose the communication and transport infrastructure route where geological conditions are convenient?
- How are the building bases constructed safely and economically in terms of geological and geotechnical aspects?
- How to create a slope both safely and economically?
- How is a safe tunnel and underground facility excavation done?
- How is location geological materials required for construction of dams and road construction determined?
- What are the measurements and application methods for improvements of ground conditions and controlling instability, infiltration etc.?
- What are required geological and geotechnical conditions store urban, toxic and radioactive waste?
- How are to identify, prevent or reduce geological hazards identified, prevented and reduced?

Time...

Geology deals with **complex historical systems** that have **evolved and changed** over time.

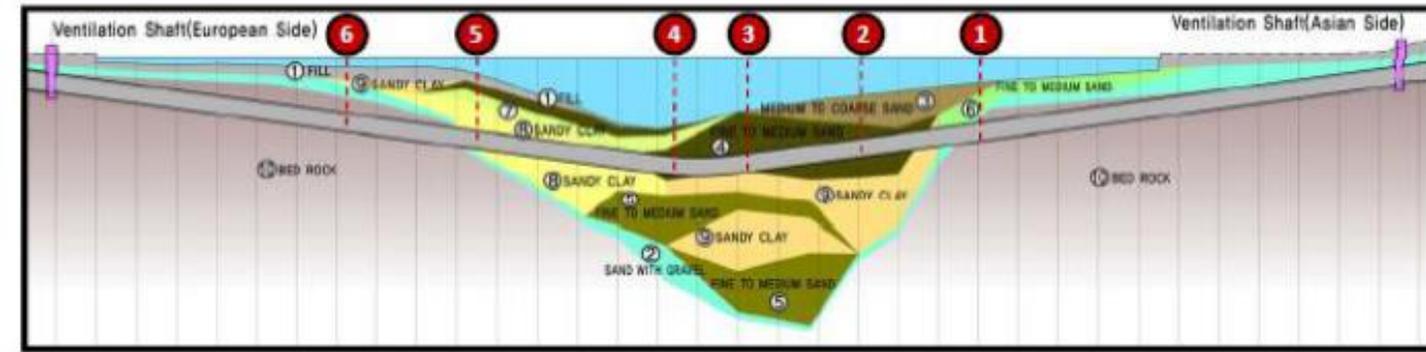
Time is thus a **fundamental variable** in geology.

Coupled processes, operating over time produce all that we see.



Various Projects

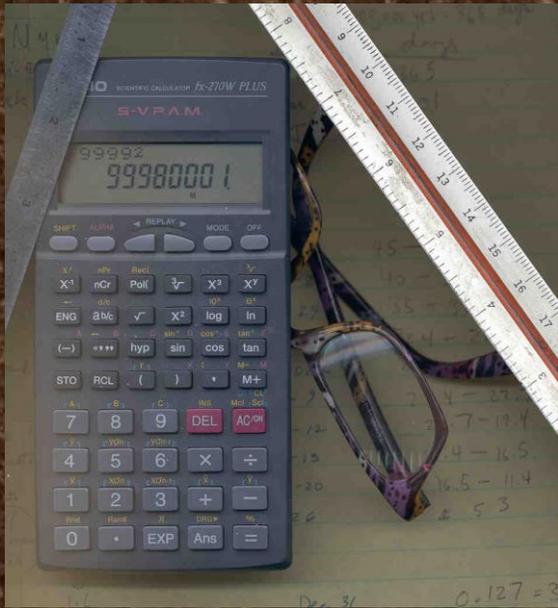
❖ İstanbul Karayolu Tünel Projesi (Yapı Merkezi İnşaat A.Ş.)



ÜST SİSTEM	SİSTEM	SERİ	FORMASYON	SEMBOLLER	KALINLIK (m)	LİTOLOJİ	AÇIKLAMALAR
SENOZOYİK	KUVAKTERNER	HOLOSEN		Yd	2-40		Dolgu: Moloz ve kaya parçaları
				Qal	10-15		Alüvyon: Kumlu, siltli, kumlu akarsu çökelleri
					40-60		Bogaz Çökelleri: Kum, kil, kavkulu çum ve silt
	TERSİYER	MİYOSEN	Kuşdili	Kd	20-50		Çakıl, Kum, kil
			Bakırköy	Tba	15-20		Kil arabantılı, Macralı kireçtaşı
			Güngören	Tg	10-80		Yer yer silt ve kireçtaşı aratabakalı kil
		Çakırçeşme	Tç	20-30		Sarımsı kahverenkli siltli, çakıllı çum	
PALEOZOYİK	KARBONİFER		Trakya	Kt	600-1700		Kumtaşı, silttaşı, kilitaşı, ardalanması, mercekli kireçtaşı ve konglomera Diyabaz ve Andezit dayk ve silleri
			Baltalimanı	Kb	25-30		siyah renkli ve radiolaryalı çört
	DEVONİYEN		Tuzla	Dt	115-180		Siyah çört, alacalı şeyl ve yumrulu-bantlı kireçtaşı
			Kartal	Dk	325-400		kumtaşı, silttaşı, kilitaşı, şeyl ardalanması

Şekil 4.1. Marmaray Projesi güzergahı stratigrafik kesiti (Aydın, 2006)

2. Week



Nature of scientific inquiry

Basic Concepts:

- 👉 Scientific method
- 👉 Observation
- 👉 Hypothesis
- 👉 Test
- 👉 Scientific "certainty"
- 👉 Paradigms and the nature of scientific revolutions
- 👉 Theory



Science is based on:

- ❖ assumption that the natural world behaves in a **consistent & predictable** manner

Goals of science:

- ❖ understand underlying **patterns** in nature (from careful observations/measurements form **hypotheses** that lead to **predictions**)

Nature of scientific inquiry

Four basic steps:

- 1) collect the facts (observation/measurement)**
- 2) develop hypothesis (one or more)**
- 3) test hypothesis**
- 4) accept/modify/reject**

Process begins with Observation!

Formulation of Hypotheses:

Construction of a tentative (untested) explanation for something observed
Value of multiple working hypotheses

Testing hypotheses

Evaluate explanatory power.

Certainty in science and the nature of scientific proof

Science has been described as the orderly accumulation of rejected hypotheses.

Theory

- ❖ well-tested/widely accepted hypothesis that “acceptably” predicts observed facts.
- ❖ also: explains additional observations not used originally to form theory
 - predictive power
 - still testable and subject to disproof!

THE BIG BANG THEORY

TIME BEGINS

ONE SECOND

PRESENT DAY

Time	10^{-43} sec.	10^{-32} sec.	10^{-6} sec.	3 min.	300,000 yrs.	1 billion yrs.	15 billion yrs.
Temperature		10^{27}°C	10^{13}°C	10^8°C	$10,000^{\circ}\text{C}$	-200°C	-270°C

1 The cosmos goes through a superfast "inflation," expanding from the size of an atom to that of a grapefruit in a tiny fraction of a second

2 Post-inflation, the universe is a seething, hot soup of electrons, quarks and other particles

3 A rapidly cooling cosmos permits quarks to clump into protons and neutrons

4 Still too hot to form into atoms, charged electrons and protons prevent light from shining; the universe is a superhot fog

5 Electrons combine with protons and neutrons to form atoms, mostly hydrogen and helium. Light can finally shine

6 Gravity makes hydrogen and helium gas coalesce to form the giant clouds that will become galaxies; smaller clumps of gas collapse to form the first stars

7 As galaxies cluster together under gravity, the first stars die and spew heavy elements into space; these will eventually form into new stars and planets

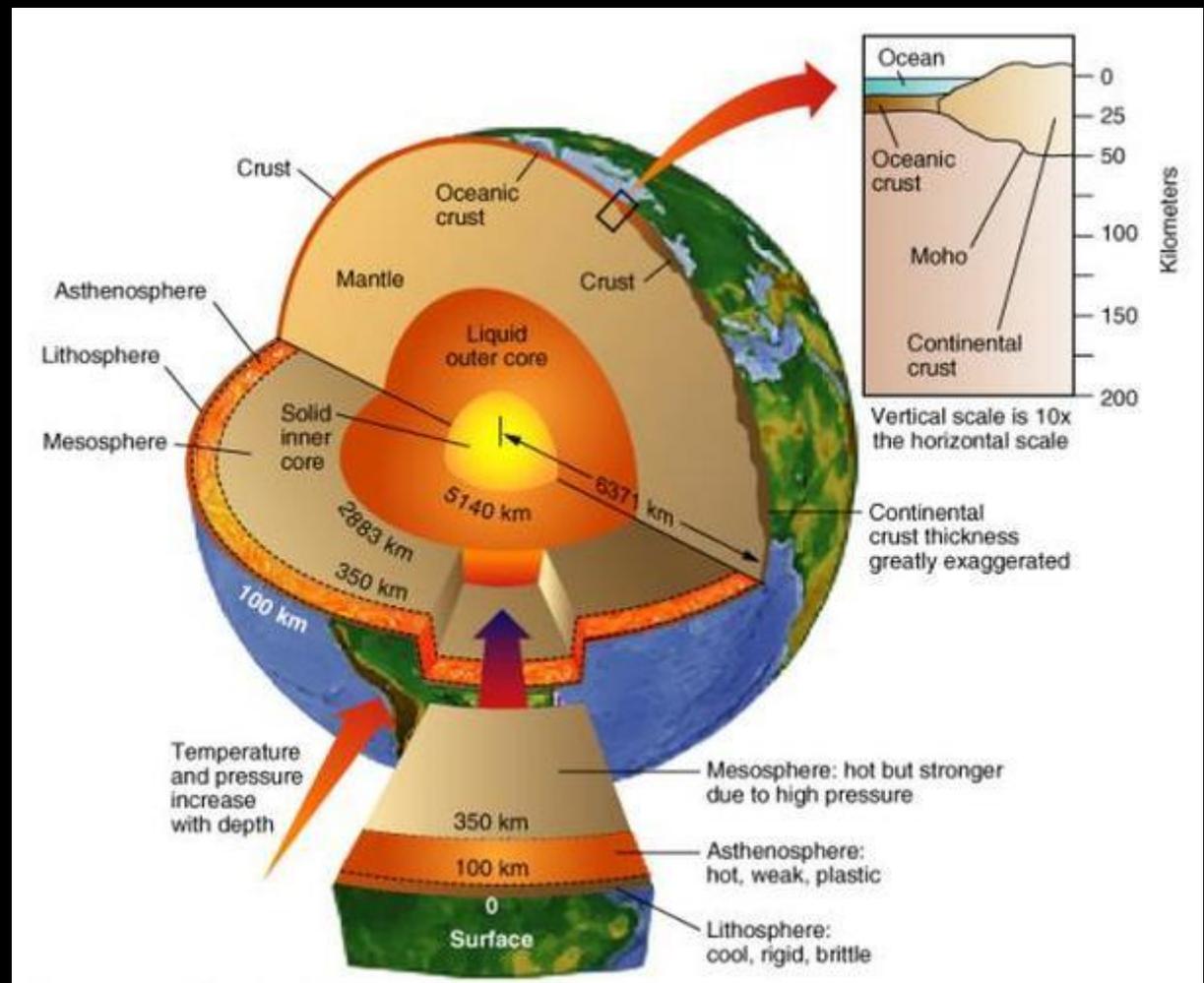
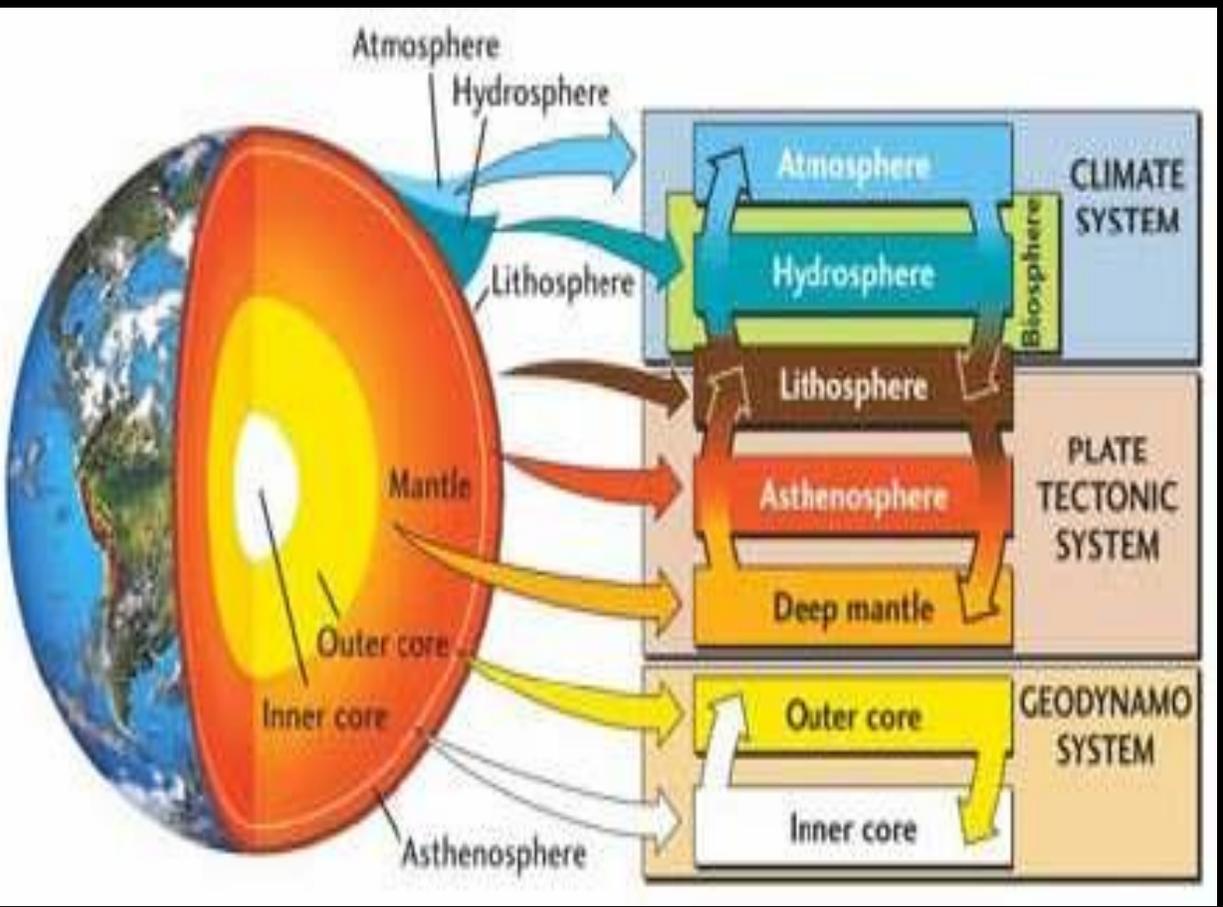
NOTE: The numbers in cosmology are so great and the numbers in subatomic physics are so small that it is often necessary to express them in exponential form. Ten multiplied by itself, or 100, is written as 10^2 .

Geology: The study of the Earth and its systems

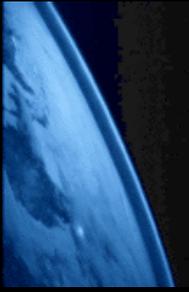


You are here!

Layers of EARTH



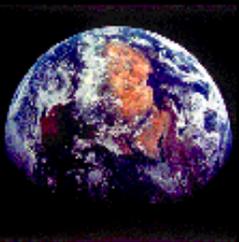
Prelude: Earth Systems



 Atmosphere



 Hydrosphere

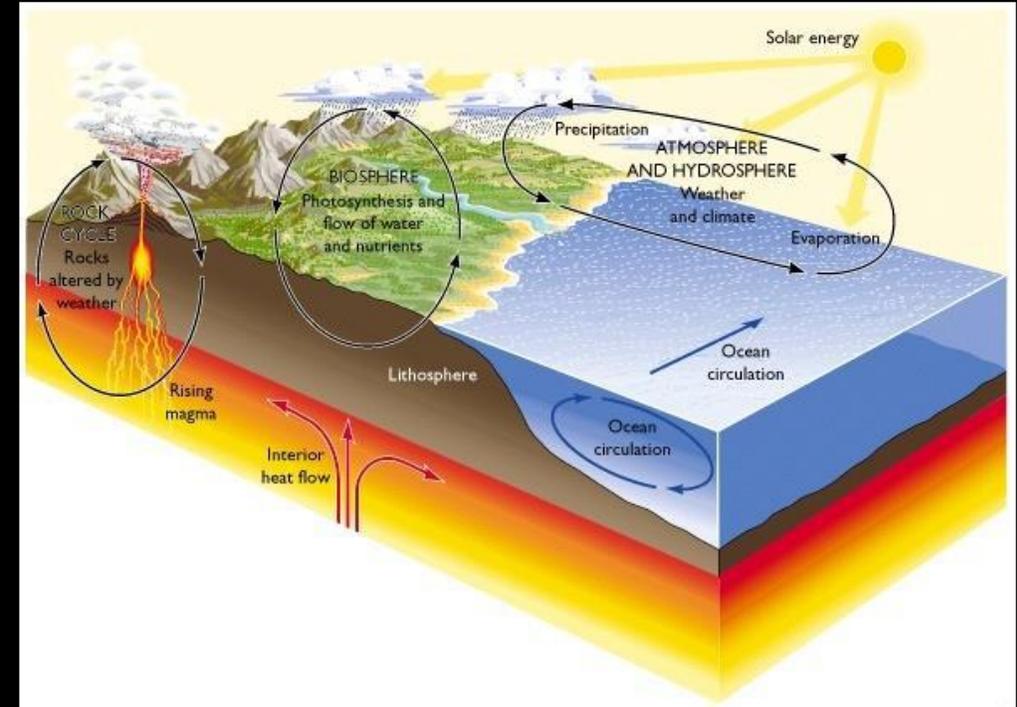


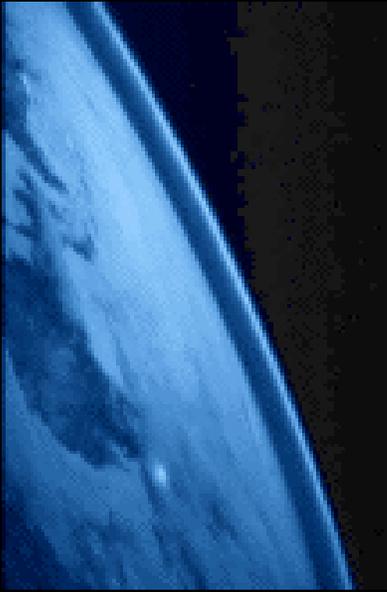
 Cryosphere

 Solid Earth



 Biosphere





Atmosphere

Blanket of gases surrounding the Earth

- Protection from Sun's heat & UV rays
- Weather: due to exchange of energy
 - between Earth's surface & atmosphere
 - between atmosphere & outer space
- Strongly interacts water/ surface



Hydrosphere

Water portion of Earth

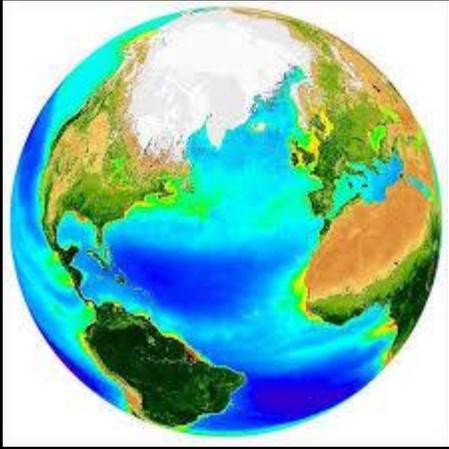
- Oceans (most prominent)
71% of surface of Earth
- Streams, lakes, glaciers, underground water
- Atmosphere



Cryosphere

Icy portion of Earth's crust

- Glaciers
- Permafrost and ground ice
- Polar ice caps
- Frozen polar seas

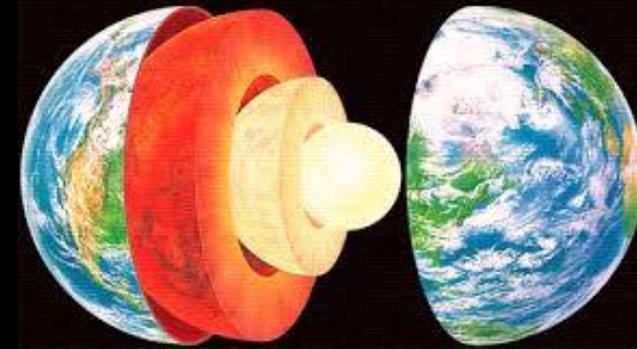


Biosphere

Earth's Ecosystems

- Earth's surface and subsurface to depths of a few kilometers
- Life occupies an extreme range of environments
- Life strongly interacts with the atmosphere, the hydrosphere and the solid earth (these interactions are called ecology!)

Prelude: Earth's internal structure

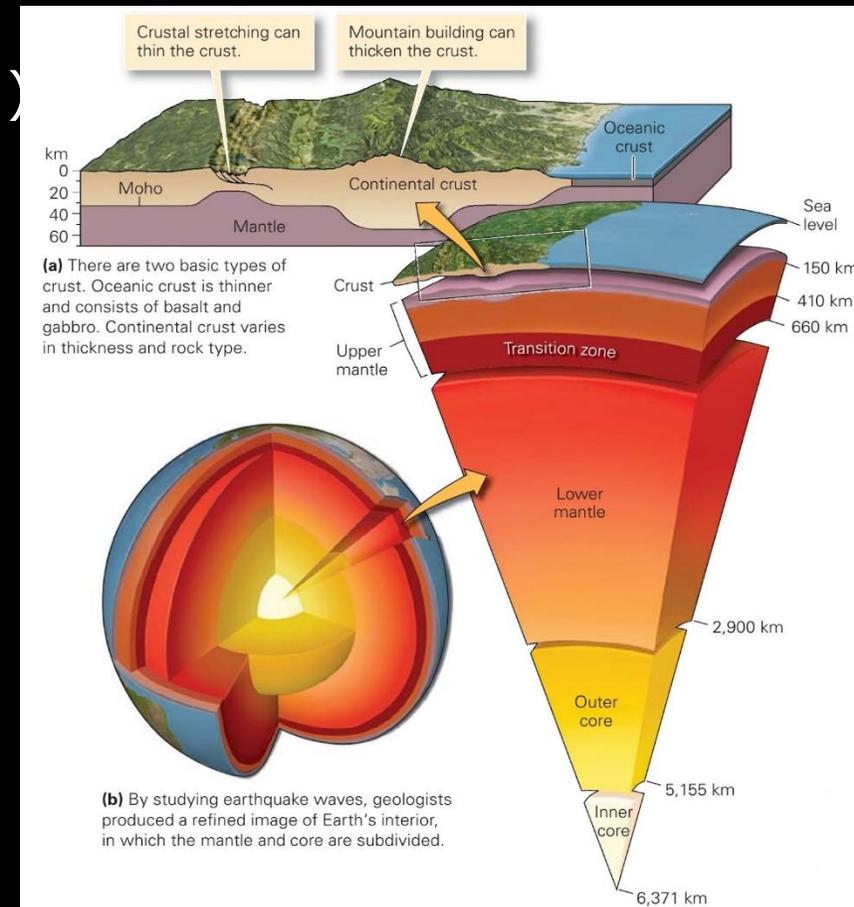


3 distinct divisions:

☼ crust Oceanic 0-6 km ("young", < 180 m.y.)
Continental 0-34 km (older, up to 3.8 b.y.)

☼ mantle Upper 34-670 km
Lower 670-2900 km

☼ core Outer – Liquid
Inner – Solid



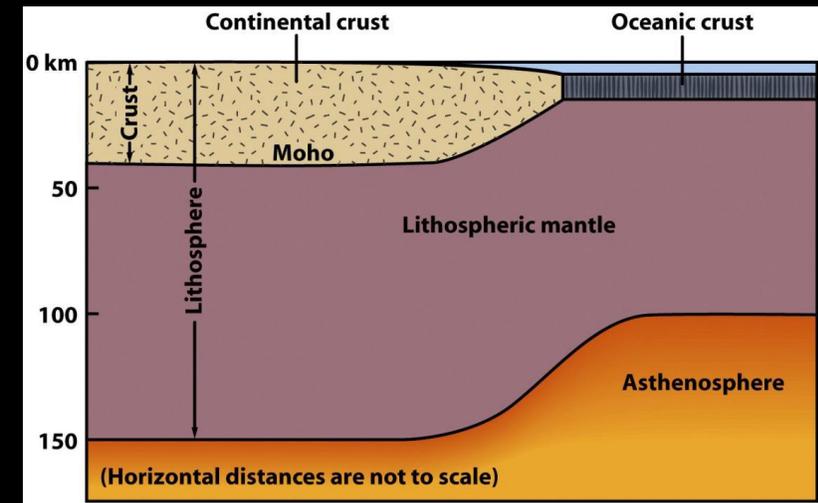
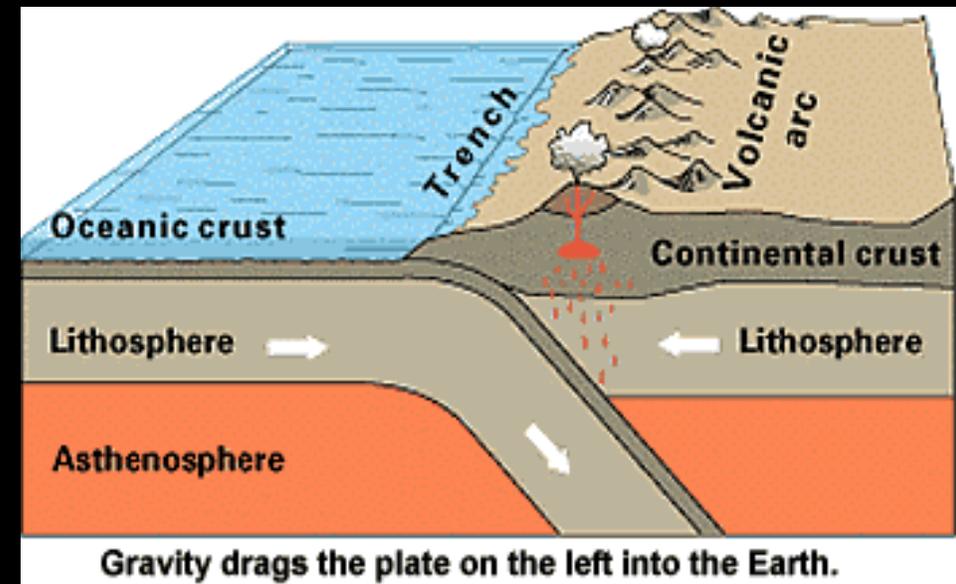
Earth's internal structure

Continental crust – Underlies the continents.

- Avg. rock density about 2.7 g/cm³.
- Avg. thickness 35-40 km.
- Felsic composition. Avg. rock type = Granite

Oceanic crust – Underlies the ocean basins.

- Density about 3.0 g/cm³.
- Avg. thickness 7-10 km.
- Mafic composition
- Avg. rock type = Basalt/Gabbro



Crust ve Earth's internal structure

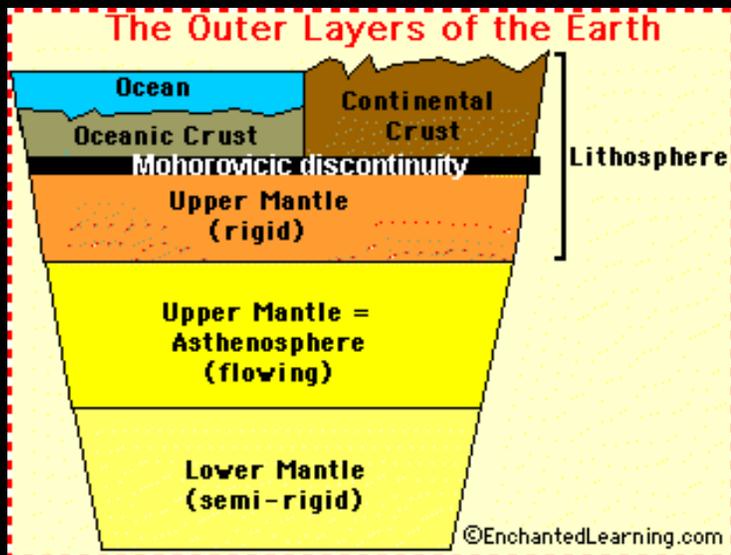
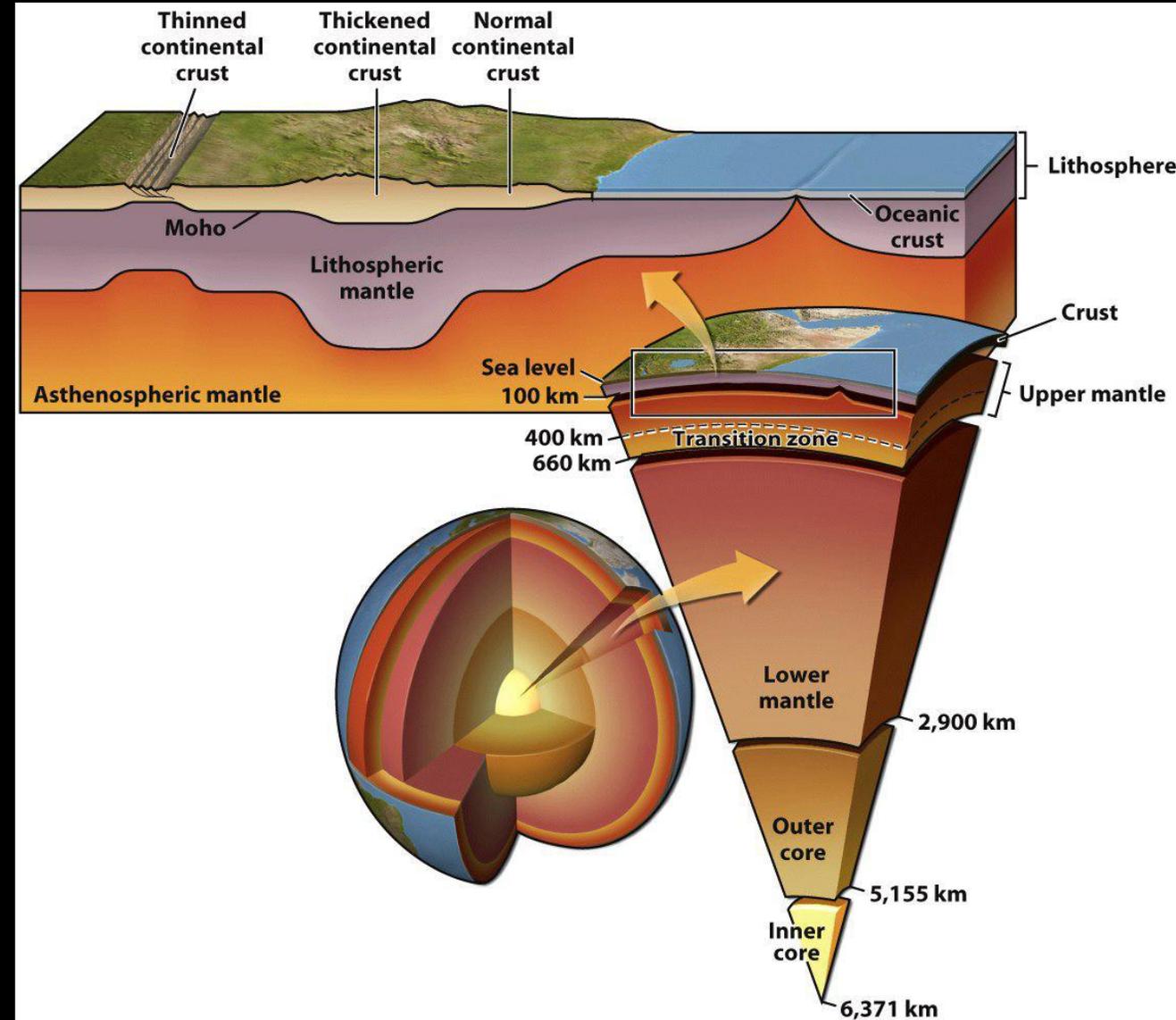
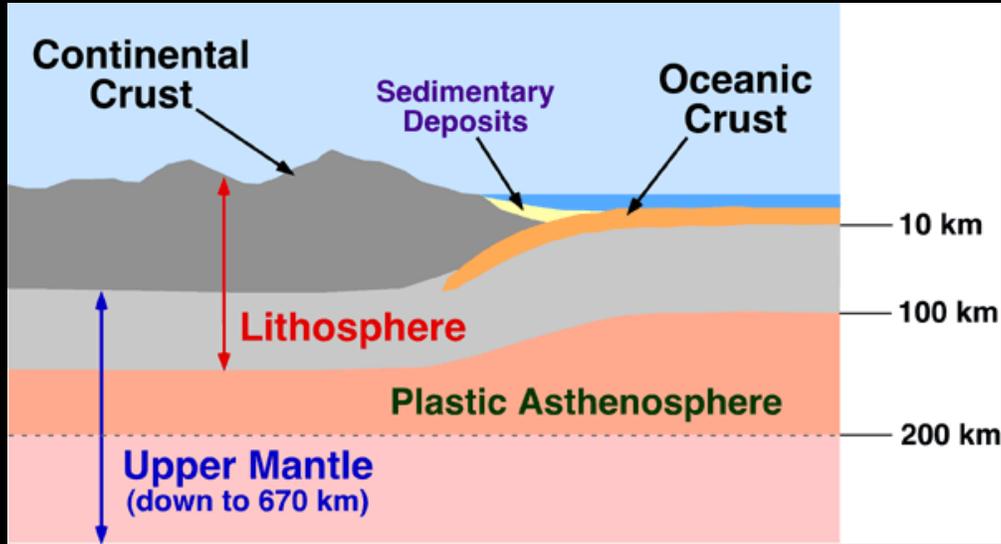


Plate tectonics

- Plate tectonics, theory dealing with the dynamics of Earth's outer shell, the lithosphere, that revolutionized Earth sciences by providing a uniform context for understanding mountain-building processes, volcanoes, and earthquakes, as well as understanding the evolution of Earth's surface and reconstructing its past continental and oceanic configurations.
- ***Describing in detail the processes that make up the Earth's fundamental surface features, «The definition of lithospheric separation of rigid plates moving on the asthenosphere» (Alfred Wegener 1915) forms the basis of the plate tectonics theory.***

Plate tectonics

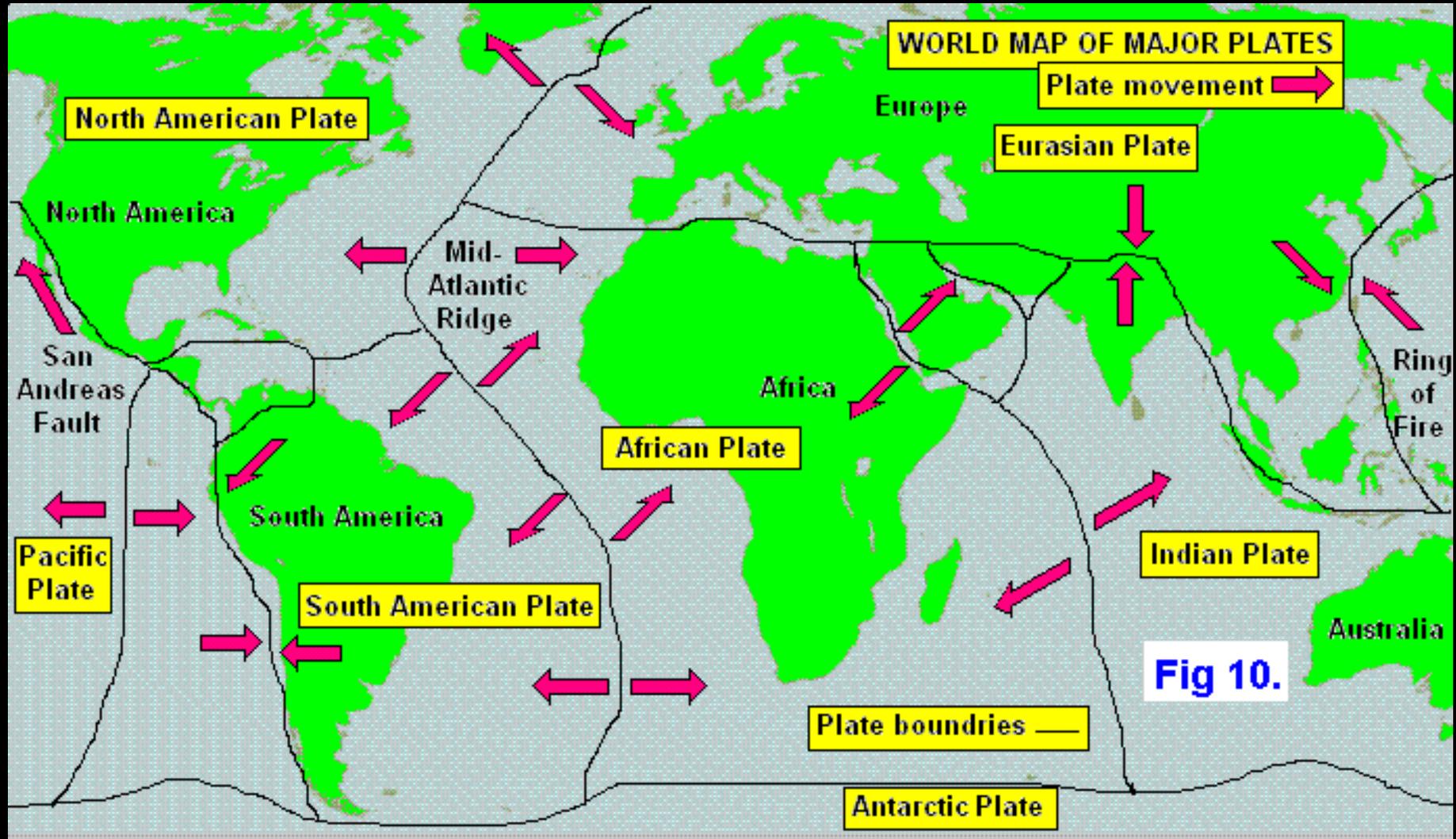


Plate tectonics

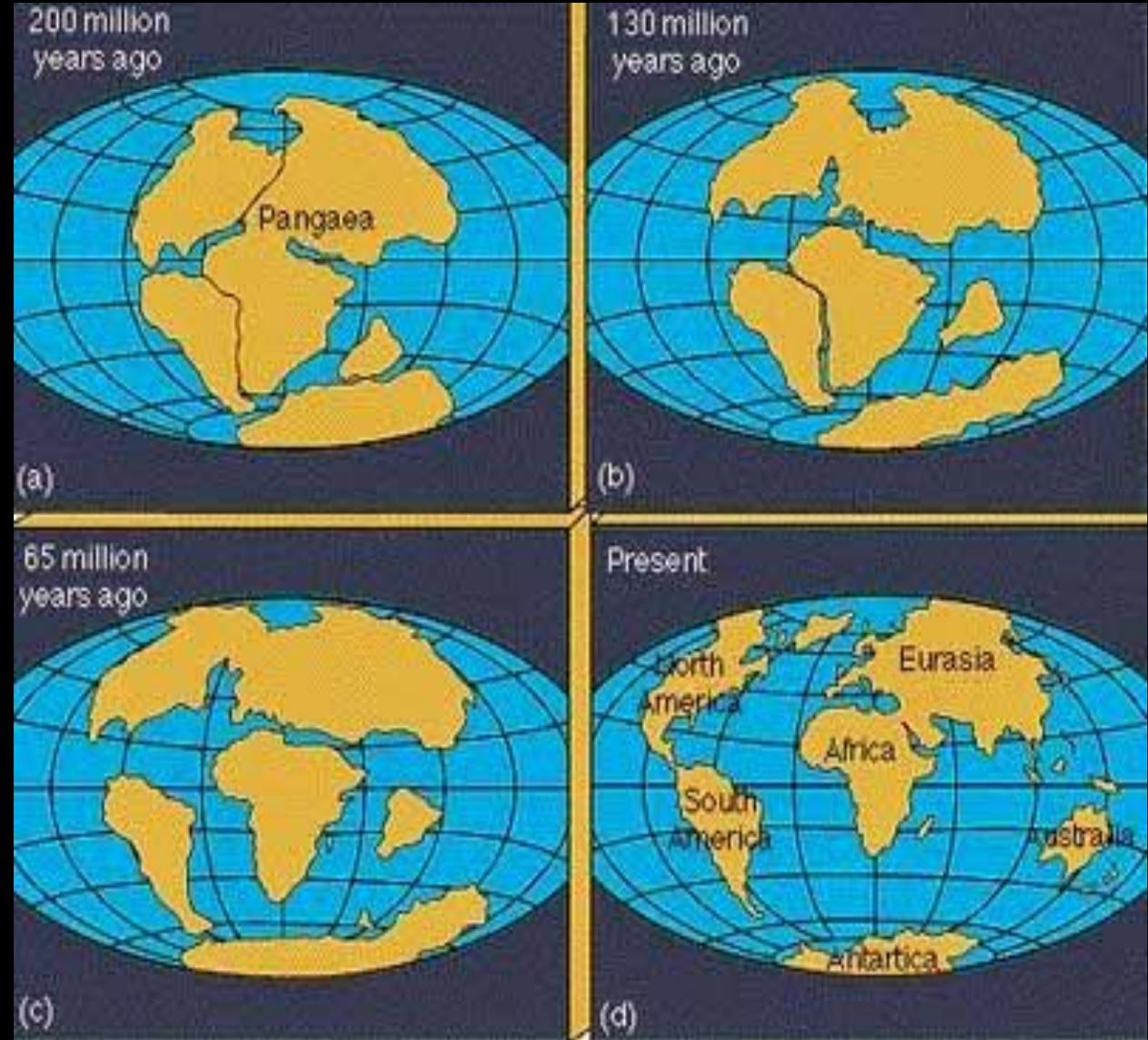
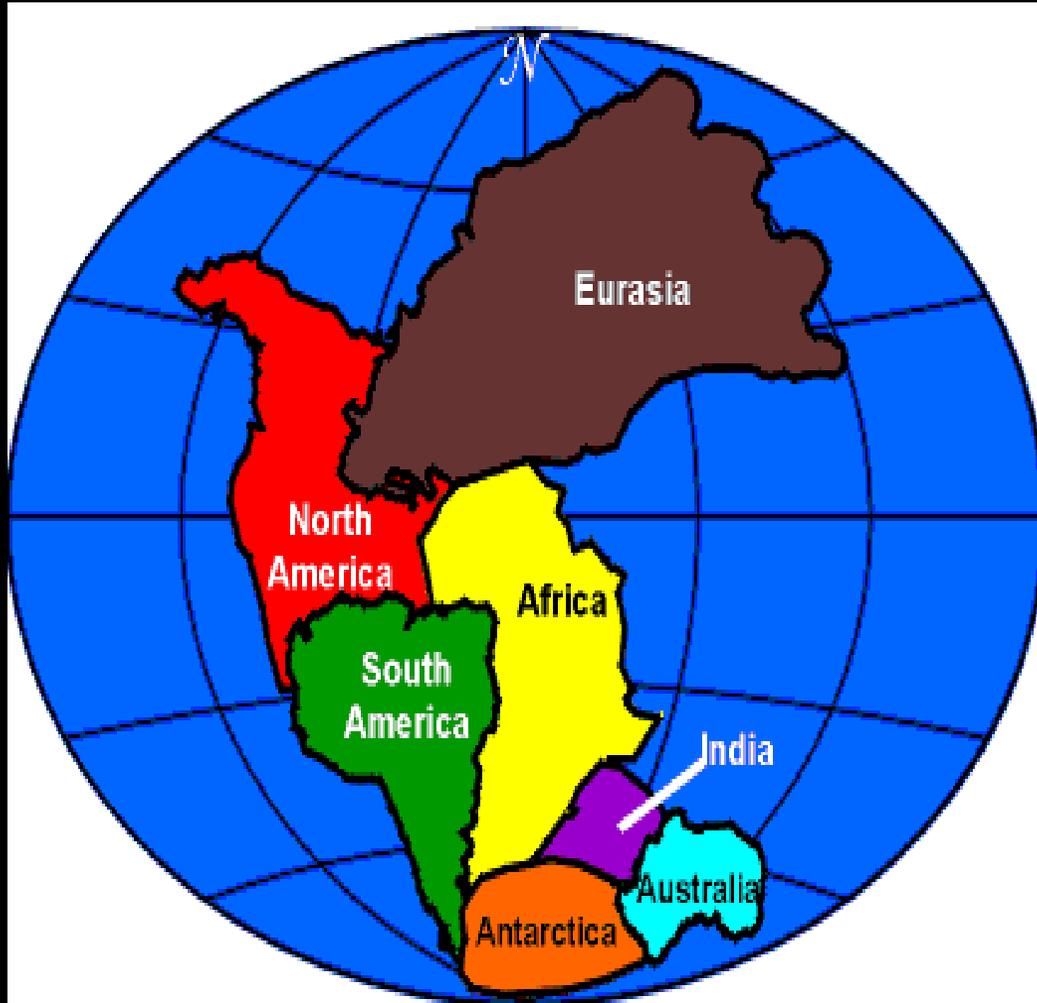


Plate tectonics

Data indicates that Plates separate from each other

- Coastal forms and continents match each other
- Similarity of sediment deposits; The continuation of the vegetation and geological structure of Africa, India, Australia, Madagascar, South America which make up Gondwana,
- Similarity of mountain ranges; When the continents are brought side by side, the mountain lines form a single continuous mountain line in the same age and deformation style.
- The glaciation that began in Gondwana was also experienced at the same time (carboniferous) by parts separated from Gondwana
- The remains of the reptile family which is impossible to swim the ocean were found only in South West Africa and Brazil
- Palaeomagnetism
- Propagation of the sea floor

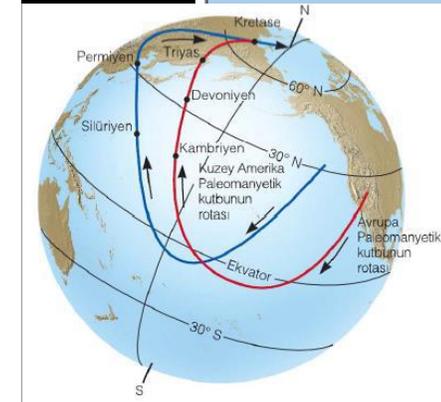
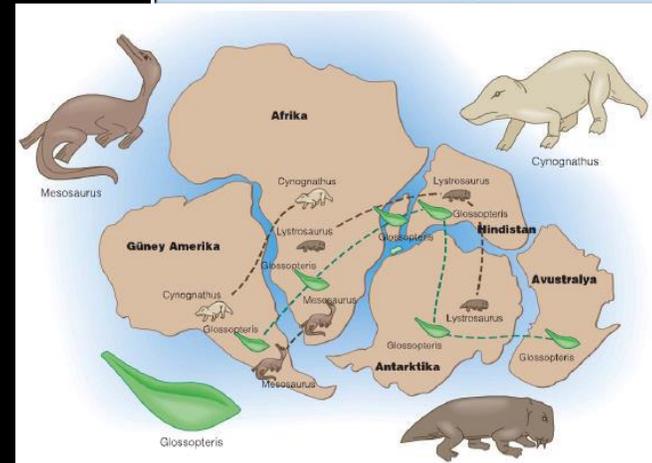
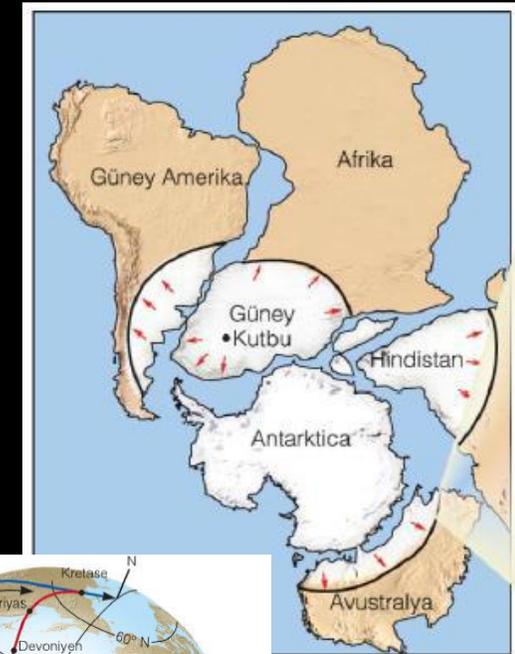
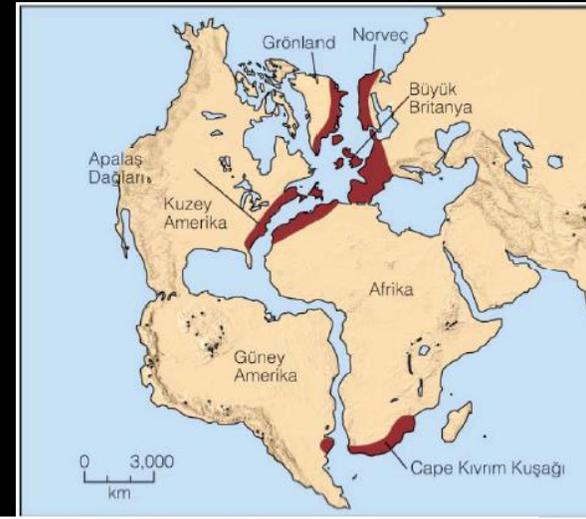
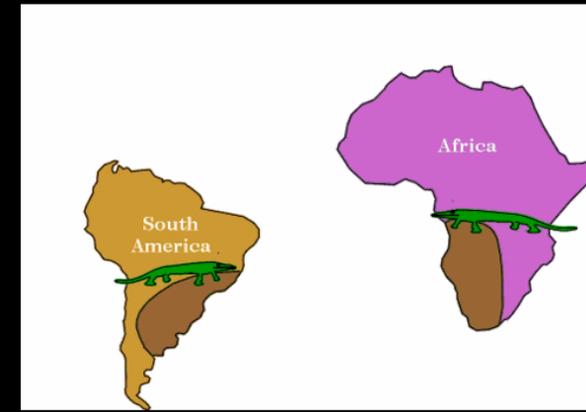
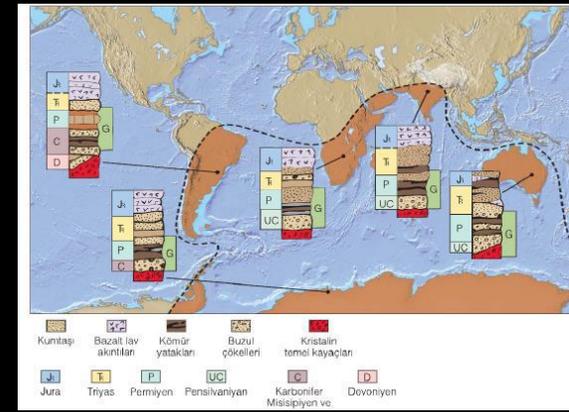
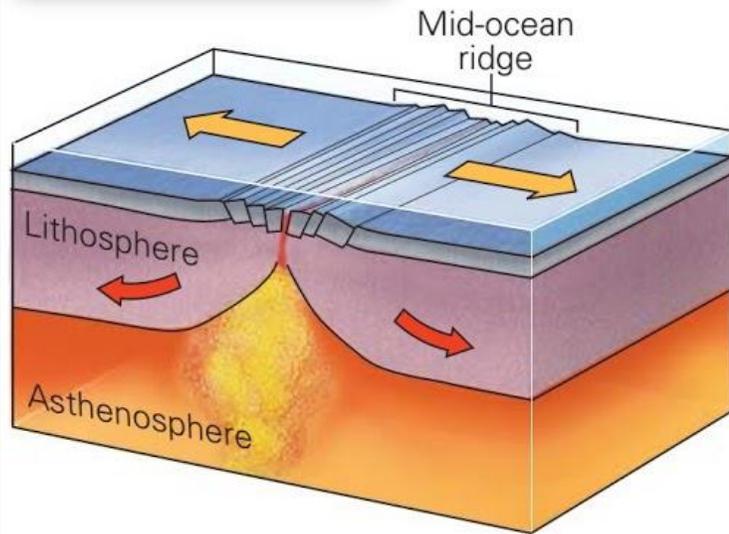


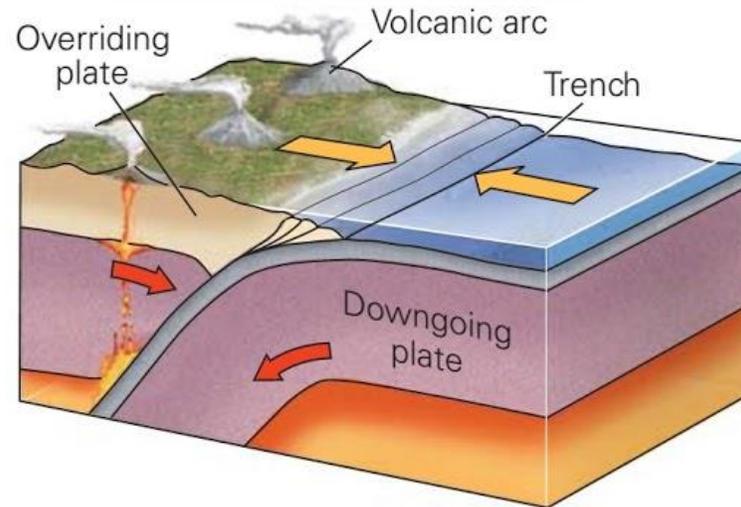
Plate tectonics

Lithosphere thickens away from the axis.



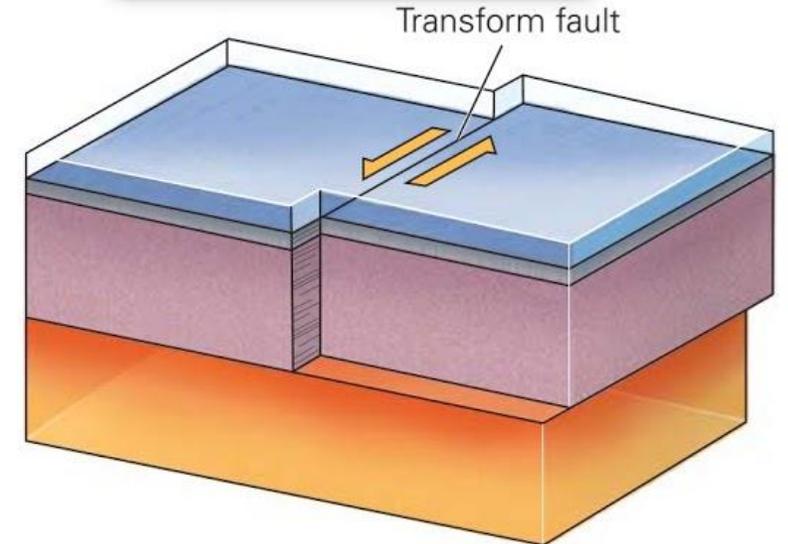
(a) At a divergent boundary, two plates move away from the axis of a mid-ocean ridge. New oceanic lithosphere forms.

The process of consuming a plate is called subduction.



(b) At a convergent boundary, two plates move toward each other; the downgoing plate sinks beneath the overriding plate.

No new plate forms, and no old plate is consumed.



(c) At a transform boundary, two plates slide past each other on a vertical fault surface.

Plate tectonics

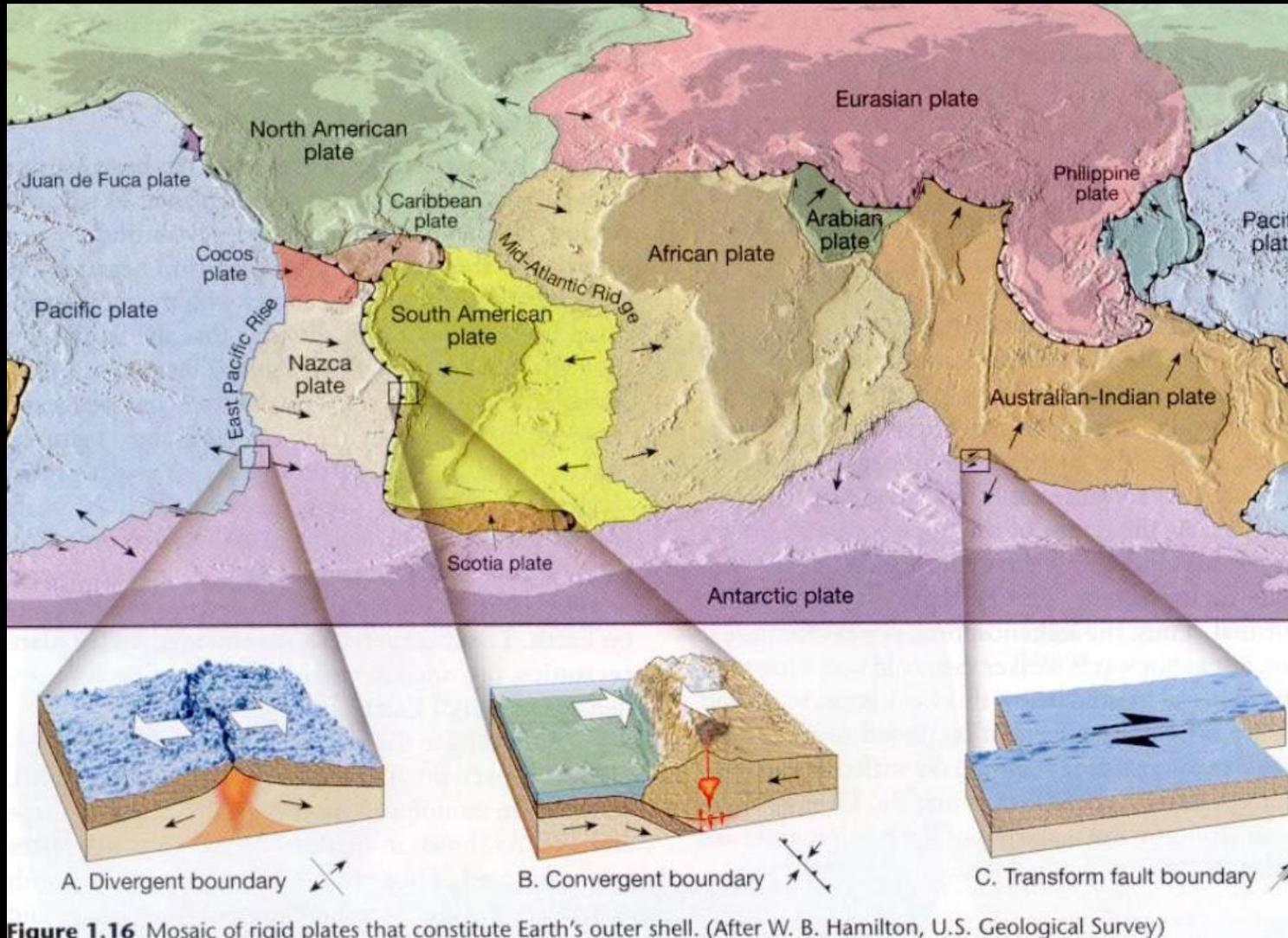


Plate tectonics

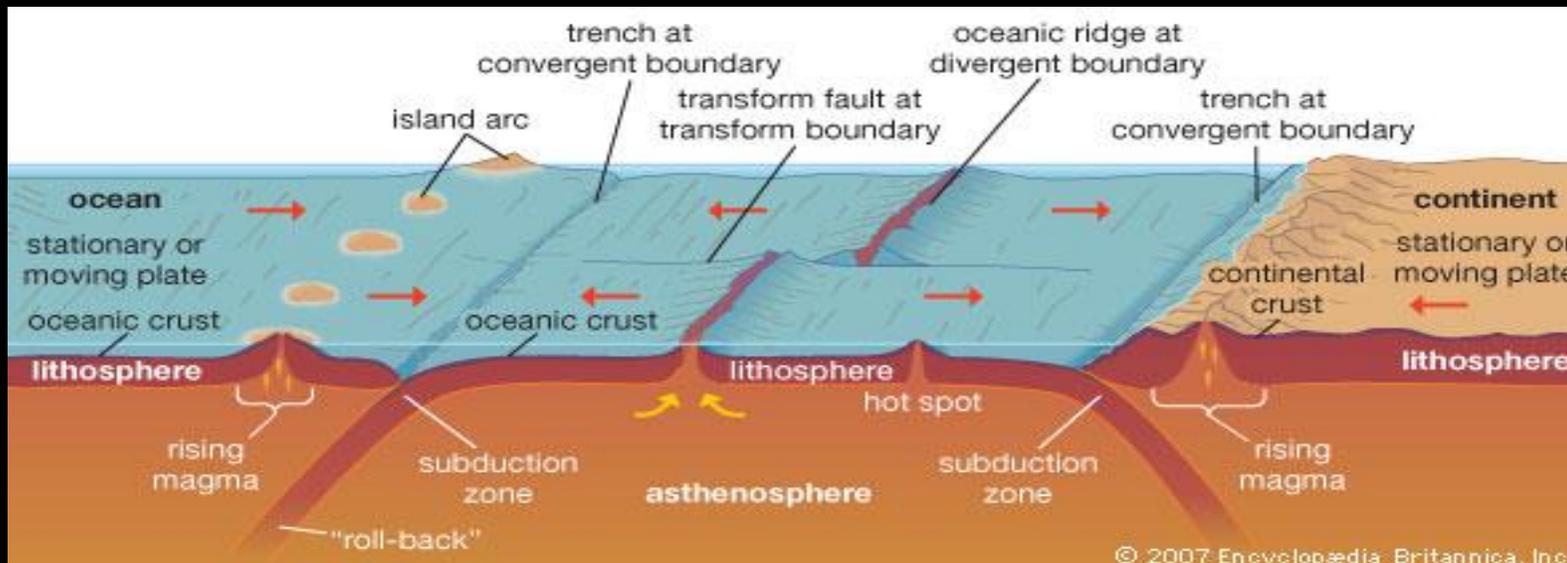
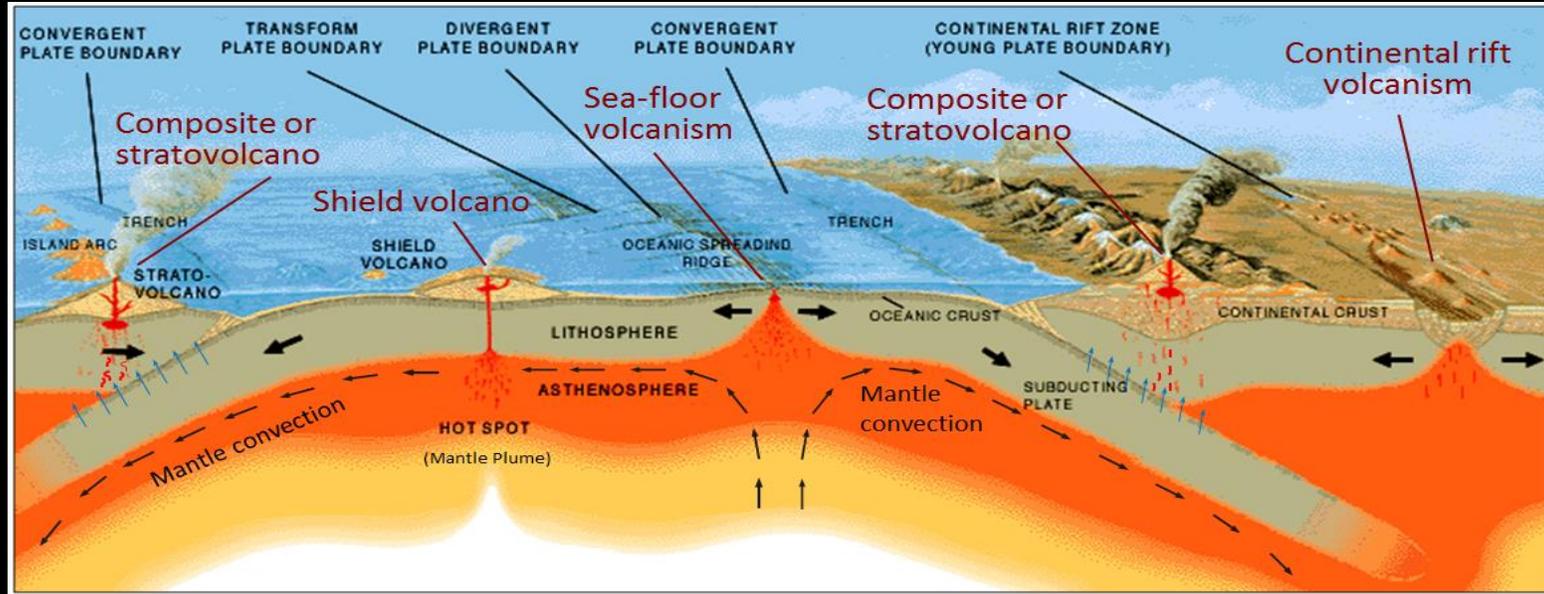
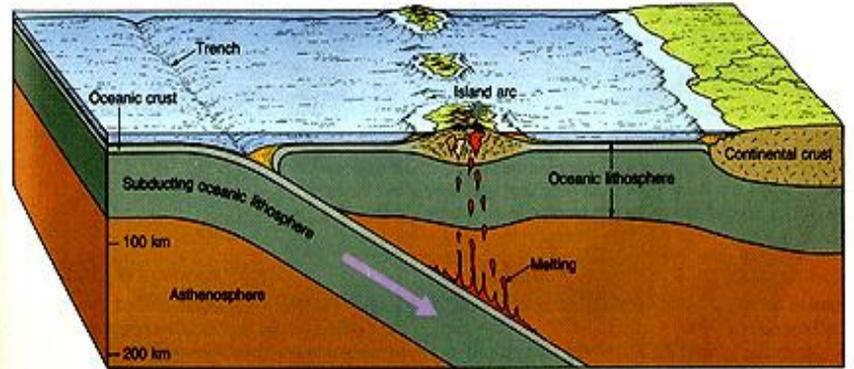
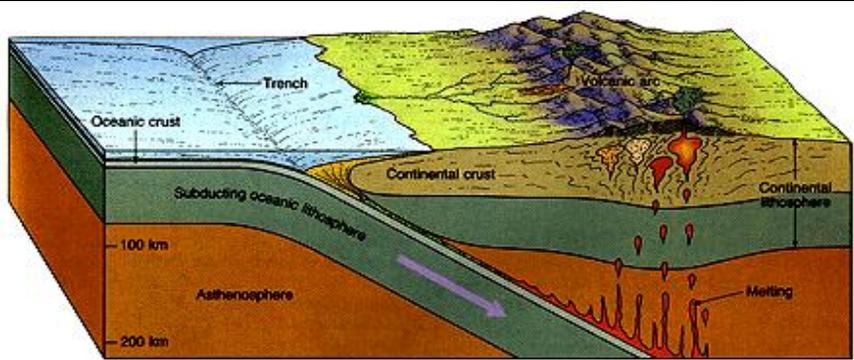
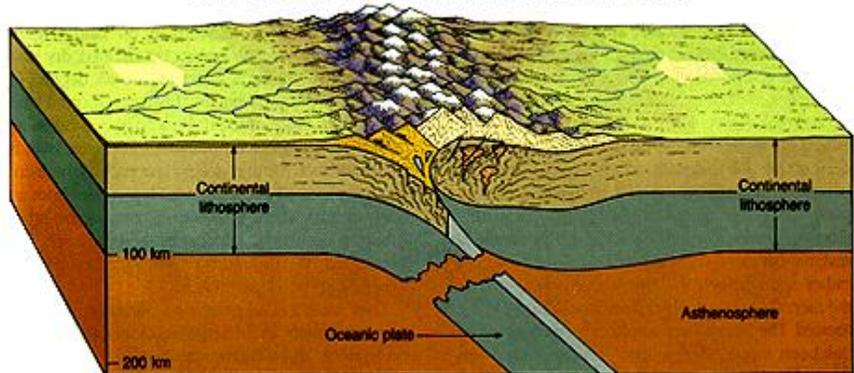


Plate tectonics



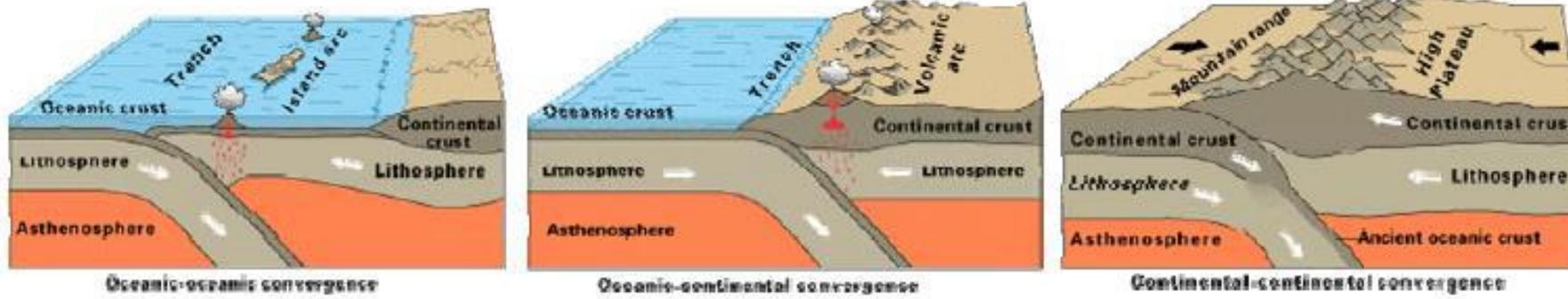
Continental-Continental Boundary



Convergent plate boundaries

- Subduction event occurs
- Colliding with Oceanic/oceanic or oceanic/continental plate generated a deep ocean trenches
- Crust melting and magma generation occur
- Volcanism and volcanic island arcs occur, volcanic island arcs arranged like a barrier can form inner seas between continents and the oceans
- Events of metamorphism occur
- Two continental or continental and an oceanic plate collides to form a curved mountain line

Plate tectonics



Şekil 1.5: Değişik türde levhaların yaklaşmasına göre gelişen mekanizmalar. (a) Okyanusal levha-okyanusal levha; (b) okyanusal levha-kıtasal levha; (c) kıtasal levha-kıtasal levha yaklaşması.

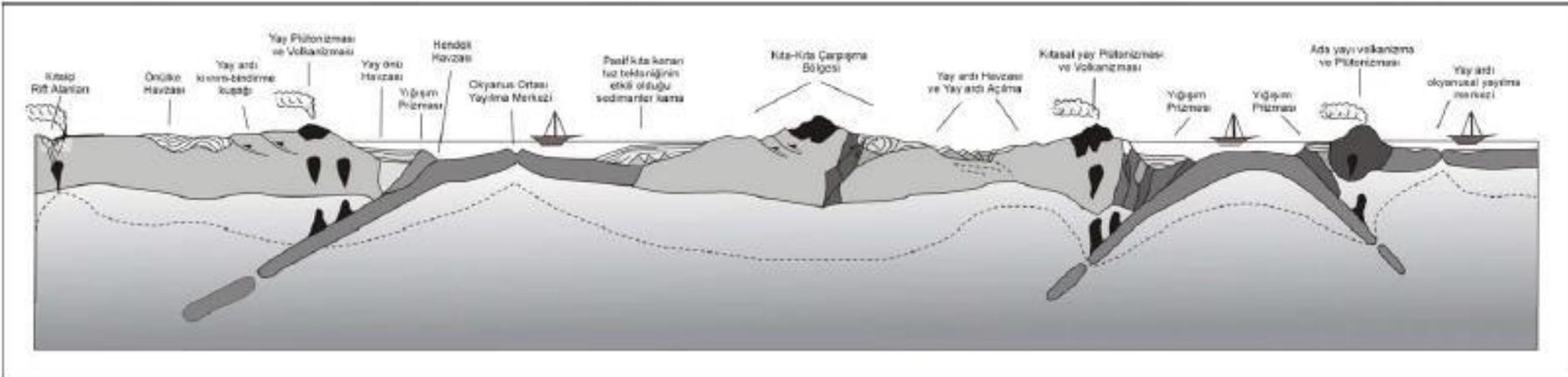
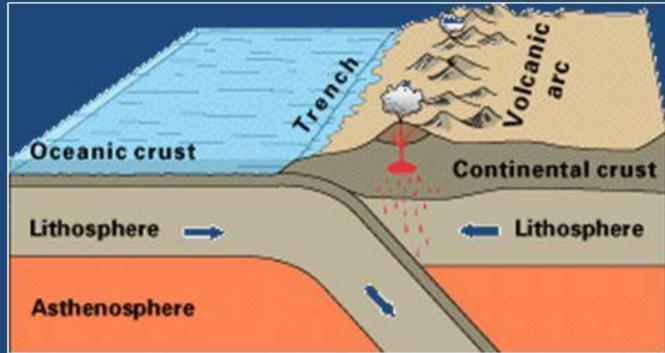
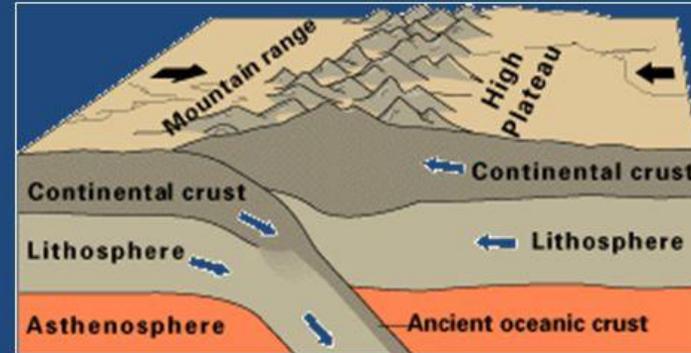


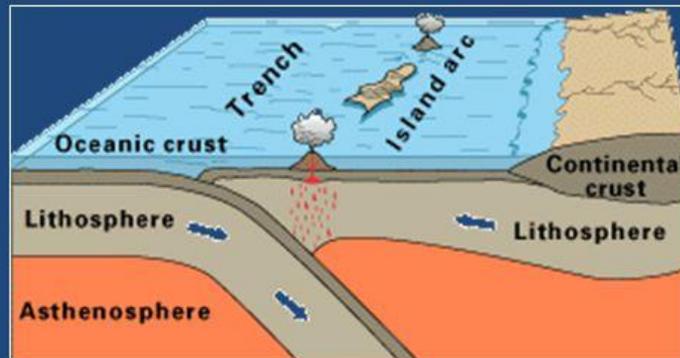
Plate tectonics



Okyanus-kita

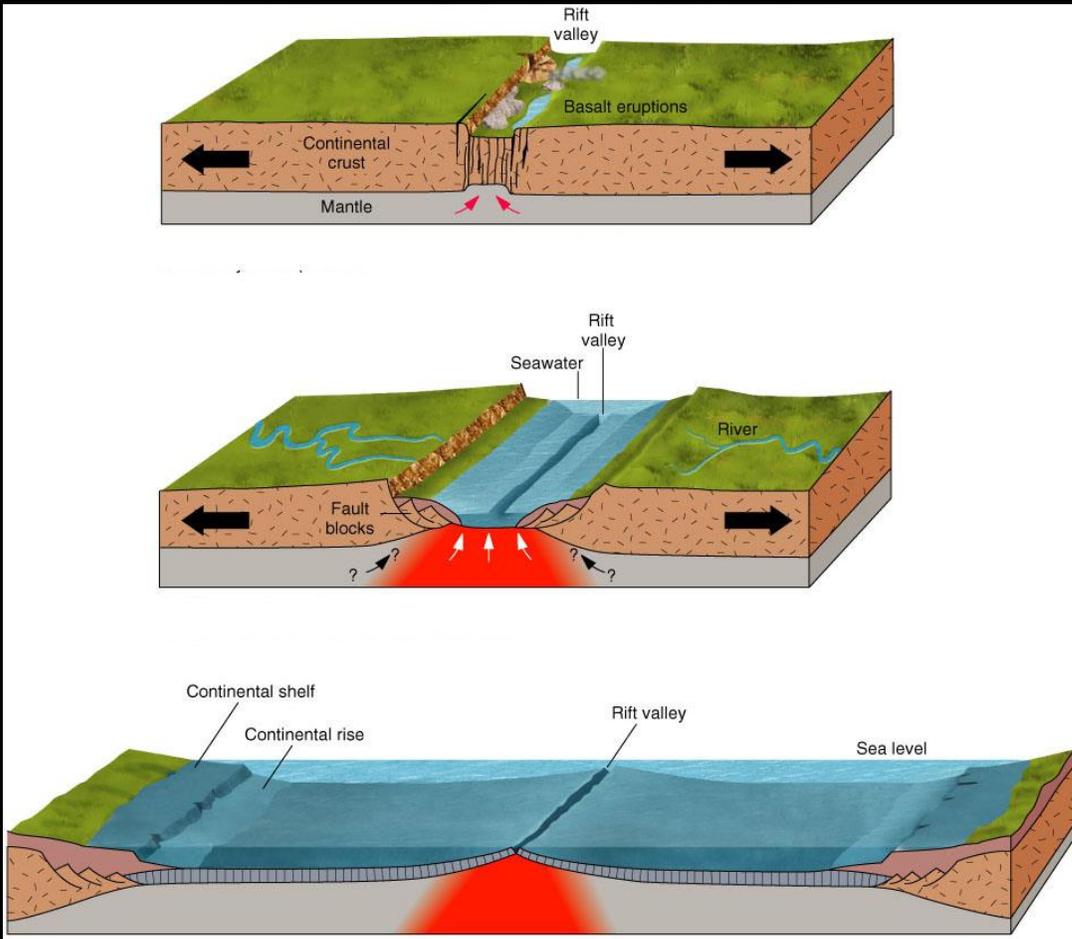


Kita-kita



Okyanus-okyanus

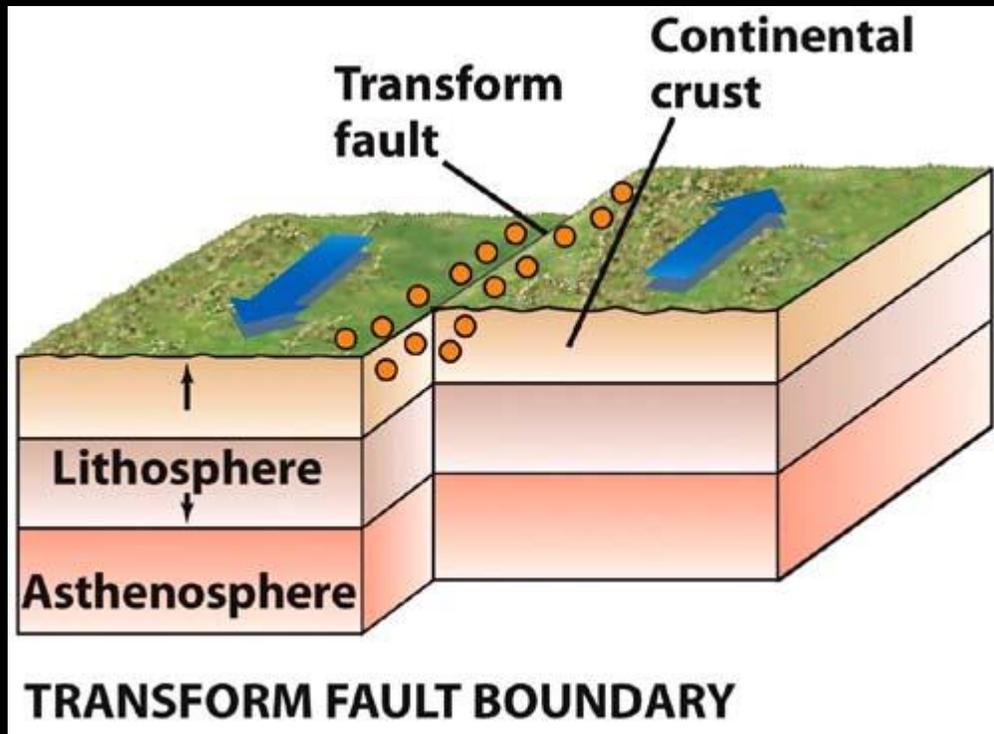
Plate tectonics



Events happening in places where plates are moving away from each other :

- Mid-ocean ridge (2500 m high ridge in the Atlantic Ocean)
- Volcanic islands
- New crust formation
- Basaltic lavas are solidified and added to the continental margins, The ocean floor expands and the continents move away from each other
- Magma is emerged from the fractures generated by divergent event and volcanic events occur
- Best example of that is Atlas Ocean

Plate tectonics



- Transform Plate Boundaries are locations where two plates slide past one another.
- The fracture zone that forms a transform plate boundary is known as a transform fault.
- Most transform faults are found in the ocean basin and connect offsets in the mid-ocean ridges.
- A smaller number connect mid-ocean ridges and subduction zones.
- The most famous example of this is the San Andreas Fault Zone of western North America.
- Another example of a transform boundary on land is the Alpine Fault of New Zealand.

Plate tectonics

The most common areas of tectonic earthquakes in the world are:

- Great Oceanic boulders (Pacific waters): Kamchatka in the east of Asia, Japan, the Philippines, Indonesia, the Aleut Islands in the west of America, California, Mexico, Chile, Peru.
- Mediterranean Himalayan Belts: Spain, Italy, North Africa, Yugoslavia, Greece, Turkey, Iran, India, Pakistan, Afghanistan, East Indian islands.
- Central part of Atlantic Ocean: Asor Islands and Iceland Island

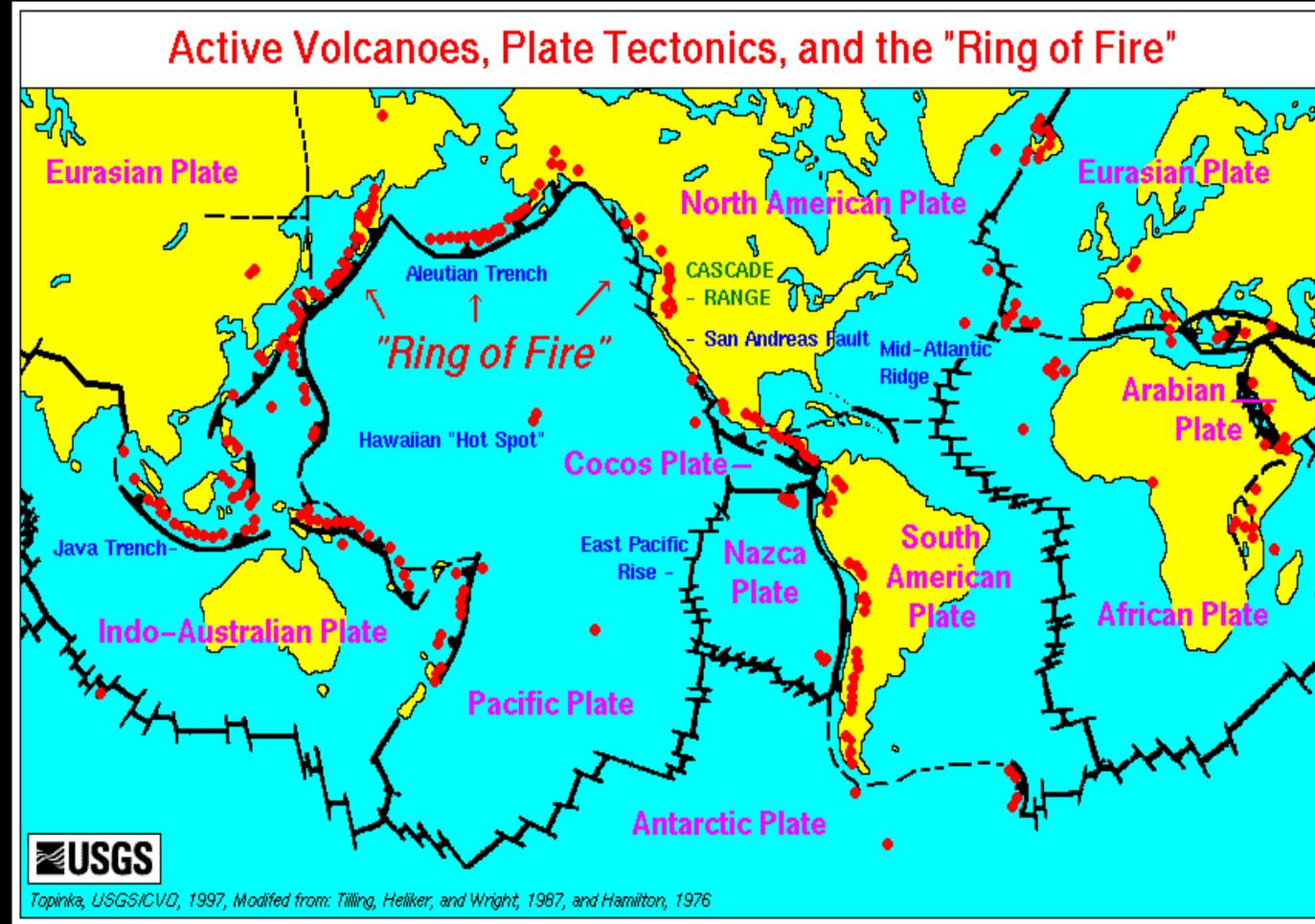
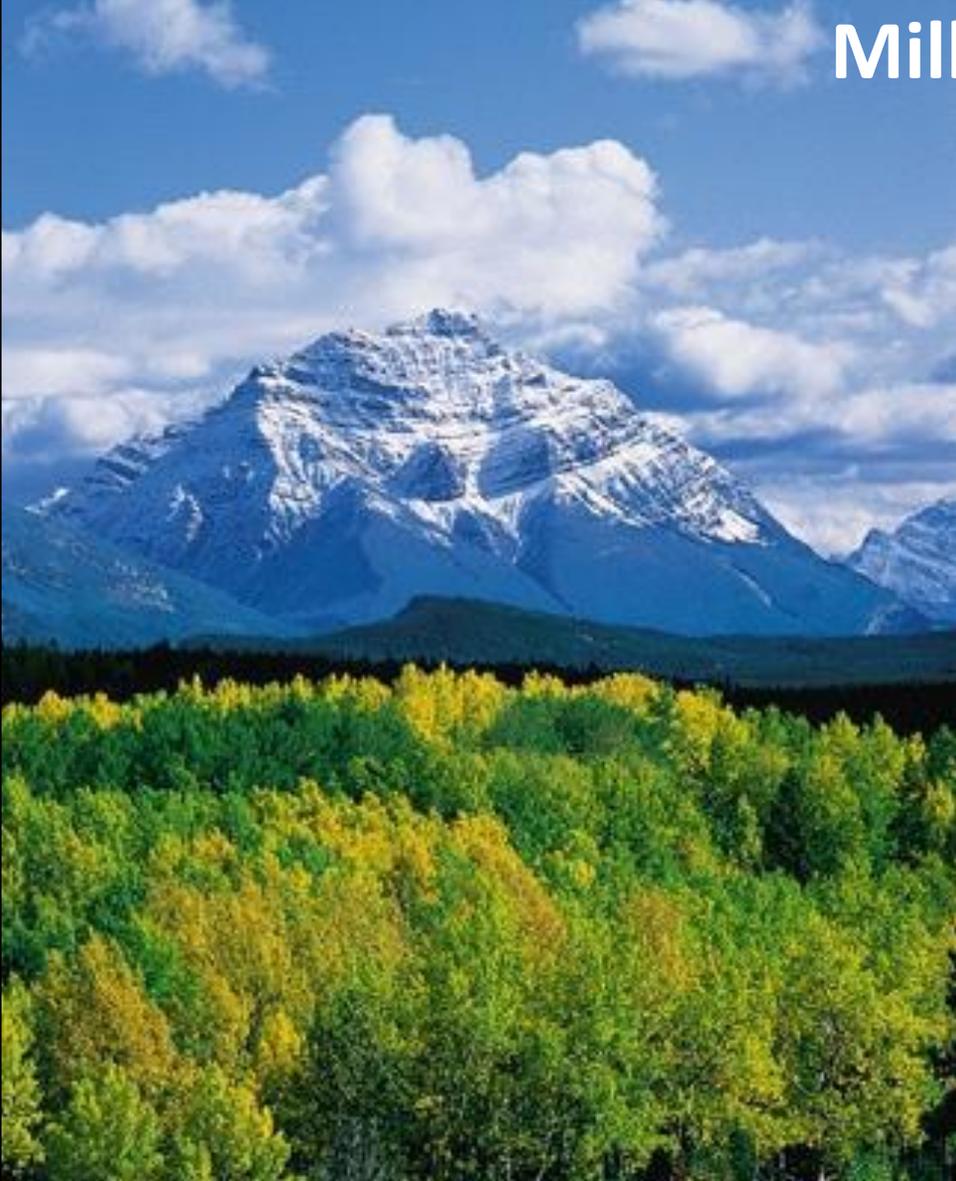


Plate tectonics

- The least common areas of tectonic earthquakes in the world are:
 - The Western of Australian,
 - The Eastern of USA and Canada
 - Iceland of N.West European-Grönland, Ískandinav peninsula,
 - Eastern Europe • Northern of Asia
 - Sourthern and Middlest of Africa

Geologic Time...



Millions years

A few seconds.



Geologic Time...

Washington May 17, 1980



September 10, 1980

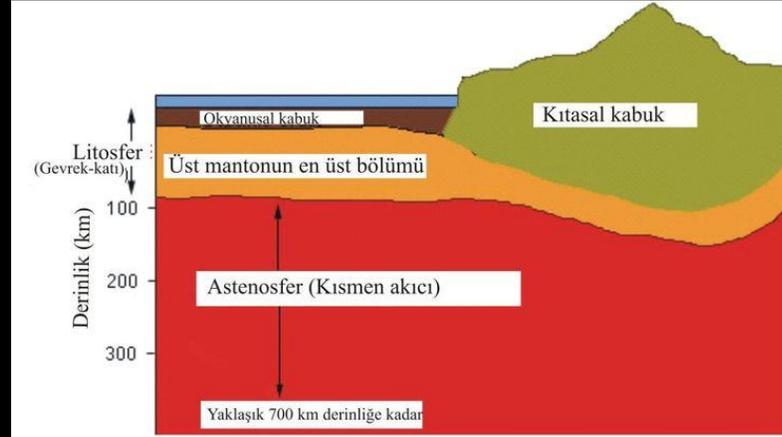


3. WEEK

MINERALS AND ROCKS GROUPS WHICH GENERATES
EARTH CRUST

EARTH CRUST

- Average depth of the earth crust thickness is 8-10 km.
- There are two different rocks which have different chemical and biological content.
 - Sial; average density: 2.7 gr/cm²
(granite, sandstone and limestone)
 - Sima; 2,8-3 gr/cm³
(bazalt type rocks)
- The sial layer in the ocean floor is almost absent.
- Sima reaches 8-10 km thickness.



Yeryuvarı'nın yapısını ve özelliklerini gösteren şematik tablo

Jeosferin adı	Kısımları	Ort.derinliği (Km)	Yaklaşık Kalınlığı (Km)	Hakim Elementleri	Yoğunluğu (gram cm ³)	Sıcaklık (°C)
Yerkabuğu (Litosfer)	Granitik Yerkabuğu veya Kıtasal Kabuk (Sial)		22	Si+Al	2,7- 2,8	
	Bazaltik Yerkabuğu veya Okyanusal Kabuk (Sima)	33	11	Si+Mg	3-3-3,5	
Manto (Pirosfer veya sima)	Üst manto veya Astenosfer	350	317	Fe+Mg	3,5 - 8	
	Orta Manto	740	390			
	Alt Manto	2890	2150			
Çekirdek (Barisfer veya Nife)	Dış Çekirdek	5000	2110	Ni+Fe	10-12	
	İç Çekirdek	6370	1370		12-13	

MATERIALS WHICH GENERATES THE CRUST

- Eight of the 108 elements found on the Earth's surface are very common.
- The 8 most common elements in the crust form 98.59% by weight of the ground shell.
- The remaining 98 elements constitute 1.4% by weight of the earth's crust.

Oxygen	%46.6
Silisium	%27.72
Aluminum	%8.13
Iron	%5
Calcium	%3.63
Sodium	%2.83
Potassium	%2.59
Magnesium	%2.09

MINERALS

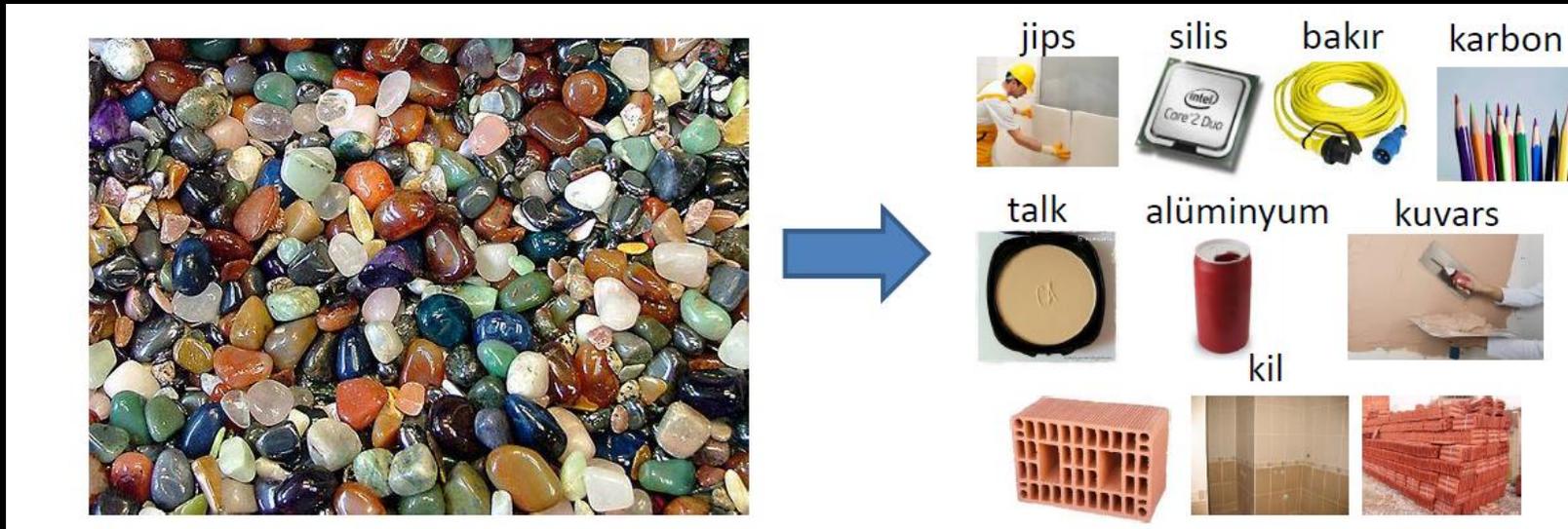
More than 2000 minerals on Earth generates rocks, rocks constitutes the crust.

- It is found naturally
- Has chemical composition(element or compound form).
- It can be expressed by a specific crystal system.
- It is mostly solid, liquid (mercury and water)
- Generally inorganic, at least organic compounds.



The Importance of Minerals

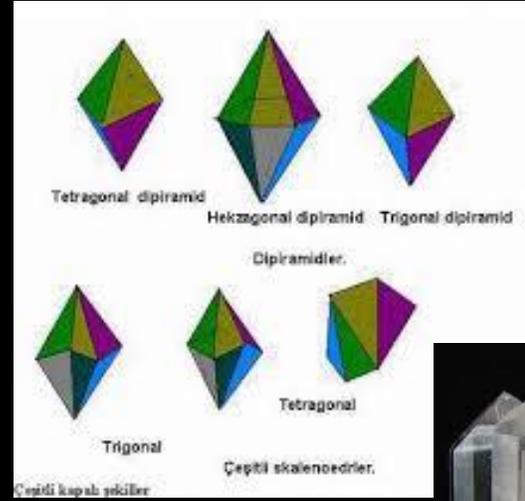
- Minerals and mines are part of the legacy that remains to us from the geological past. These are the basic building blocks of the solid part of the earth and are very important for construction geology;
- The minerals and rocks are the main sources for the production of automobiles, computers and many other things we use,
- Minerals and rocks play an important role in many earth processes such as landslides, coastal erosion and volcanic activity,
- Studies on minerals and rocks provide important information on earth history,
- Knowing process properties of the minerals and rocks provides to how the mechanisms in the earth and to understand how we can best manage the our earth resources



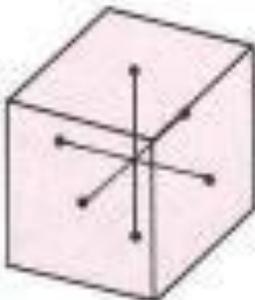
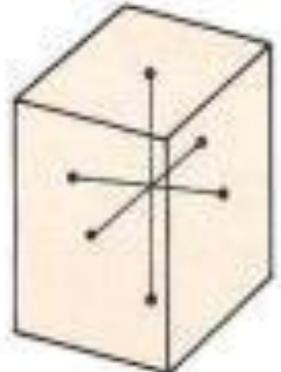
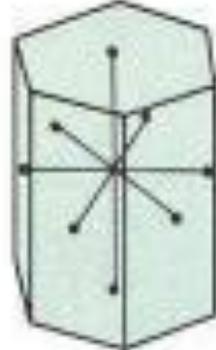
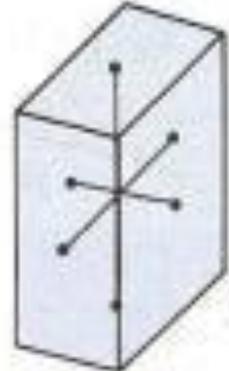
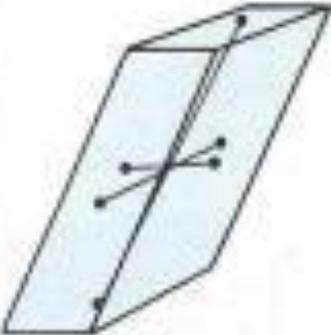
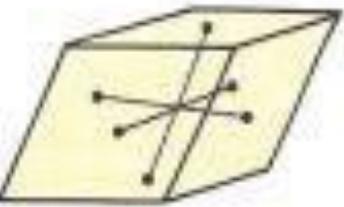
CRYSTAL SHAPES OF MINERALS

Crystal Systems and Examples / Kristallsysteme und Beispiele

cubic kubisch						
tetragonal						
hexagonal trigonal						
rhombic rhombisch						
monoclinic monoklin						
triclinic triklin						



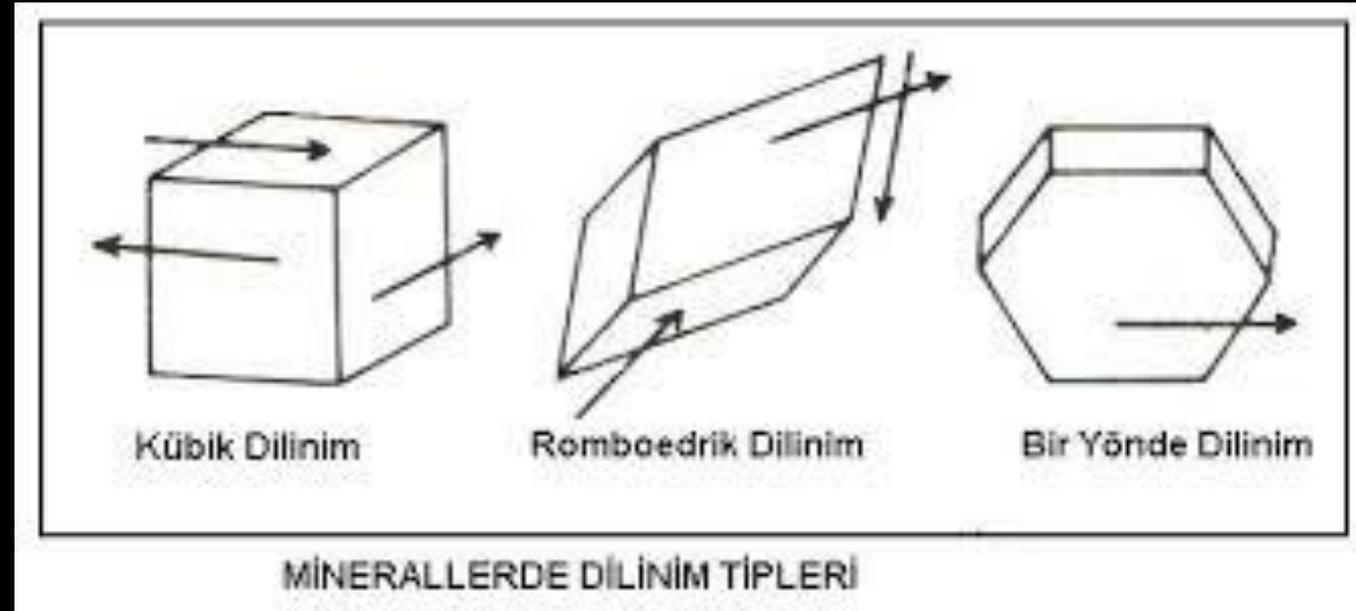
CRYSTAL SHAPES OF MINERALS

cubic	tetragonal	hexagonal	orthorhombic	monoclinic	triclinic
 A 3D diagram of a cubic crystal. It is a pink cube with a central point from which six lines radiate outwards to the centers of each of the six faces.	 A 3D diagram of a tetragonal crystal. It is an orange rectangular prism with a square base and a taller top. A central point has six lines radiating to the centers of the faces.	 A 3D diagram of a hexagonal crystal. It is a green hexagonal prism with a central point and six lines radiating to the centers of the faces.	 A 3D diagram of an orthorhombic crystal. It is a blue rectangular prism with a central point and six lines radiating to the centers of the faces.	 A 3D diagram of a monoclinic crystal. It is a light blue parallelepiped with a central point and six lines radiating to the centers of the faces.	 A 3D diagram of a triclinic crystal. It is a yellow parallelepiped with a central point and six lines radiating to the centers of the faces.
<p>examples: halite galena</p>	<p>examples: zircon chalcopyrite</p>	<p>examples: quartz calcite</p>	<p>examples: sulfur staurolite</p>	<p>examples: mica gypsum</p>	<p>examples: feldspar rhodonite</p>

PHYSICAL PROPERTIES OF MINERALS

The main physical properties of minerals;

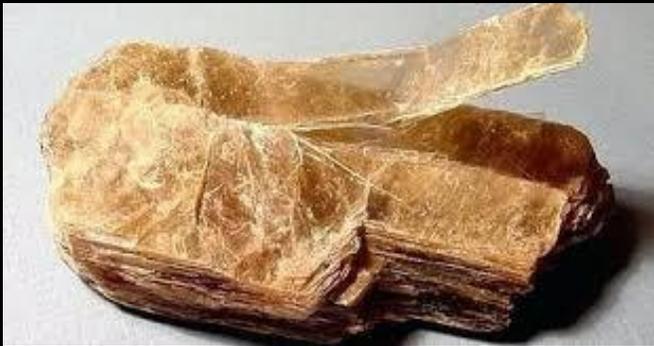
- Tenacity,
- Hardness,
- Fracture,
- Cleavage,
- Streak,
- Luster,
- Density



Tenacity

- The property of tenacity describes the behavior of a mineral under deformation. It describes the physical reaction of a mineral to externally applied stresses such as crushing, cutting, bending, and striking forces. Adjectives used to characterize various types of mineral tenacity include 'brittle,' 'flexible,' 'elastic,' 'malleable,' 'ductile,' and 'sectile'

Mica (turns back to its original state when twisted), Chlorite (remains twisted)



- When the hammer hit some minerals can become extended or plate.

Gold, silver, copper.



Tenacity

- *Brittle* - Breaks or powders easily.
- *Malleable* - can be hammered into thin sheets.
- *Sectile* - can be cut into thin shavings with a knife.
- *Ductile* - bends easily and does not return to its original shape.
- *Flexible* - bends somewhat and does not return to its original shape.
- *Elastic* - bends but does return to its original shape.

Tenacity

Most mineral species are **brittle**, and will crumble or fracture under pressure or upon the application of a blow. Such materials break or powder easily.

Antimony and quartz etc.



Hardness

Hardness has traditionally been defined as the level of difficulty with which a smooth surface of a mineral specimen may be scratched.

The hardness of a mineral species is dependent upon the strength of the bonds which compose its crystal structure.

Hardness is a property characteristic to each mineral species and can be very useful in identification.

Hardness

- Hardness minerals are resistance to scratching.
- It is the result of the cohesion between these molecules.
- It is determined with the aid Mohs hardness scale formed by mineral hardness.



Mohs Hardness Scale

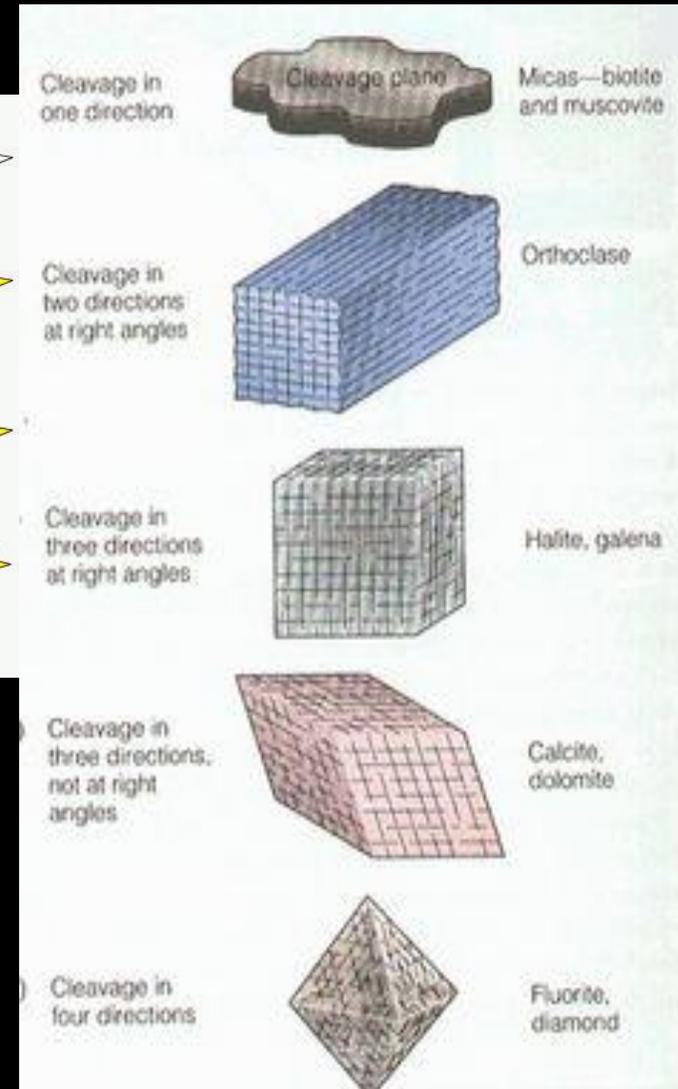
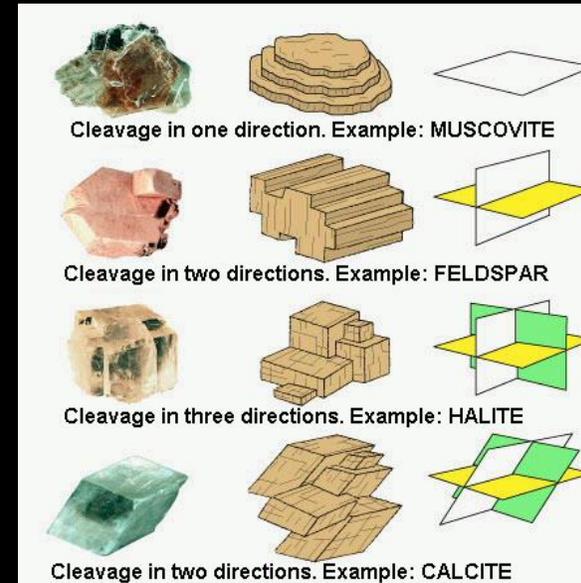
	Mineral Name	Scale Number	Common Object
↑ Increasing Hardness	 → Diamond	10	
	 → Corundum	9	 Masonry Drill Bit (8.5)
	Topaz	8	
	 → Quartz	7	 Steel Nail (6.5)
	Orthoclase	6	
	Apatite	5	 Knife/Glass Plate (5.5)
	 → Fluorite	4	 Copper Penny (3.5)
	Calcite	3	
	Gypsum	2	 Fingernail (2.5)
	 → Talc	1	

Hardness

RATING	DESCRIPTION	MINERAL EXAMPLE
1: VERY SOFT	EASILY CRUMBLES. CAN BE SCRATCHED WITH A FINGERNAIL (2.2)	TALC 
2: SOFT	CAN BE SCRATCHED WITH A FINGERNAIL (2.2)	GYPSUM 
3: SOFT	CAN BE SCRATCHED WITH A COPPER PENNY (3.5)	CALCITE 
4: SEMI-HARD	CAN BE SCRATCHED WITH A NAIL (5.2)	FLUORITE 
5: HARD	CAN BE SCRATCHED WITH A NAIL (5.2)	APATITE 
6: HARD	MINERAL WITH HARDNESS OF 6 OR MORE CAN SCRATCH GLASS	FELDSPAR 
7: VERY HARD	CAN BE SCRATCHED WITH A CONCRETE NAIL (7.5)	QUARTZ 
8: VERY HARD		TOPAZ 
9: EXTREMELY HARD	USED IN INDUSTRIAL TOOLS FOR CUTTING AND GRINDING	CORUNDUM 
10: THE HARDEST	DIAMOND IS USED TO CUT ALL MINERALS	DIAMOND 

Cleavaga

- A **cleavage plane** is a plane of structural weakness along which a mineral is likely to split smoothly.
- **Cleavage** thus refers to the splitting of a crystal between two parallel atomic planes.
- Despite the fact that every mineral belongs to a specified crystal system, not every mineral exhibits cleavage.
- Cleavage planes, if they exist, are always parallel to a potential crystal face. However, such planes are not necessarily parallel to the faces which the crystal actually displays. Fluorite, for example, has octahedral cleavage yet forms cubic crystals.
- Nonetheless, the property of cleavage, if it is present, can offer important information about the symmetry and inner structure of a crystal.



Fracture

If the mineral contains no planes of weakness, it will break along random directions called fracture. Several different kinds of fracture patterns are observed.

- Conchoidal fracture - breaks along smooth curved surfaces.
- Fibrous and splintery - similar to the way wood breaks.
- Hackly - jagged fractures with sharp edges.
- Uneven or Irregular - rough irregular surfaces



Fracture

Fracture is the way a mineral breaks when it doesn't break along cleavage planes.



Quartz has conchoidal fracture.



Asbestos has splintery or fibrous fracture.

Colour

- Color is sometimes an extremely diagnostic property of a mineral, for example olivine and epidote are almost always green in color.
- But, for some minerals it is not at all diagnostic because minerals can take on a variety of colors. These minerals are said to be allochromatic. For example quartz can be clear, white, black, pink, blue, or purple.



Streak

Streak is the color produced by a fine powder of the mineral when scratched on a streak plate. Often it is different than the color of the mineral in non-powdered form

Hematite: red; Limonite: brown; Magnetite: dark gray; Chromite: brown;
Magnetite: dark gray; Chromite: brown



Luster

Luster refers to the general appearance of a mineral surface to reflected light. Two general types of luster are designated as follows:

- ***Metallic*** - looks shiny like a metal. Usually opaque and gives black or dark colored streak.
- ***Non-metallic*** - Non metallic lusters are referred to as

vitreous - looks glassy - examples: clear quartz, tourmaline

resinous - looks resinous - examples: sphalerite, sulfur.

pearly - iridescent pearl-like - example: apophyllite.

greasy - appears to be covered with a thin layer of oil - example: nepheline.

silky - looks fibrous. - examples - some gypsum, serpentine, malachite.

adamantine - brilliant luster like diamond.

Structure

Kidney, chordal, chordal radial, concussion, lump and concentric.

- Kidney : Chalcedon, hematite
- Chordal: Asbestos, gypsum, calcite,
- Radial: Antimuan,
- Chordal radial: Pyrite, barite
- Concussion: Calcite, agate, pyrite, ag
- Lump: Flintstone
- Concentric: Agat, Calcedon



Specific Gravity

- Density refers to the mass per unit volume.
- Specific Gravity is the relative density, (weight of substance divided by the weight of an equal volume of water).
- In cgs units density is grams per cm^3 , and since water has a density of 1 g/cm^3 , specific gravity would have the same numerical value as density, but no units (units would cancel).
- Specific gravity is often a very diagnostic property for those minerals that have high specific gravities.
- In general, if a mineral has higher atomic number cations it has a higher specific gravity.

Specific Gravity

Mineral	Composition	Atomic # of Cation	Specific Gravity
Aragonite	CaCO_3	40.08	2.94
Strontianite	SrCO_3	87.82	3.78
Witherite	BaCO_3	137.34	4.31
Cerussite	PbCO_3	207.19	6.58

Specific Gravity

Specific gravity can usually be qualitatively measured by the heft of a mineral, in other words those with high specific gravities usually feel heavier.

Most common silicate minerals have a specific gravity between about 2.5 and 3.0. These would feel light compared to minerals with high specific gravities

Mineral	Composition	Specific Gravity
Graphite	C	2.23
Quartz	SiO ₂	2.65
Feldspars	(K,Na)AlSi ₃ O ₈	2.6 - 2.75
Fluorite	CaF ₂	3.18
Topaz	Al ₂ SiO ₄ (F,OH) ₂	3.53
Corundum	Al ₂ O ₃	4.02
Barite	BaSO ₄	4.45
Pyrite	FeS ₂	5.02
Galena	PbS	7.5
Cinnabar	HgS	8.1
Copper	Cu	8.9
Silver	Ag	10.5

Radioactivity

The radioactivity in the minerals comes from the uranium (U) and thorium (Th) found in them. Some elements such as potassium (K) and rubidium (Rb) also have a small amount of radioactivity.

It is aimed to determine the geological age by making use of the radioactivity feature in minerals.

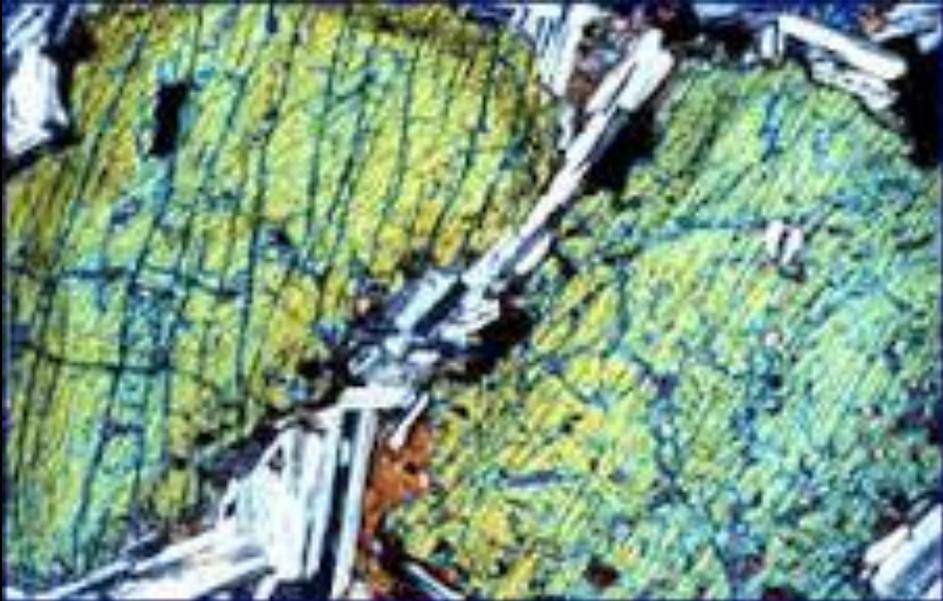
Chemical properties of the minerals

- Minerals have a special composition
 - It is determined by qualitative and quantitative analyzes and indicated by related formulas.
 - The same chemical composition, a different crystal system polymorphism (multidimensionality) is used.
 - Calcite with aragonite and diamond with graphite are polymorph minerals.
 - If minerals have the same shape but they have different chemical composition, isomorphism (coordination) is used.
 - Calcite (CaCO_3) dolomite ($\text{CaCO}_3 \cdot \text{MgCO}_3$) and siderite (FeCO_3) are isomorphic minerals

Bileşim	İsim	Sistem	Özgül Ağırlık (gr/cm^3)	Sertlik (Mohs)	Optik Özellik
CaCO_3	Kalsit	Romboedrik	2,7	3,0	Tek eksenli
	Aragonit	Ortorombik	2,9-3,0	3,5-4,0	Çift eksenli

Optical properties of the minerals

- The light-related properties of the minerals make up the optical properties of minerals. Optical properties of the minerals provides colours, fracture properties, single and double breaking properties, and the shapes they show under a polarizing microscope.
- Apart from these properties of minerals, some minerals have their own unique characteristics. Some minerals are magnetic, some minerals are radioactive, some minerals are good conductors, and some minerals are poor conductors. Some minerals have piezoelectric properties. Industry benefits from these properties of the minerals.



THE IMPORTANCE OF MINERALS FOR CIVIL ENGINEERING

- Many minerals are used as building materials in the construction industry.
- The concrete is generally obtained with a mixture of gravel, sand, cement and water
- Aggregate (aggregate): sand, gravel, crushed stone (blasted rock), slag (slag) as concrete (concrete) course used for the construction or artificial or both types often broken in various sizes up to 10cm or broken granular material stack (sand + gravel + natural rock material consisting of crushed stone).
- Gypsum (gypsum); ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ -Mohs hardness 2); colorless or white color is converted into plaster losing some of the water at 120°C . Plaster is used in indoor and outdoor applications.
- Various clay minerals have been used in mud bricks, bricks, tiles since ancient times.

THE IMPORTANCE OF MINERALS FOR CIVIL ENGINEERING

- Pale limestone which is white or black without include silisium and clay is used for making lime
 - Lime is used as a binder in mortar and also in stabilization of roads.
 - Limes which are found various colour and pattern and well polished are used as coating materials in the buildings
- Apart from this, the mechanical behavior of the clays directly reflects on the structures and causes the forces to deform the structures.

THE IMPORTANCE OF MINERALS FOR CIVIL ENGINEERING

- Feldspar and feldspathoids, which are found in the composition of many masses, can be very dangerous for engineering because they are decomposed by environmental factors.
 - The behaviors of fully matured clay minerals vary with increasing water uptake rate and progressive dissociation time.
 - Therefore, if feldspars are encountered in the basement, applications are carried out, ranging from project changes to new measures to extend the construction time.
 - In such cases, a series of precautions are taken, such as removal of the dissimilar part, placement of the foundation in a firm-to-undeformed section, selection of the concrete quality with the appropriate foundation system and construction of a good drainage network.

THE IMPORTANCE OF MINERALS FOR CIVIL ENGINEERING

- The concrete is generally obtained with a mixture of gravel, sand, cement and water depending on the importance and size of the engineering structure to be built, the chemistry of each of these components forming concrete may be primary importance.
- Especially aggregate (sand-gravel) which is added to concrete and constitutes 75-85% by weight of concrete is either naturally extracted from the earth's crust or artificially broken by rock masses.
- If quartz sand and pebbles are to be used as aggregates in a dam body concrete, they must be well studied.
- The high alkaline cement in the concrete is affected by the hydration caused by the hardening of the concrete and the alkali such as sodium-potassium in the cement are released.
- Quartz, opal, chalcedony, agate, tridimite sand and gravel composed of siliceous minerals and silicates interact with the alkalis released in the concrete, cause expansion, cracking and fracturing of the concrete.
- This results in concrete can be easily damaged by being non-resistant against external influences. The volume percentages of the silica minerals constituting the aggregate component in the concrete are as follows; Opal 0,20%; Calcinedon 5%; Acid volcanic mass% 3

The main minerals found in the rocks

The rocks are mineral assemblages; either by the combination of various minerals or pieces of stone, or by the accumulation of a large number of single minerals.

Main minerals: Mass forming and called minerals play a role in their nomenclature. A number of them are 20 to 30.

Quartz, feldspar, nepheline, olivine etc. They play a role in the name of this rock minerals.

Accessory minerals: tourmaline, magnetite, zircon, etc. There are also minerals that rarely enter into the masses and have no effect on their naming.

Secondary minerals: New minerals that have formed as a result of various environmental factors of the existing main minerals, mostly due to the effects of decomposition, metamorphism and melt, and their composition.

Kaolin, serpentine, chlorite, zeolite etc.

The main minerals found in the rocks

Mineral	Kimyasal Bileşimi	Kristal Sistemi	Dilinimi	Sertliği (Mohs)	Yoğunluğu (gr/cm ³)
Kuvars	SiO ₂	Heksagonal	± Yok	7	2,65
Ortoz-Sanidin	KAlSi ₃ O ₈	Monoklinal	İyi, çok iyi	6	2,56
Albit	NaAlSi ₃ O ₈	Trikilinal	Çok iyi	6	2,62
Anortit	CaAl ₂ Si ₂ O ₈	Triklinial	İyi	6	2,72
Nefelin	NaAlSiO ₄	Heksagonal	Zayıf	6	2,60
Lösit	KAlSi ₂ O ₆	Kübik	Zayıf	6	2,47
Biyotit	K(Mg,Fe) ₃ (AlSi ₃ O ₁₀)(OH) ₂	Monoklinal	Çok iyi	2,5	2,80
Muskovit	KAl ₂ (AlSi ₃ O ₁₀)(OH) ₂	Monoklinal	Çok iyi	2,5	2,90
Klorit	(Mg,Fe,Al) ₆ (Al,Si) ₄ O ₁₀ (OH) ₈	Monoklinal	Çok iyi	2,5	2,60-3,30
Ojit	Ca(Mg,Fe,Al)(Al,Si) ₂ O ₆	Monoklinal	İyi	6	3,25-3,55
Enstatit	MgSiO ₃	Ortorombik	İyi	6	3,20-3,90
Hornblend	NaCa ₂ (Mg,Fe,Al) ₅ (Si,Al) ₈ O ₂₂ (OH) ₂	Monoklinal	İyi	6	3,0-3,4
Pirop	Mg ₃ Al ₂ (SiO ₄) ₃	Kübik	Yok	7-7,5	3,56
Almandin	Fe ₃ Al ₂ (SiO ₄) ₃	Kübik	Yok	7-7,5	4,32
Olivin	(Mg,Fe) ₂ SiO ₄	Ortorombik	Belirsiz	6,5	3,22
Apatit	Ca ₅ (PO ₄) ₃ (F,Cl,OH)	Heksagonal	Belirsiz	5	3,20
Zirkon	ZrSiO ₄	Tetragonal	Belirsiz	7,5	4,60-4,70
Andalusit	Al ₂ SiO ₅	Ortorombik	Orta	7,5	3,15
Kalsit	CaCO ₃	Trigonal	Çok iyi	2,7 (3)	2,71
Jips	CaSO ₄ .2H ₂ O	Monoklinal	Çok iyi	2	2,50-2,80

Main minerals in Magmatic rocks;

- Quartz
- Feldspar: Orthoclase, Plagioclase
- Feldspathoid: leucite, nepheline; Sodalite
- Pyroxene: Bronzite, Enstatite, Hipersten, Augite, Diyalage, Deiodopsite
- Amphibole: Hornblend
- Mica: Biotite, Muscovite
- Perido: Olivin



Main minerals in sedimentary rocks

- Magmatic rock fragments (especially quartz and feldspar)
- Clay minerals
- Calcite, Dolomite
- Siderite
- Limonite



Main minerals in metamorphic rocks

- Quartz
- Feldspar
- Biotite, Muscovite
- Hornblend
- Epidote
- Garnet
- Silimanite
- Andalusite
- Calcite
- Serpentine
- Talc
- Chlorite

Metamorphic Minerals



Secondary minerals

- The most important ones are Tourmaline, Magnetite, Ilmenite, Rutil, Apatite, Zircon and Topaz.



Quartz Group

- It is found in Magmatic, metamorphic and sedimentary masses.
- Crystal system Hexagonal,
- Density is 2.65 and hardness is 7.
- Usually colorless and transparent.
- Other elements that come into crystal structure can offer different colors. In this case, it gets different names. Some contain liquid or gaseous inclusions.
- Quartz has not cleavage.
- It offers its own unique twinning.
- The face of the fracture is conchoidal, glassy and oily.
- It is not affected from acids apart from fluorur.
- Quartz which is pure and clean is used in optical and chemical industry and ceramic industry
- Bright and colorful varieties (Necefaşı, Amethyst, Sitrin, Agat, etc.) are used in making ornaments.

Quartz Group

- There are many types of quartz. The most important ones are;
Chalcedony; chrysoprase; Heliotrop; Agate; Flintstone; Jasper; Silicified Tree; Opal;
- If quartz sand and gravel are to be used as building material, it is necessary to carry out the analyzes thoroughly.
- When the quartz and its species used as aggregates in cement start to harden with high alkali cement, hydro treatment occurs and Na, K etc. The alkalies are released.
- All silicates, especially opal, chalcedony and agate, and siliceous minerals act with alkalis, causing the concrete material to expand, crack, break down and eventually reduce its strength.
- Therefore, cement-aggregate reactions become important according to the size and importance of the structure to be constructed.



Quartz Group

Yüksek alkali çimento+agrega

Sertleşirken hidratasyon olayları

Alkaliler (Na, K vs.) açığa çıkar

Silikat ve silisli minerallere etkir

Betonda genişleme, çatlama, dağılma gelişir. Mukavemet azalır.

Feldspars

- They form 40-50% of the earth's crust, their composition is potassium-sodium-calcium aluminum silicate.
- The crystal system is Monoclinical or Triclinical.
- There are cleavages in two directions and by the angle between the cleavage planes;
 - 1. orthoclases**
 - 2. Plagioclase**

Feldspars

Ortoklas Group; Cleavage angles are 90 degrees. They are crystallized in the monoclinic system. Orthoclase mineral is important in this group.

Plagioklas Group; the angles of cleavage of feldspar is 86,80.

This group of minerals;

Albite and Anorthite consist of a mixture of different proportions.

They are crystallized in the triclinic system. Colors are variable. The fracture faces are glassy.

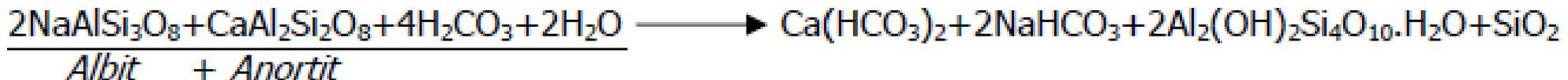
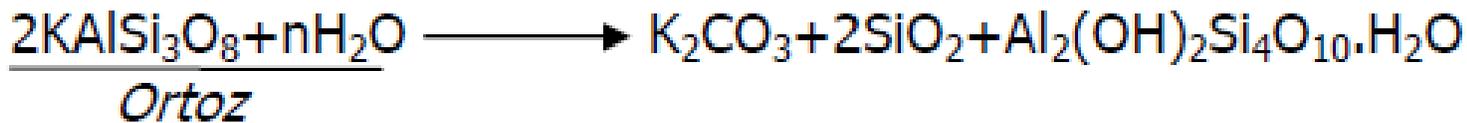
- Their hardness is 6-6,5 and their specific weights are 2,60-2,76. They are found in different proportions in the composition of Magmatic stones and play an important role in naming these rocks.
- It is also found in metamorphic and sedimentary rocks.

Feldspars

- Nomenclature is based on the percentage of Na and Ca in the compositions. The main minerals of this group are;
 1. Albite (NaAl_2O_3), (90-100% Albite + 0-10% Anorthite)
 2. Oligoclas
 3. Andesine (50% Albite + 50% Anorthite)
 4. Labrador
 5. Bitovnit
 6. Anorthite ($\text{CaAl}_2\text{O}_3\text{SiO}_2$), (90-100 Anorthite + 0-10% Albite)

Decomposition of feldspar;

- As a result of the decomposition events, quartz occurs with clay minerals that are soluble in water.
- Factors affecting decomposition; Climate, temperature, humidity, the effect of superficial acid waters and fumarols or hydrothermal processes which are deeply magic.
- The shape and depth of the variable increase in volume is the result of decomposition of 5-30%.
- The carrying capacity of the decomposition mass and pressure resistance are reduced. When building on such masses, it is necessary to pay attention to disintegration events.



Kaolenization-argillisation

Feldispat+(CO₂+H₂O)+iklim (sıcaklık-nem)+yüzeysel asidik sular

↓
Kil mineralleri (kaolen)+kuvars±zeolit+%5-30 hacim artışı

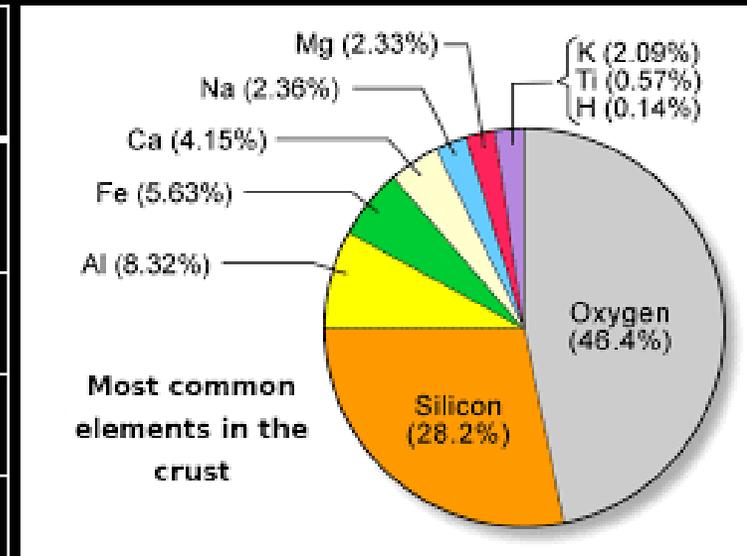
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Taşıma gücü ve basınç dayanımında düşme

4. WEEK

Rock forming minerals

- Rocks is assemblies of minerals, it is formed by various minerals or rock fragments come together or consists of a large number of accumulations of a single mineral.
- It is found in the majority of 8 element minerals as rock builder, representing more than 98% of the weight of the continental crust.

Oxygen	%46.6
Silisium	%27.72
Aluminum	%8.13
Iron	%5
Calcium	%3.63
Sodium	%2.83
Potassium	%2.59
Magnesium	%2.09

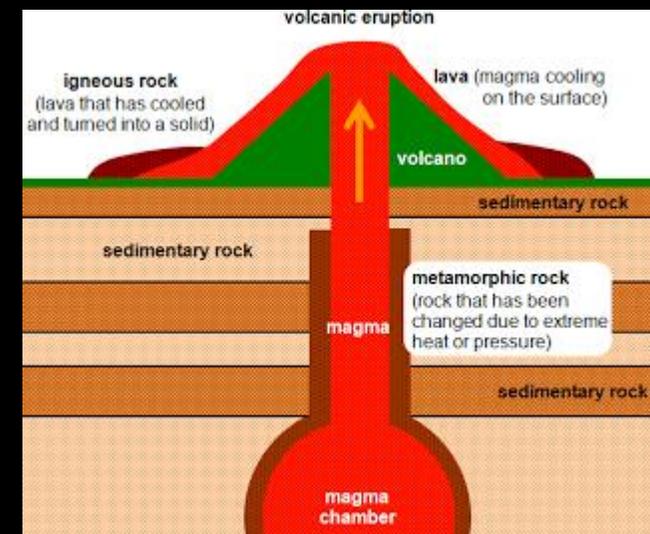
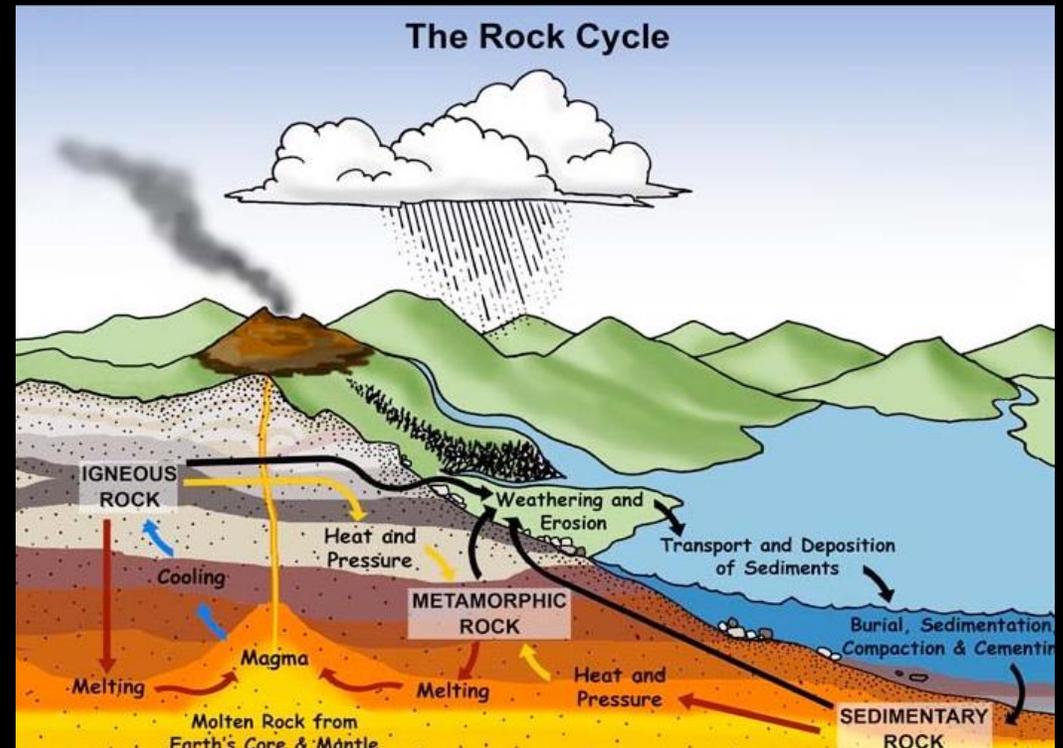


The rocks that make up the Earth's crust are the various minerals or single minerals, rock fragments, or both mineral and rock fragments.

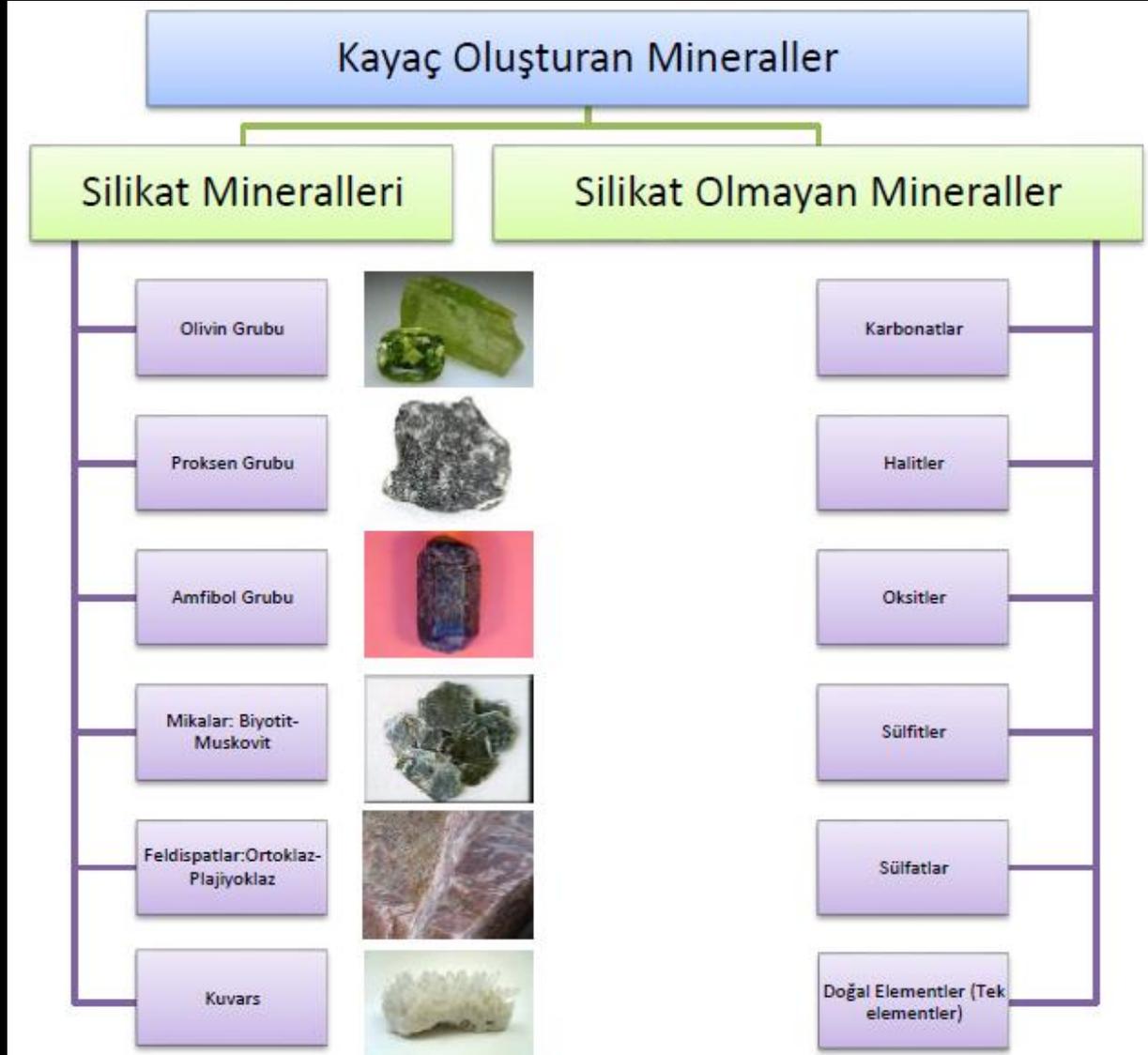
For example, Magmatic rocks such as granite, gabbro, syenite are formed by minerals; marble, quartzite is formed by a single mineral; various types of sandstones and conglomerates are formed by rocks and minerals.

The rocks are studied according to their formation conditions and their origins;

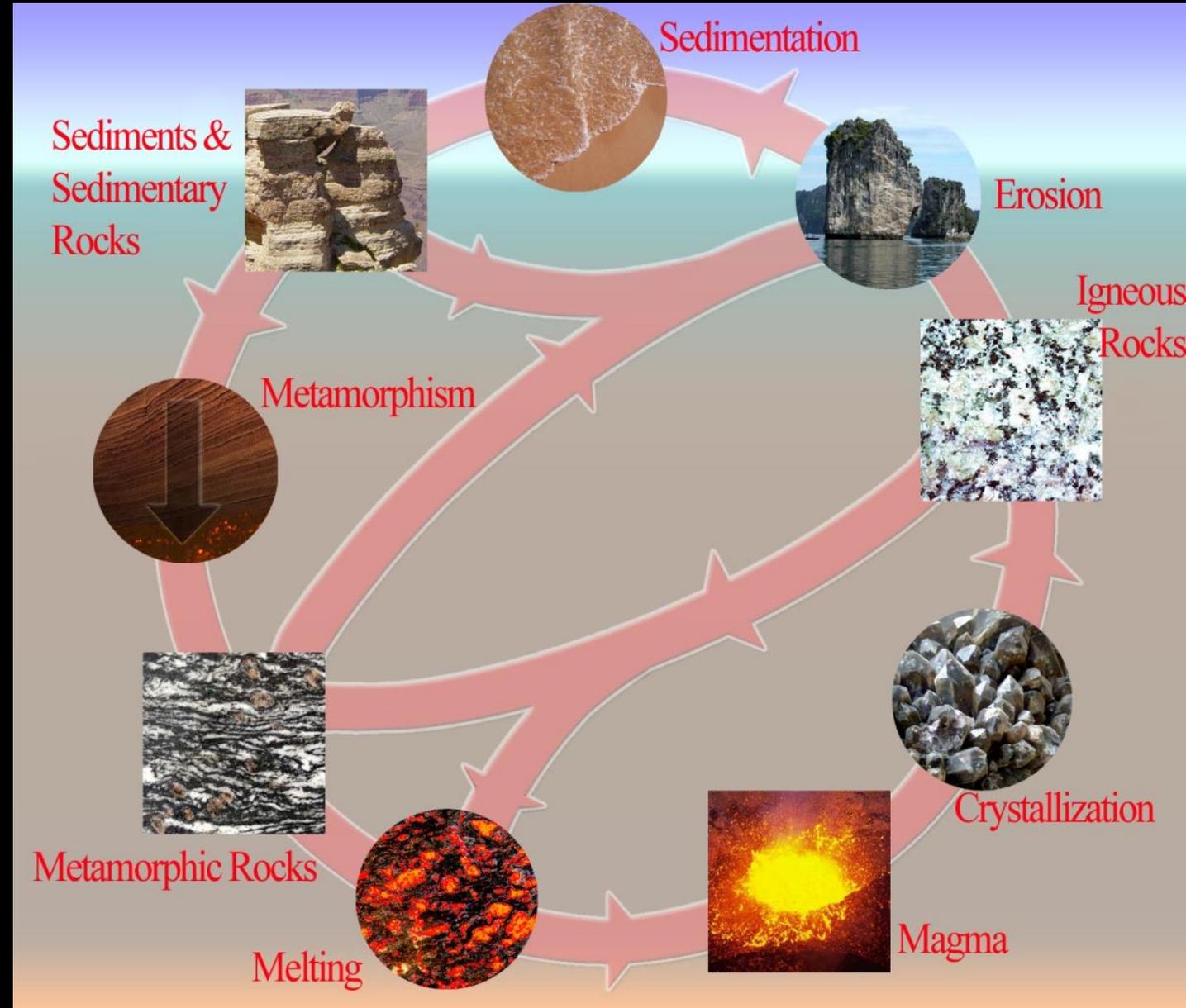
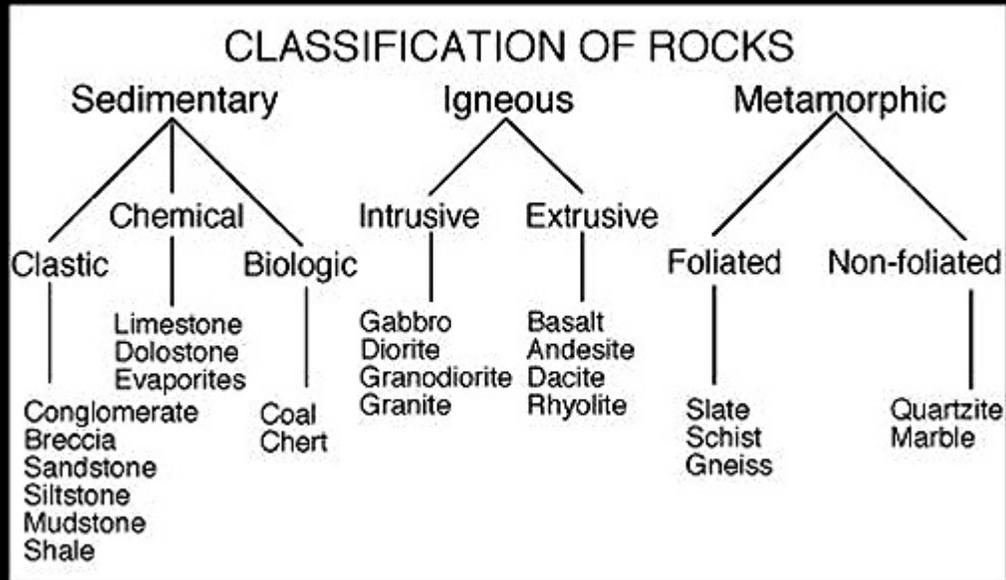
- Magmatic rocks;
- Sedimentary rocks;
- Metamorphic rocks;



Rock forming minerals



Rock Cycle



Magmatic Rocks

- If the hot and fluid melt "magma" found in the depths of the earth is cooled or crystallized, it is called as "Magmatic rocks"
- Magma contains O, Si, Al, Fe, Ca, Mg, Na, K together with water, other rare earth elements as well as CO₂, SO₂ in vapor form.

Magmatic Rock Forming Minerals

- Main minerals; Quartz, feldspar (orthoclase, plagioclase), nepheline, sodalite, leucite, mica, muscovite, biotite, pyroxene, amphibole olivine.
- Accessory minerals; Zircon, sphen, magnetite, ilmenite, hematite, apatite, pyrite, rutile, corundum, garnet.

Acidic (felsic) if it contains 65% silica and a large amount of aluminum, sodium, potassium and a small amount of calcium, iron and magnesium;

Neutral (intermediate) if it contains 52-65% silica;

It is possible to call it basic (mafic) component magma if it contains more than 45-52% of silica, calcium, iron and magnesium.

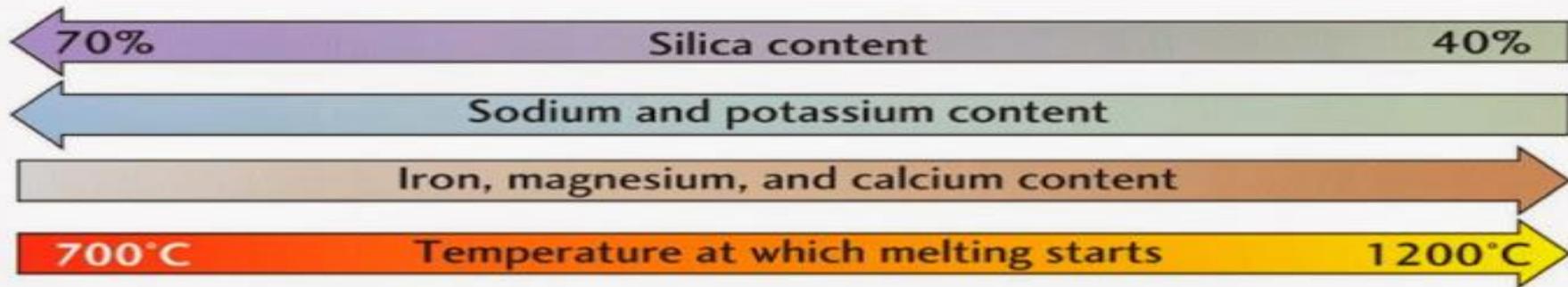
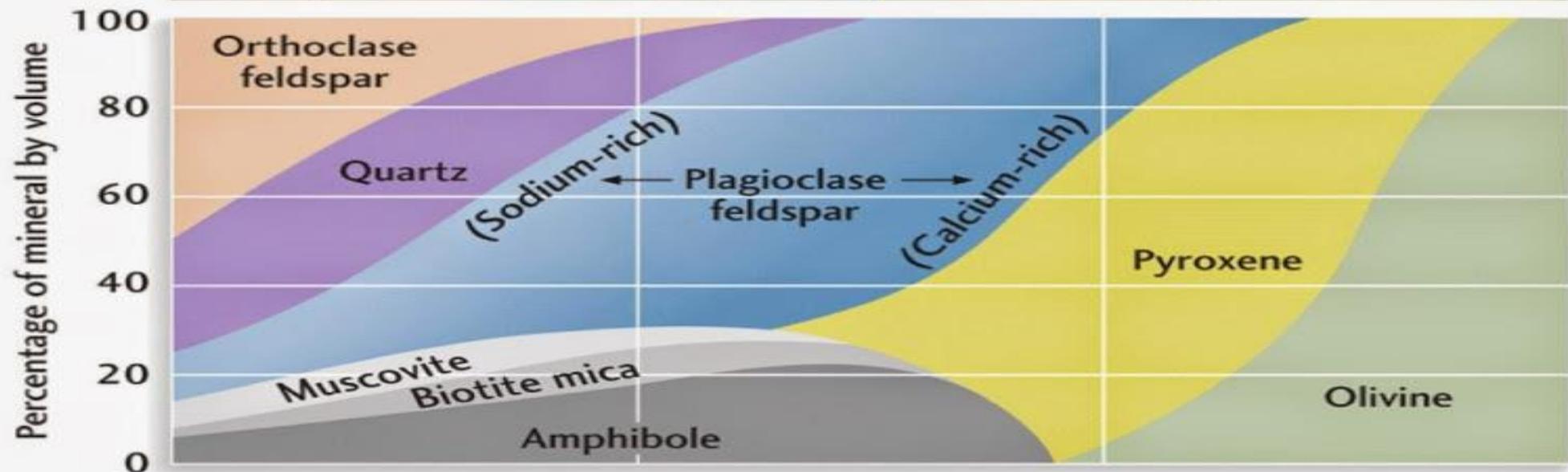
- The basic magma often reflects the composition of the mantle source area.
- The oceanic crust is a basic compound and richer in Fe and Mg elements. Therefore oceanic crust is more intense than the continental crust and the asthenosphere directly owned properties hosting site.
- The continental crust, on the other hand, consists of minerals rich in silicon and aluminum. While the magma that passes through the continental crust, it takes the material from the crust in its place. As a result of this, its composition returns from basic to neutral and acidic composition. Therefore, magmatic rock in the continental crust is richer and less intensive in terms of SiO₂ mineral.

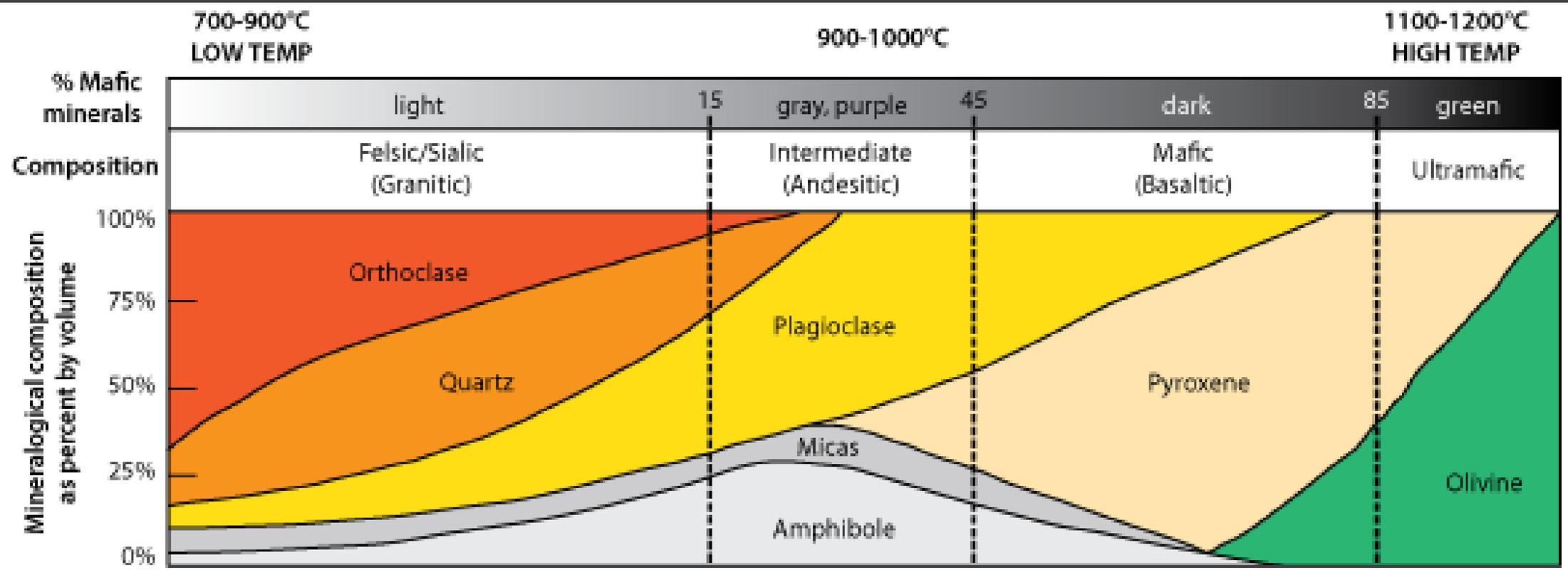
Magmatic rocks

The change in the amount of SiO_2 in the bodies of magmatic rocks causes significant changes in the color of the rocks.

The minerals and rocks rich in basic iron and nickel elements are darker, while minerals and rock which is acidic in nature and the richer in SiO_2 are lighter.

Composition	FELSIC	INTERMEDIATE	MAFIC	ULTRAMAFIC
Rock types	Granite Rhyolite	Diorite Andesite	Gabbro Basalt	Peridotite





Texture	Rock names			
Coarse-grained	Granite	Diorite	Gabbro	Peridotite
Fine-grained	Rhyolite	Andesite	Basalt	Uncommon (rarely encountered)
Pyroclastic	Rhyolite Tuff	Andesite Tuff	Basalt Tuff	
Glassy	Obsidian			
Vesicular	Pumice (like meringue)		Scoria	

Magmatic rocks

- The composition of the magmatic rock develops depending on the composition of the last melt crystallized the rock.
 - If the melt is poorly silicic, the rocks consist poorly siliceous and richly dark ferromagnesian minerals, they are formed by dark colored rocks in the melt. For example, Gabro
 - If the ratio of silica is high, quartz crystals are formed because the rocks are rich in silica and they have so less dark colored minerals
 - All of the magmatic rocks such as peridotite can be composed of ferromagnesian (dark colored) minerals. The composition of these rocks is not the same as the composition of the melt.

Magma Tipi	Silis İçeriği (%)	Sodyum, Potasyum ve Alüminyum	Kalsiyum, Demir ve Magnezyum
Ultramafik	<45	↓ Artar	↑ Artar
Mafik	45-52		
Ortaç	53-65		
Felsik	>65		

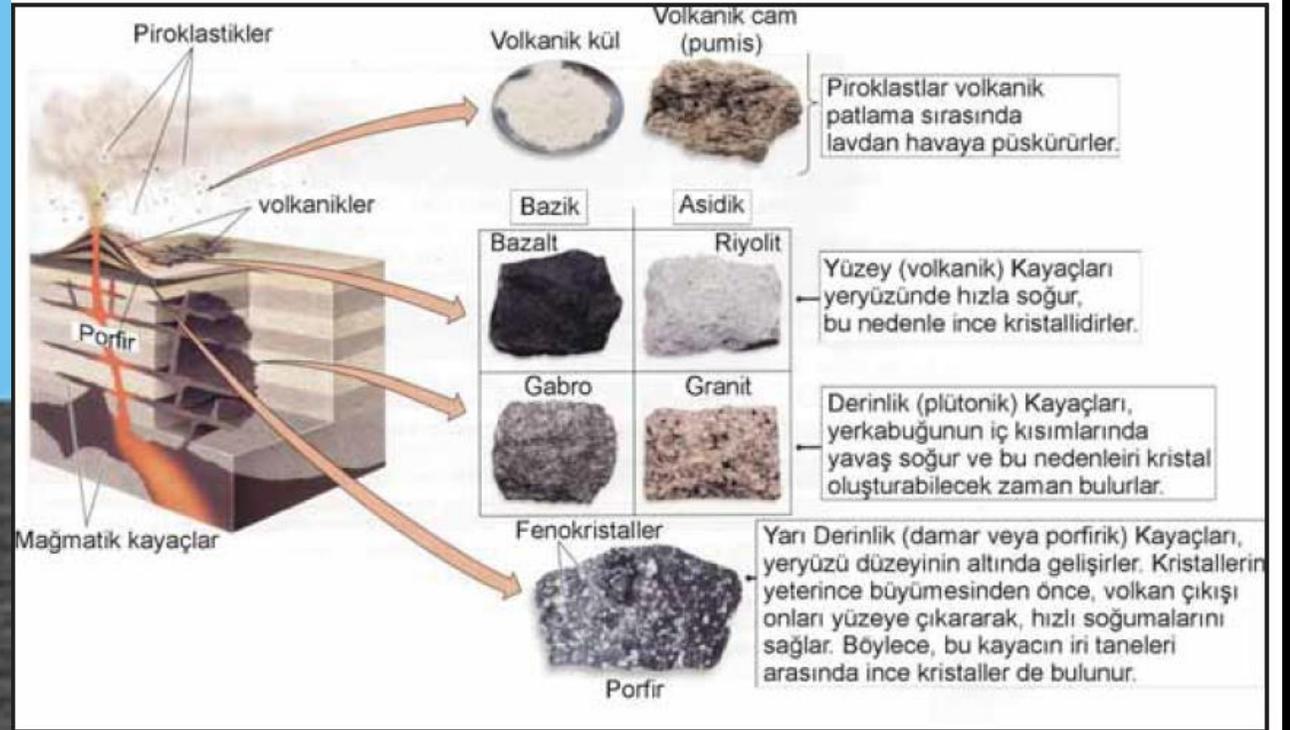
Magmatic rocks

- The magma, which is hot and fluid, moves in different depths under different composition and pressure.
- Plutonic rocks are formed underground. They involve the "intrusion" or insertion of magma between other rocks, which then cools below the surface.
- Volcanic rocks are formed above ground. They involve the "extrusion" or eruption of magma, which then is called "lava." The lava cools upon or very close to the surface. Volcanic rocks can also form from "ash", which is simply pulverized rock blown into the air (not like the "ash" that results from burning wood) -- larger rocks are "bombs."

Extrusive igneous rocks cool quickly and as a result these rocks are fine grained or has lack of crystal growth.

Intrusive igneous rocks are formed from magma that cools slowly and as a result these rocks are coarse grained.

Magma chamber



Şekil 3.4. Derinlik, yarı derinlik ve yüzey kayaçlarının yer kabuğunda oluştuğu bölgeler ile asidik ve bazik karakterli kayaçlara ait örnekler (Press vd., 2004).

Magmatic rocks

- Intrusive rocks;
 - They are sturdy and durable (because they are made of crystal only)
Granite, syenite
- Extrusive rocks;
 - It is semi-crystalline and the crystals are floating in a dough
Andesite, rhyolite, basalt
- Semi-deep rocks;
 - They form a transition between the depth rocks and the surface rocks.
 - The slurry is not glassy, and other rocks are composed of small crystals in cracks and crevices are located.
Granitporphyr, quartosporphyr, syenitporphyr

Magmatic rocks

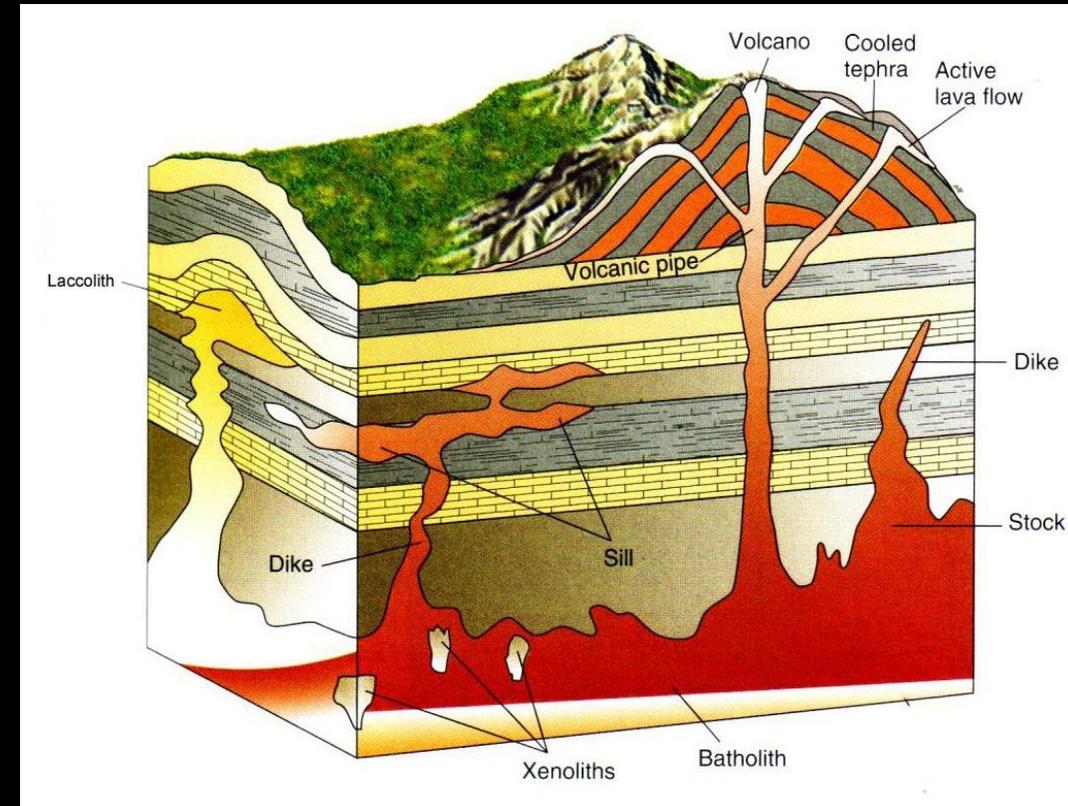
- **Plutonic rocks**; crystallize below Earth's surface, and the slow cooling that occurs there allows large crystals to form. Examples of intrusive igneous rocks are **diorite, gabbro, granite, pegmatite, and peridotite**.
- After occurring solidifies dozens or even hundreds over the years up to millions continental uplift as a result of erosion of sediments that can reach several kilometers thick on them as a result of wear of such rocks are seen today on the ground surface in the current topography.
 - Çavuşbaşı granodiorite pluton on the Anatolian side of Istanbul and granite pluton of Gebze-Sancaktepe.

Magmatic rocks

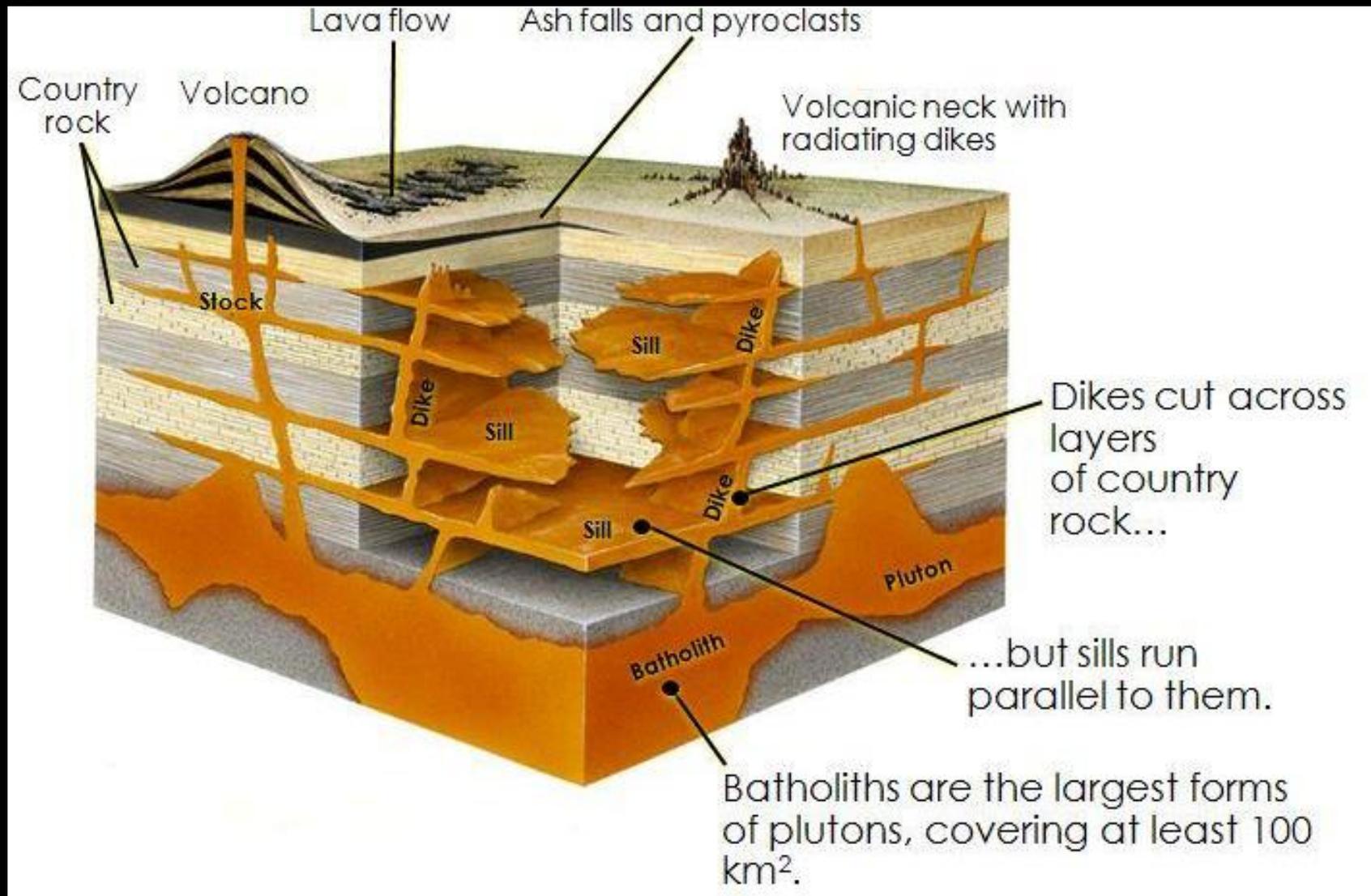
- **Semi-deep rocks;** Magmatic rocks are called semi-deep rocks as the magmatic rocks which eventually solidify on the earth in the course of upward movement following the discontinuities such as cracks and cracks in the upper part of the lithosphere.
- Intrusive rocks consist of coarse, very coarse grains of crystals that develop due to slow cooling and less pressure in spaces and cracks at depths near the earth. Granite pegmatite, gabbro pegmatite, etc. named.

Magmatic rocks

Commonly observed forms of intrusive rocks observed in the field are: dykes, sills, laccoliths, batholiths, phacoliths, lopolith, volcanic necks, batholiths and chonoliths.



Magmatic rocks



DYKES: Dykes and sills are the most common forms of the intrusive Magmatic bodies.

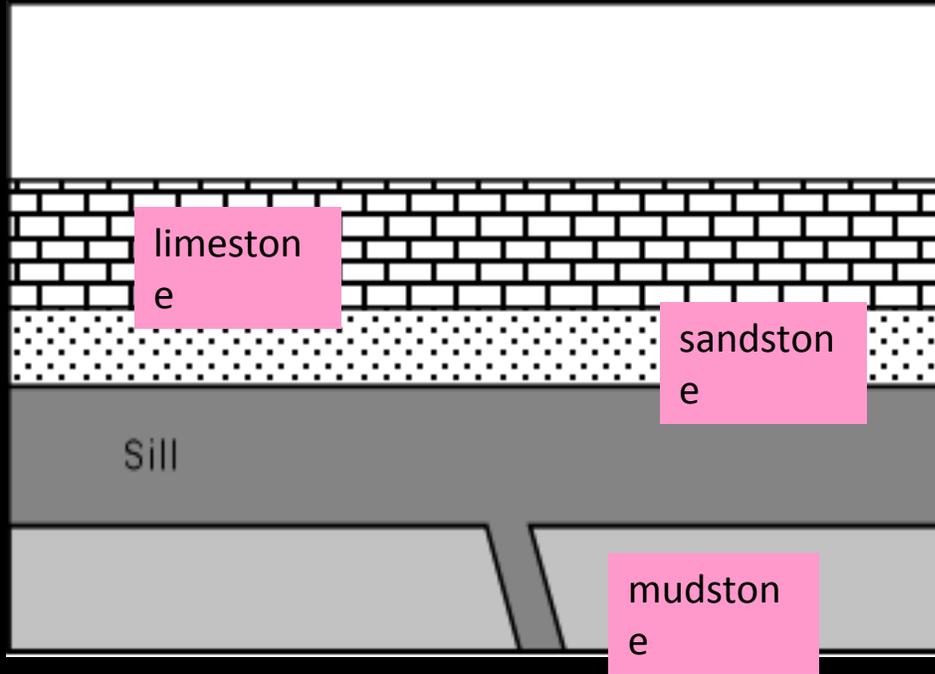
- They are discordant
- Cut across the bedding of the rocks in which they intrude
- Vertical to steeply inclined and sheet like body (extensive in lateral dimension)
- Thickness vary widely from an inch up to hundred of feet
- Injected through fractures, joints, and weak planes

- Quartz-Dolerite dykes of Midland valley of Scotland are about 50-60 km long and up to 30m thick. Few places some dykes are very short up to few meters and as thin as few cm.



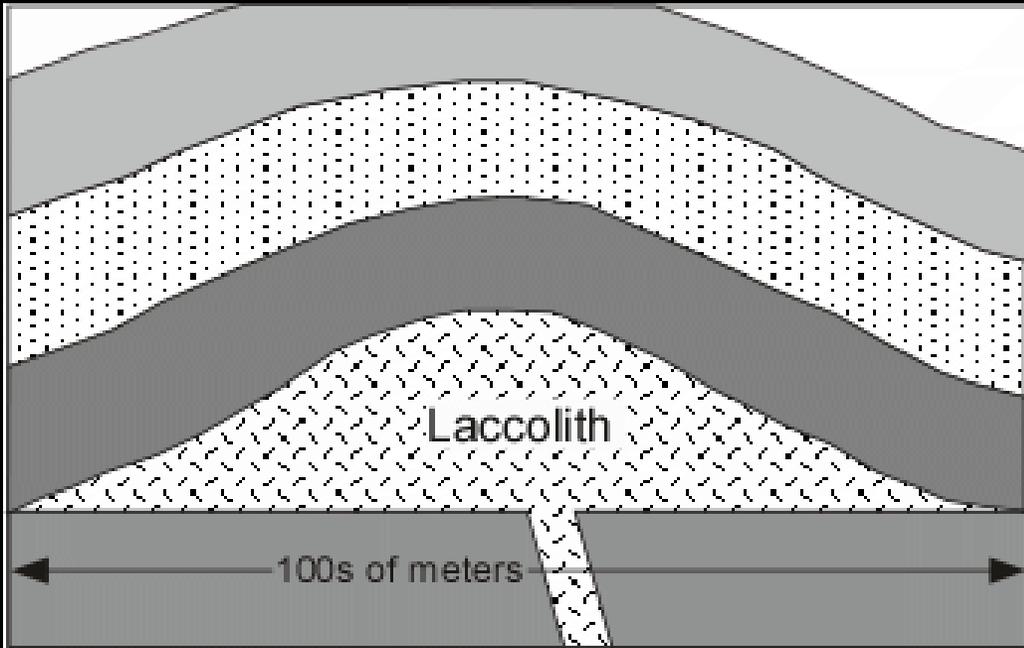
SILLS: Sills are relatively thin tabular sheet like body that penetrates parallel to the bedding planes.

- Laterally it may extends for 100s of km and up to 10 km in width.
- Lateral extend mainly depends on the hydrostatic force, temperature, degree of fluidity or viscosity, weight of overlying sediment column.
- Since basic magma are more fluid then acidic magma- mostly sills are made up of gabros, dolorites and basalts



Spreads parallel to the bedding planes of the rocks, hence concordant in nature.

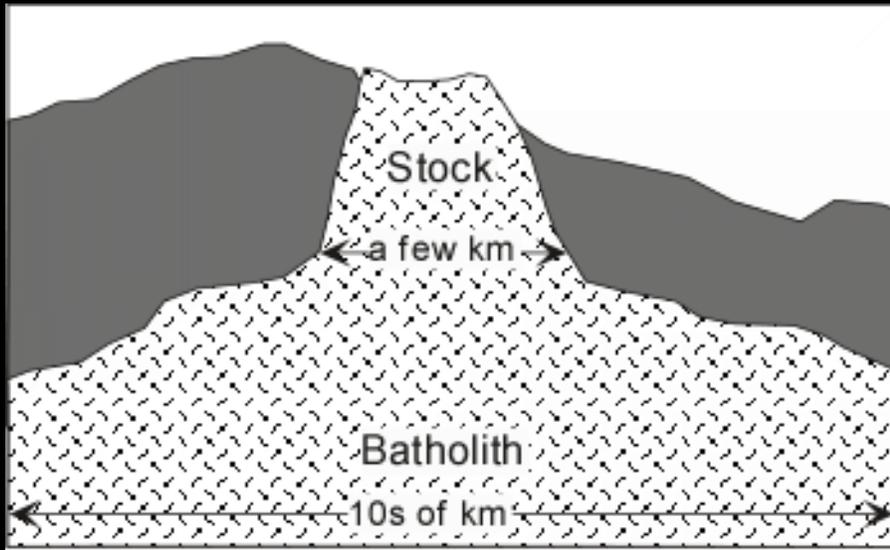
LACCOLITHS: It is a concordant body, with flat bottom and convex upward. It is dome shaped.



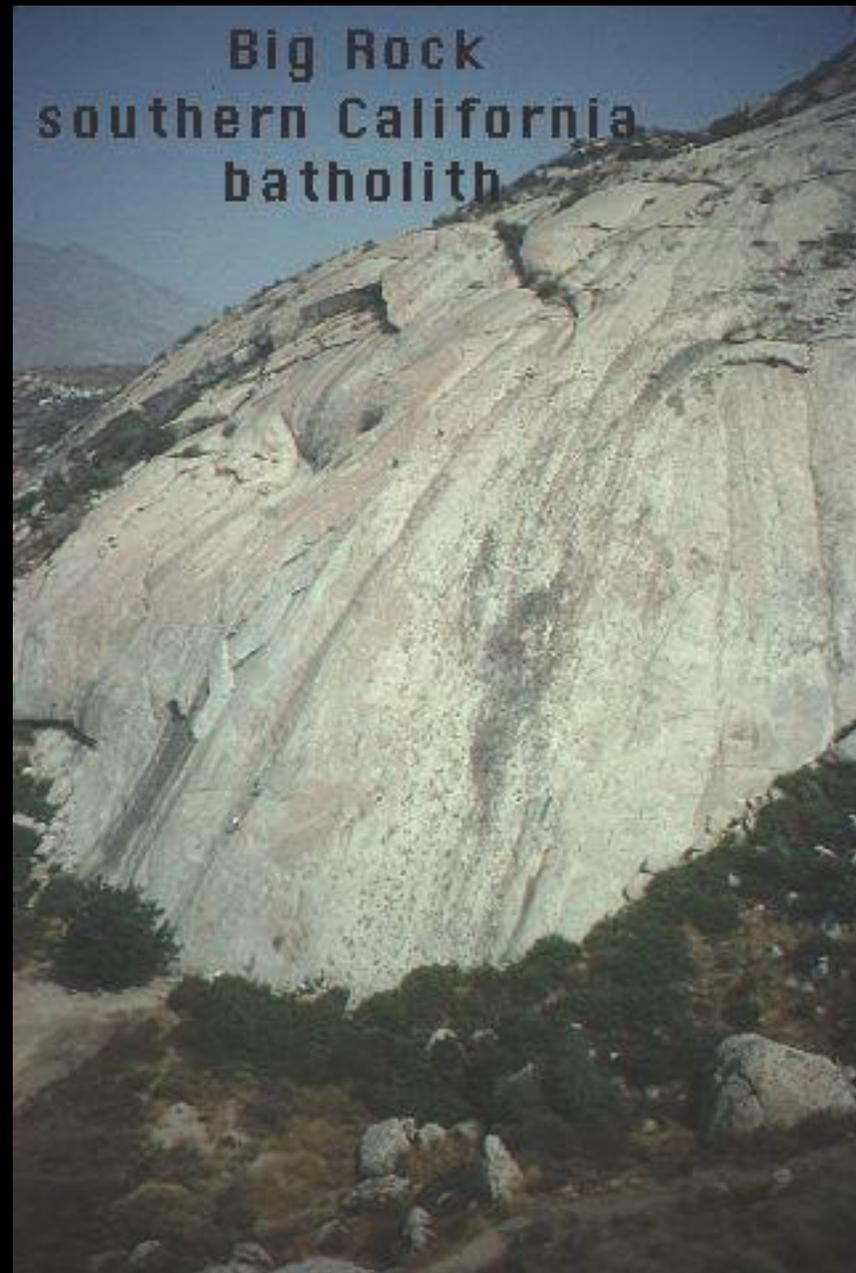
- When viscous magma is injected rapidly along the bedding, as it cannot spread it pushes up the overlying layers and keep on piling up.
- It causes folding of the overlying rock layers.

BATHOLITHS: are the largest kind of plutons, irregular in shape and occupies large area.

- **Their side sloping away from each other which makes them larger and large downwards extending to greater depth**
- **Their occurrence is commonly associated with the mountain-building process**
- **These are either granites or granodiorites in composition**



Stocks: *Are smaller irregular bodies with 10 km in maximum dimension, and are associated with batholiths.*

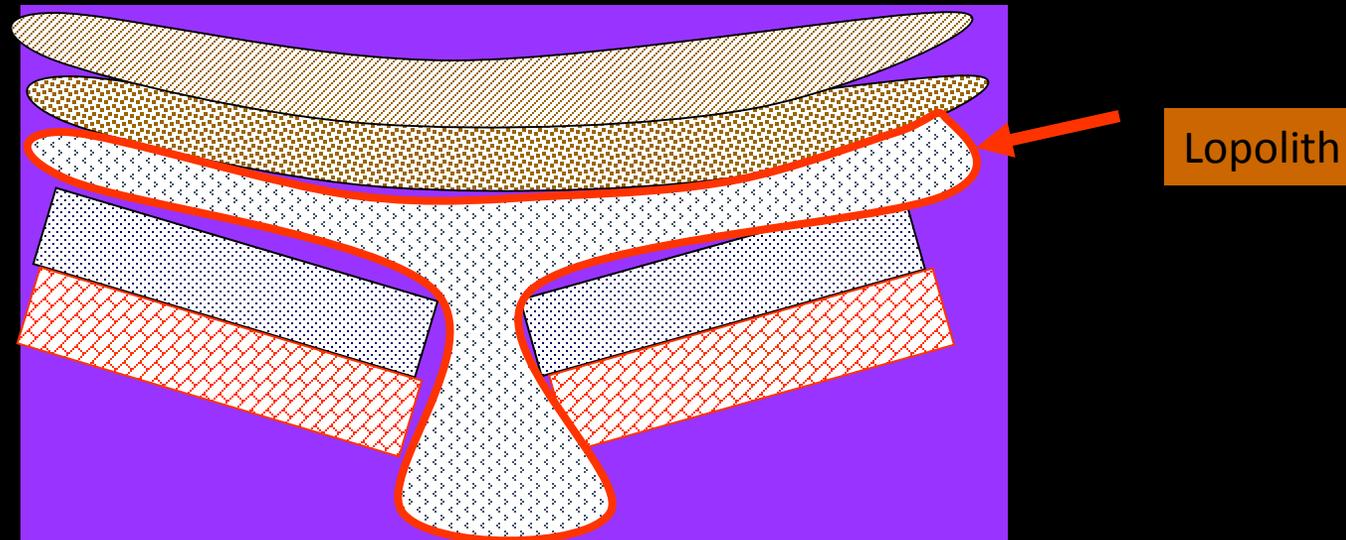


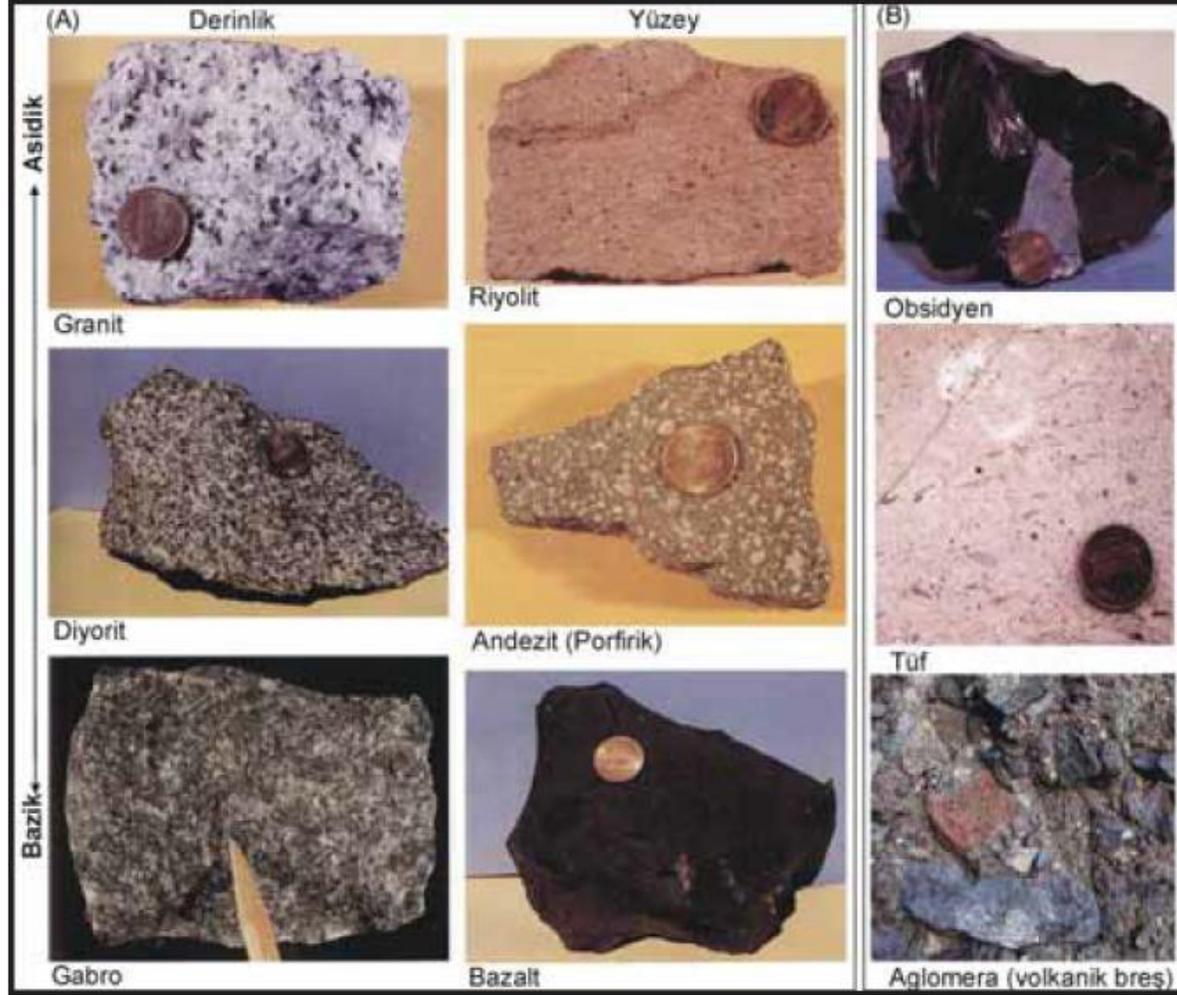
PHACOLITHS: These are concordant bodies that occurs along the crests and troughs of the folded sedimentary strata.



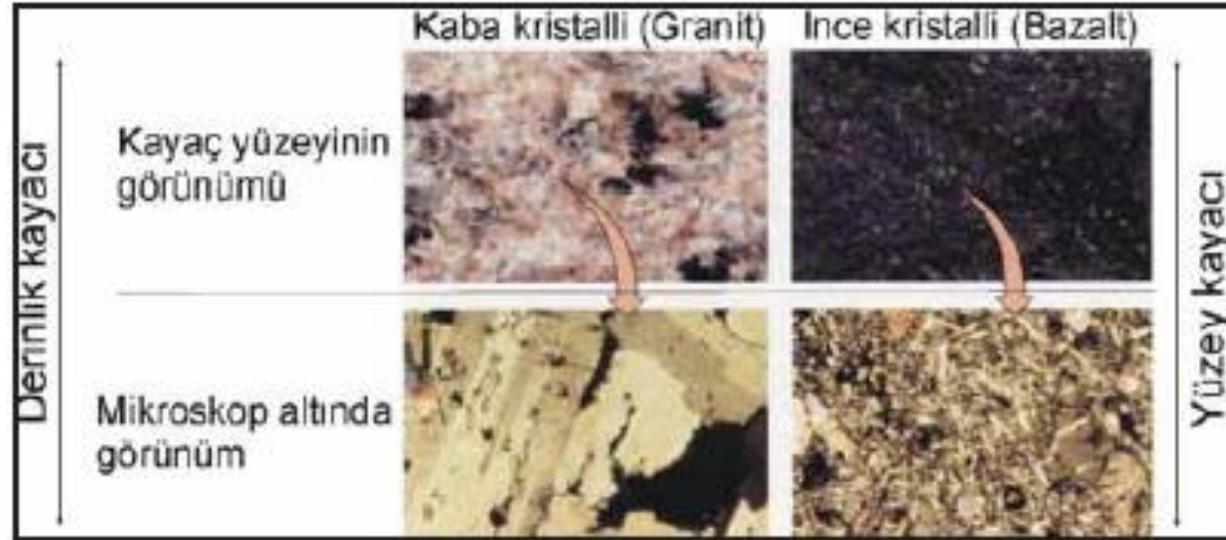
LOPOLITHS: These are basin or saucer-shaped concordant bodies with top nearly flat and convex bottom.

They are very huge body with diameter up to 150 miles (app. 240 km)





Şekil 3.7. Kimyasal bileşimlerine ve oluşum derinliklerine göre kayaç örnekleri (Press vd., 2004).



Şekil 3.6. Derinlik kayalarından granit ile diğer bir derinlik kayacı olan gabronun yüzeyde oluşmuş kayacı bazalt arasındaki kristal büyüklükleri arasındaki dokusal farkın kayaç örneği üzerindeki (üstte) ve mikroskop altındaki (altta) görüntüleri (Press vd., 2004).

Magmatic rocks

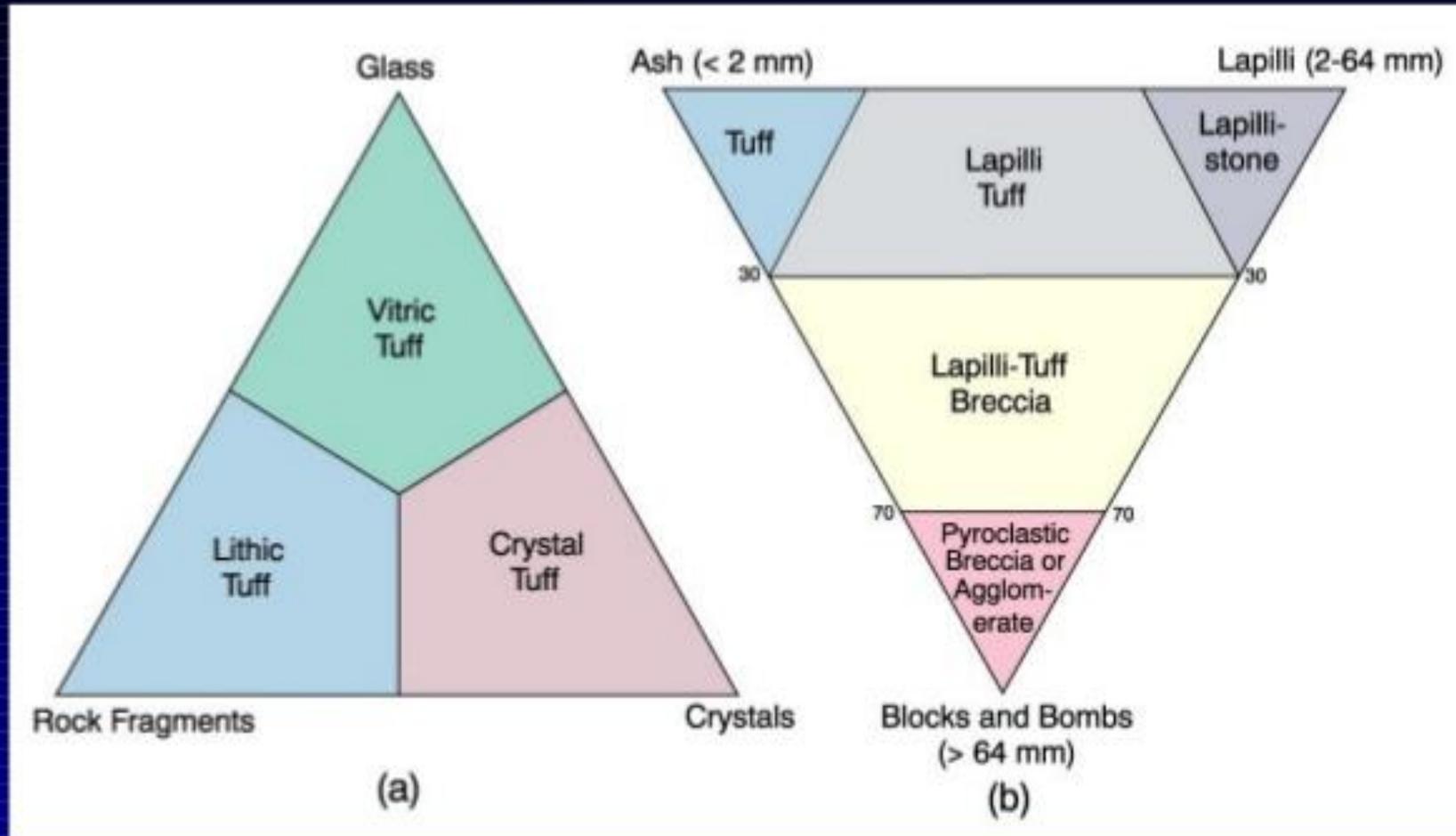
- Extrusive Magmatic rocks are rocks formed by cooling magma lavas near a surface with a chimney or by moving to the surface. The crystals are small because they cool quickly. They usually form a small crystalline matrix (porphyric texture) surrounding large crystals. In general, except for special conditions, the crystals are coarse grained rocks and the differences are fine-grained or glassy. For example when granite rocks from the depths to the surface through cracks reaches, rhyolites, diorites: andesite-dacite; Syenite: trachyte; Gabbro: basalt; Peridotite is called picrite. When the lavas cool very rapidly on the surface, there is no crystallization and the resulting texture is glassy.

Magmatic rocks

- Melt state magma can rise to the surface of the earth's crust cracks and crevices. Volcanic rocks form from magma emerging from the earth. The magma, which is fluid when it reaches the earth, solidifies after a while. Solidified magma is called "lava". Because the lava suddenly cool down, they show glassy texture. The volcanic material can sometimes rise to the earth as a solid. The grain size of the solid material changes. Classification according to grain size;
 - Block or volcano bomb larger than 32 mm,
 - lapilli those between 4-32 mm,
 - volcano ash in between 0.25-4 mm
 - Those larger than 0.25 mm are also called dust.

Classification of Igneous Rocks

Pyroclastic rocks



Classification of the pyroclastic rocks. **a.** Based on type of material. After Pettijohn (1975) *Sedimentary Rocks*, Harper & Row, and Schmid (1981) *Geology*, **9**, 40-43. **b.** Based on the size of the material. After Fisher (1966) *Earth Sci. Rev.*, **1**, 287-298.

Structure and texture of igneous rocks

- Structure: The natural architectural features of a rock mass seen on the ground in large scale. Here, the physical appearance of the rock mass determines character of the rock-forming mineral assemblages and plays an important role in shaping the rock mass structure. Faults are taken into account in the concept of platoon structure in joints, folds, flow or sedimentary rocks.

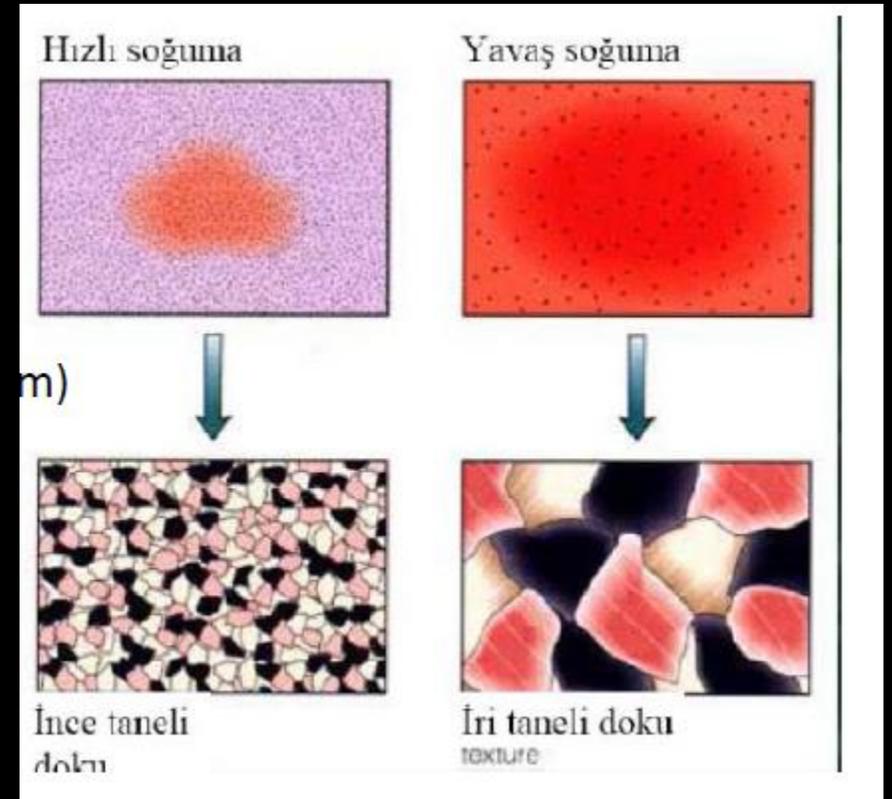
Structure and texture of igneous rocks

- Texture; The geometry and appearance of the minerals of the rocks, including the appearance, size, shape and arrangement of the rocks forming the rock, including their size, shape and sequence under a hand sample or microscope.
- The texture of Magmatic rocks depends on the conditions of the environment, such as **magma or lava cooling rate, pressure and temperature, and slow cooling** usually causes deep crystals to form at depths of the earth, and this texture is called fanaritic texture. The texture of minerals is visible in all plutonic rocks. In surface rocks, very fine grained texture, which is formed by rapid cooling on the surface and near the surface, can be seen only by magnification. Large grain crystals and the texture formed by the small crystals surrounding them are also called porphyric texture.

Structure and texture of igneous rocks

- In Magmatic rocks, they are classified according to their crystallization grades (whole or semi-crystalline, all glass), crystal sizes (phaneretic, aphanatic), grain sizes in relation to each other (granular and porphyric texture) and their relations with each other (panidiomorphic and hidiomorphic).
- The textures of Magmatic rocks play a major role in determining the physical and mechanical properties of Magmatic rocks, mineral species, mineral sizes, dissociation states. These qualities play an important role in the use of Magmatic rocks as construction or building materials.

- Textures by crystallization degree
 - Holocrystalline (all crystalline) texture
 - Hypocrystalline texture (semicrystalline)
 - Holohyalin (crystalline / vitreous) texture
- Textures according to the crystal size
 - Afaneritic (<1 mm)
 - Faneritic (distinguishable by 5mm-1mm)
 - Pegmatitic (very coarse > 5 mm)
 - Porfiric (two-phase)
- Textures according to the crystal forms
 - Diamorph (self-shaping)
 - Hypidiomorph (partially self-shaped)
 - Csnomorph (self-formed)



Textures by crystallization degree

Holocrystalline (all crystalline) texture

Hypocrystalline tissue (semicrystalline)

Holohyalin (crystalline / vitreous) tissue



Hipokristalin



Hipokrsitalin



Holohyalin



Holokristalin



Holokristalin

Textures according to the crystal size

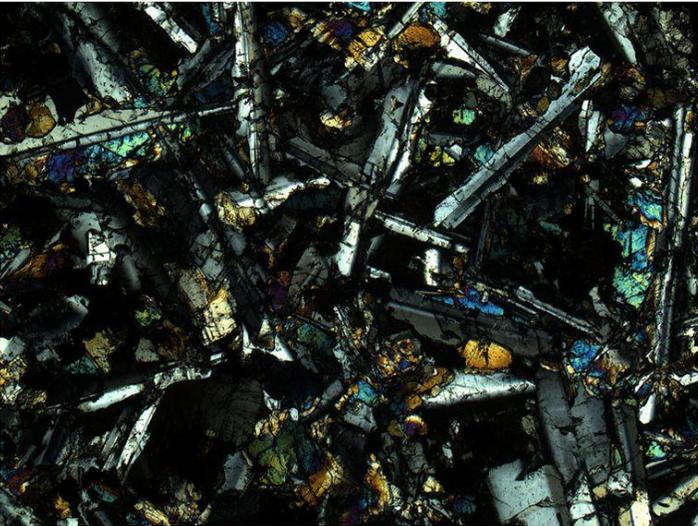
Afanitic (The particles are invisible <1 mm)

Faneritic (distinguishable by 5mm-1mm)

Pegmatitic (very coarse > 5 mm)

Porifric (two-phase)

Afanitik dokulu bir kayaç, bazalt (ince kesit)



Porfirik dokulu Rapakivi Graniti (mostra örneği)



Faneritic Granodiorite

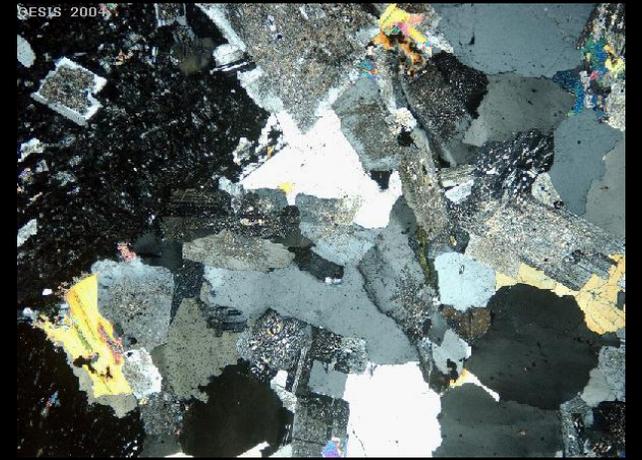
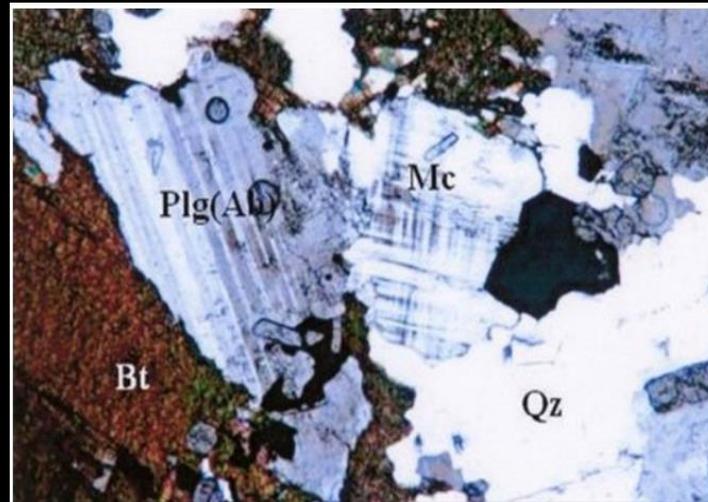
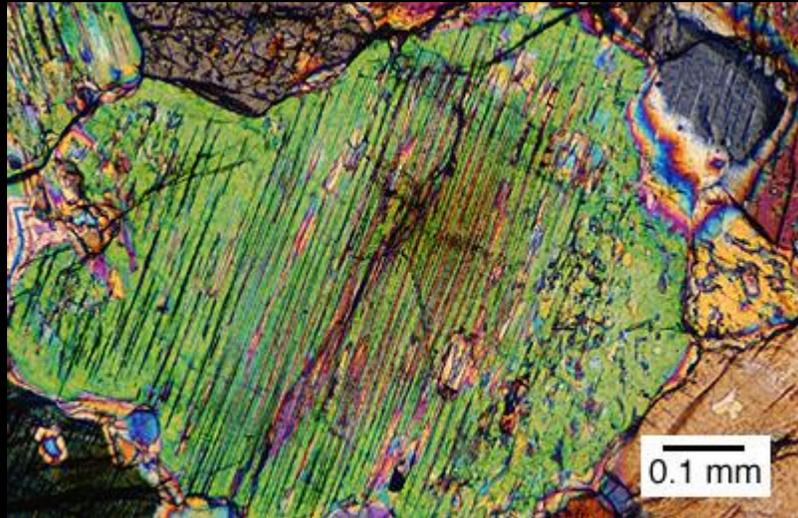
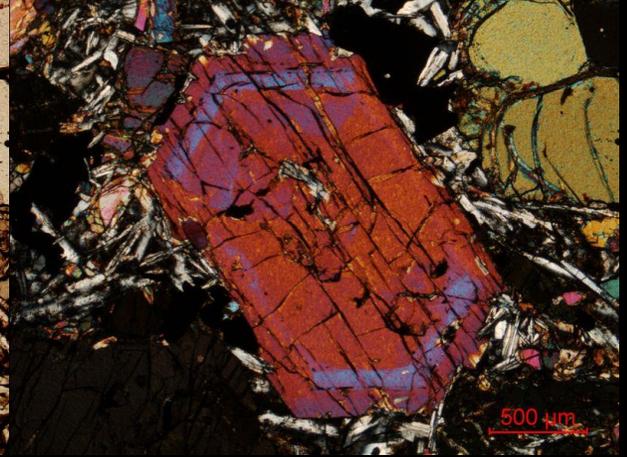
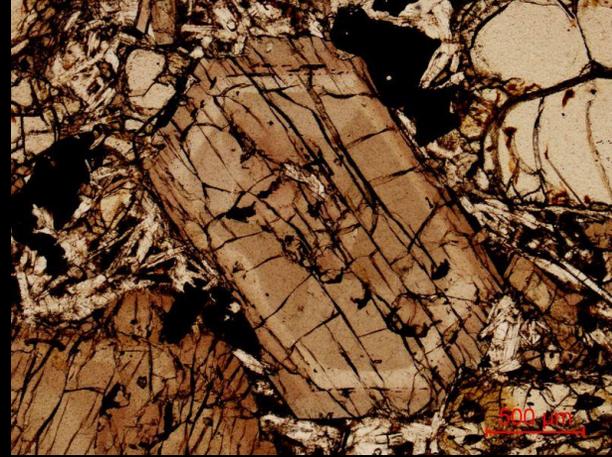


Textures according to the crystal forms

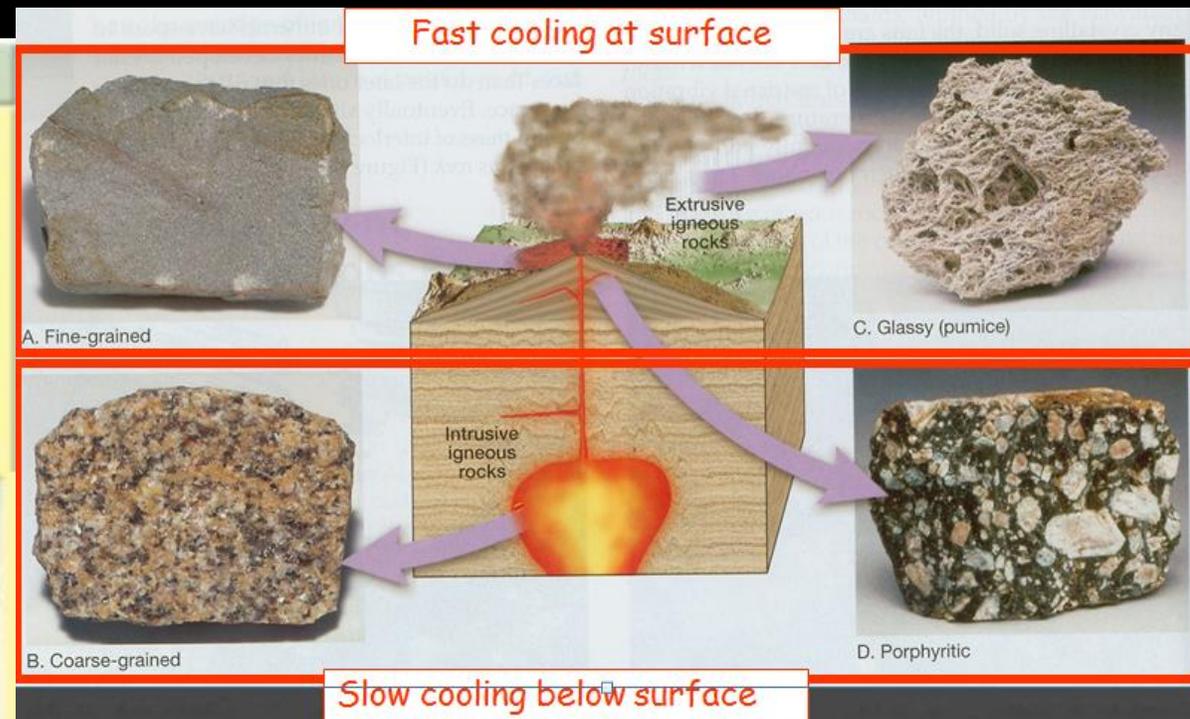
diamorph (self-shaping)

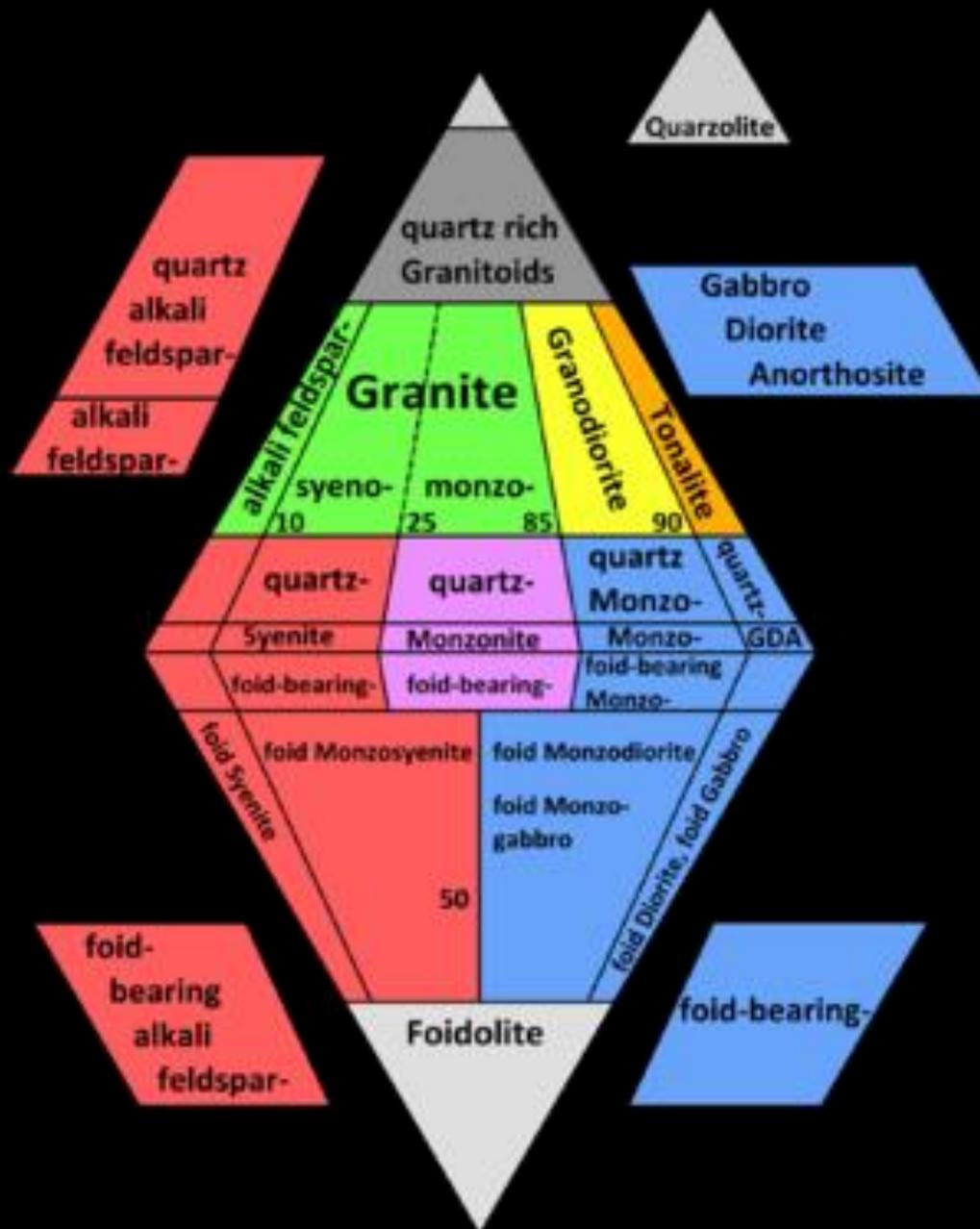
Hypidiomorph (partially self-shaped)

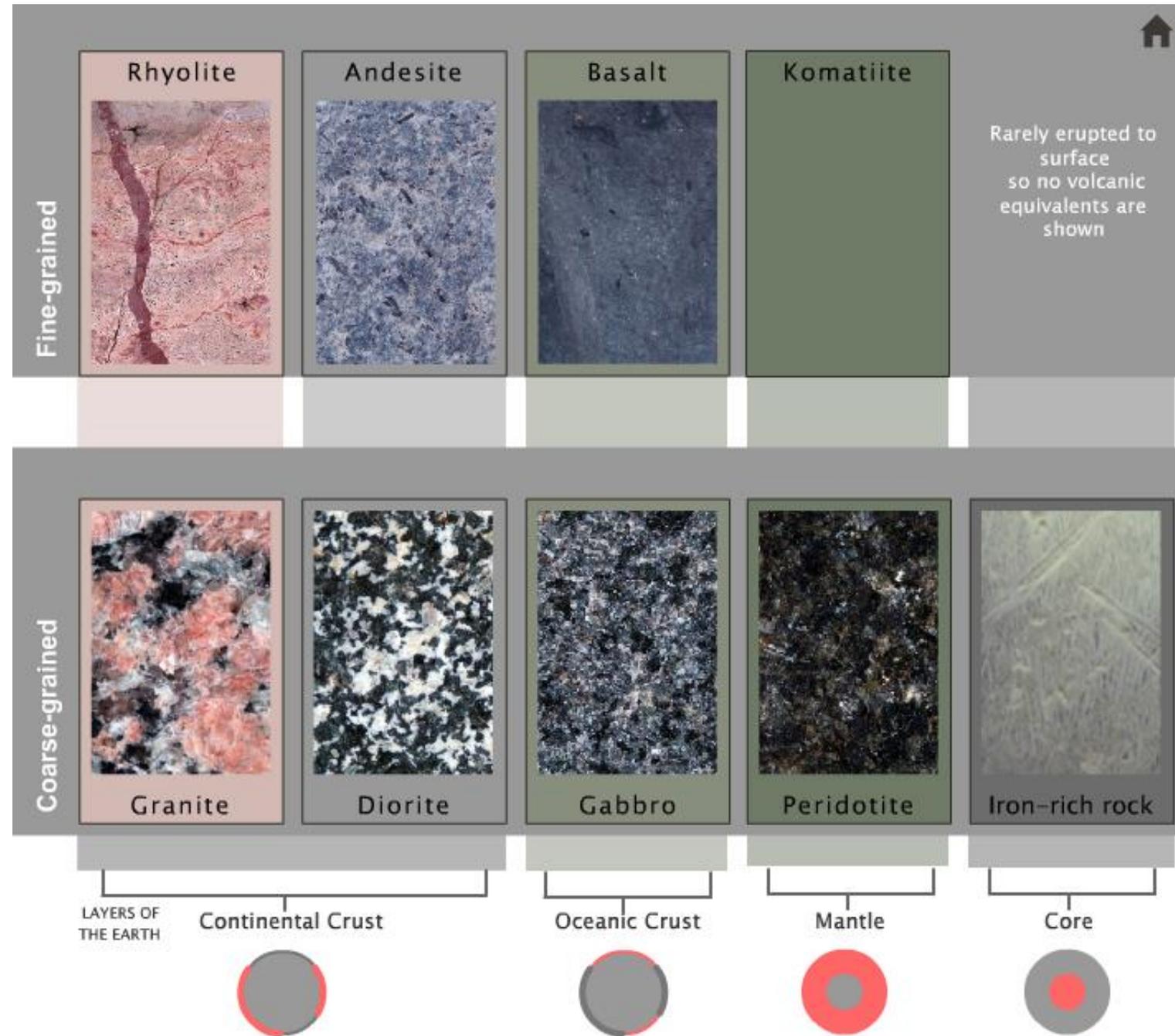
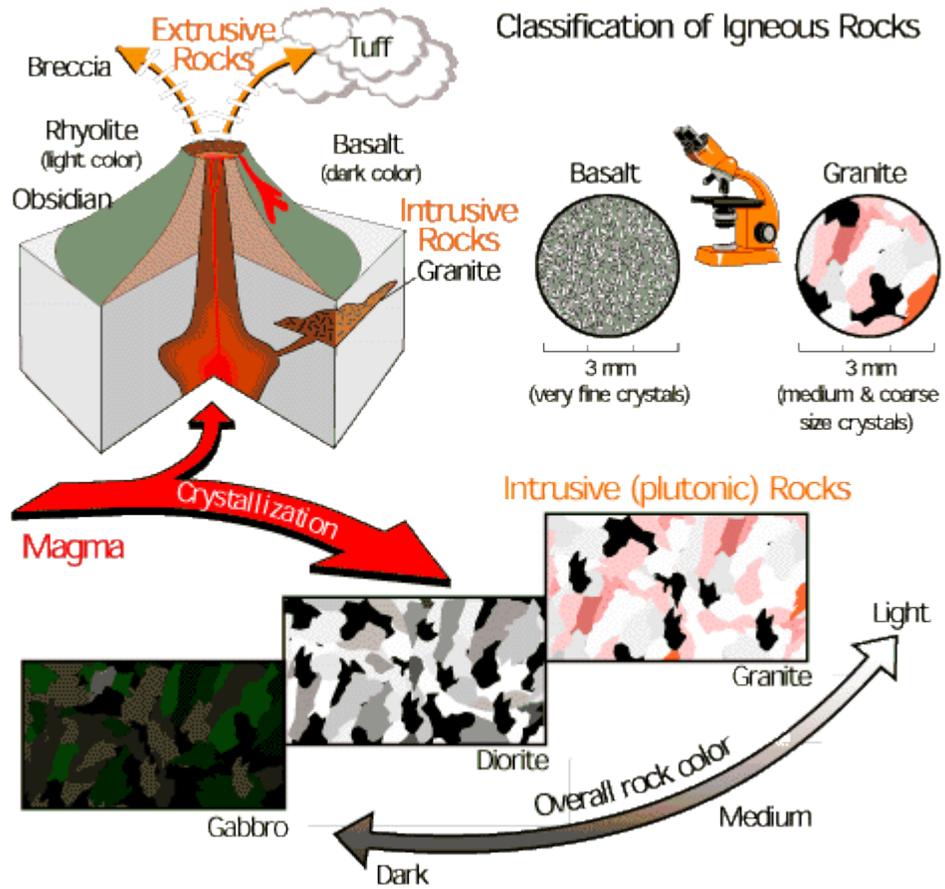
Csnomorph (self-formed)

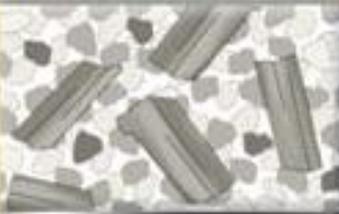


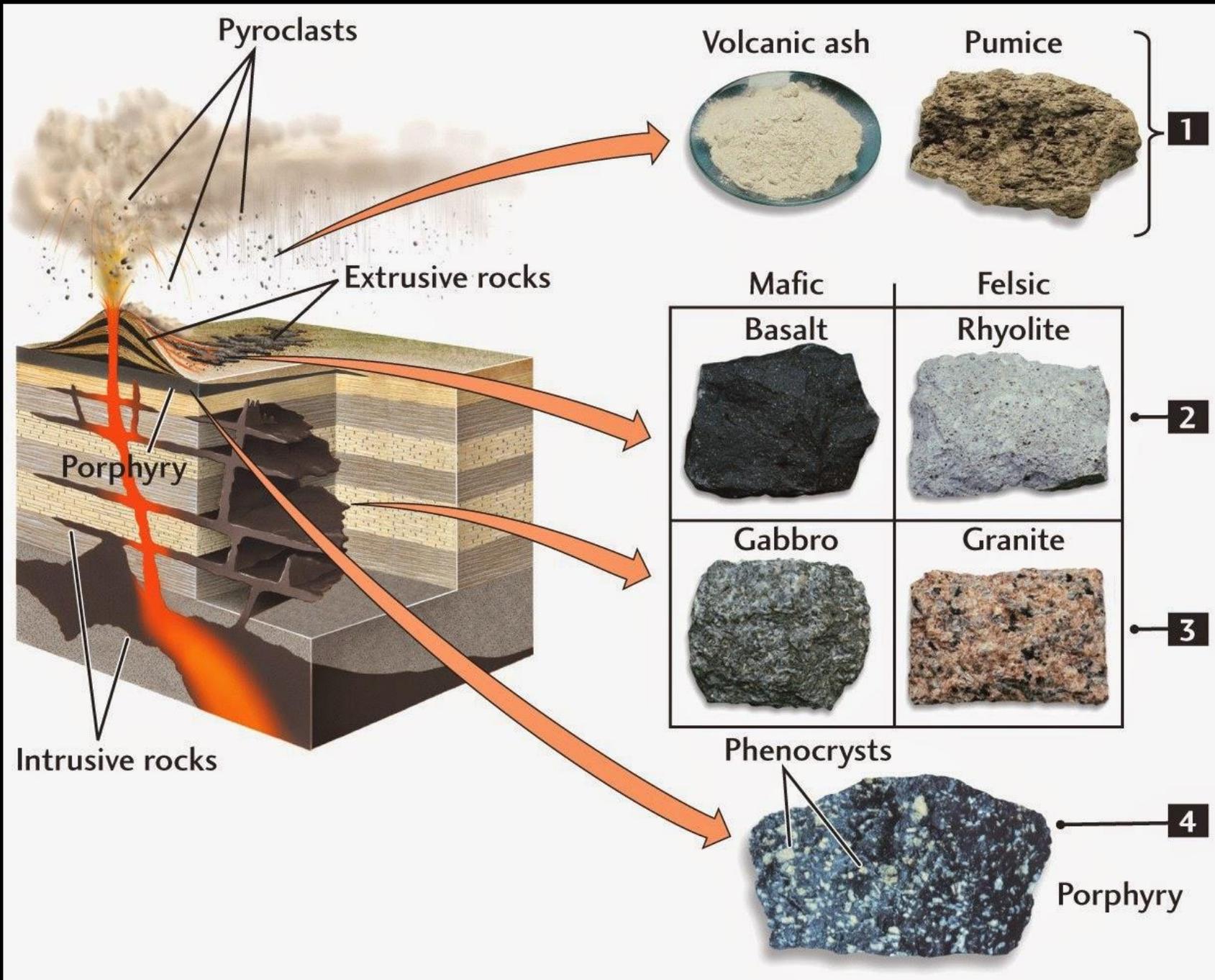
Texture	Composition		
	Felsic (Granitic)	Intermediate (Andesitic)	Mafic (Basaltic)
Phaneritic (course-grained)	 Granite	 Diorite	 Gabbro
Aphanitic (fine-grained)	 Rhyolite	 Andesite	 Basalt
Porphyritic	 Granite porphyry	 Andesite porphyry	 Basalt porphyry







Chemical Composition			Granitic (Felsic)	Andesitic (Intermediate)	Basaltic (Mafic)	Ultramafic	
Dominant Minerals			Quartz Potassium feldspar Sodium-rich plagioclase feldspar	Amphibole Sodium- and calcium-rich plagioclase feldspar	Pyroxene Calcium-rich plagioclase feldspar	Olivine Pyroxene	
TEXTURE	Coarse-grained		Granite	Diorite	Gabbro	Peridotite	
	Fine-grained		Rhyolite	Andesite	Basalt	Komatiite (rare)	
	Porphyritic		"Porphyritic" precedes any of the above names whenever there are appreciable phenocrysts				Uncommon
	Glassy		Obsidian (compact glass) Pumice (frothy glass)				
Rock Color (based on % of dark minerals)			0% to 25%	25% to 45%	45% to 85%	85% to 100%	
							



The Importance of Magmatic Rocks in Engineering

- Plutonic rocks often become resistant to breakage and pressure when they are fresh and although the rock is fractured. Therefore they show high resistance.
- They can be used in material engineering services when their resistance is between 1500-2000 kg / cm².

The Importance of Magmatic Rocks in Engineering

- The resistance of the rock depends on weathering and hence degradation degree will vary inversely with the degree of weathering.
- Since the volcanic masses have different physical properties, it is necessary to thoroughly inspect them before construction starts.
- Some lavas, agglomerates and volcanic rocks protect their freshness, so their resistance may be as high as deep rocks such as basalt. But volcanic tuffs and breccias are hollow and decayed, so they show a porous structure. At the same time they lose credibility because they show clay mineralization.

Metamorphic Rocks

- ✓ Any rock (igneous, sedimentary, or metamorphic) can become a metamorphic rock. If rocks are buried deep in the Earth at high temperatures and pressures, they form new minerals and textures all without melting. If melting occurs, magma is formed, starting the rock cycle all over again.
- ✓ Rocks that form when a pre-existing rock (protolith) changes due to temperature or pressure, and/or as a result of squashing or shearing.
- ✓ Metamorphism doesn't include weathering, diagenesis, and melting. It is a solid-state process.

Metamorphic Rocks

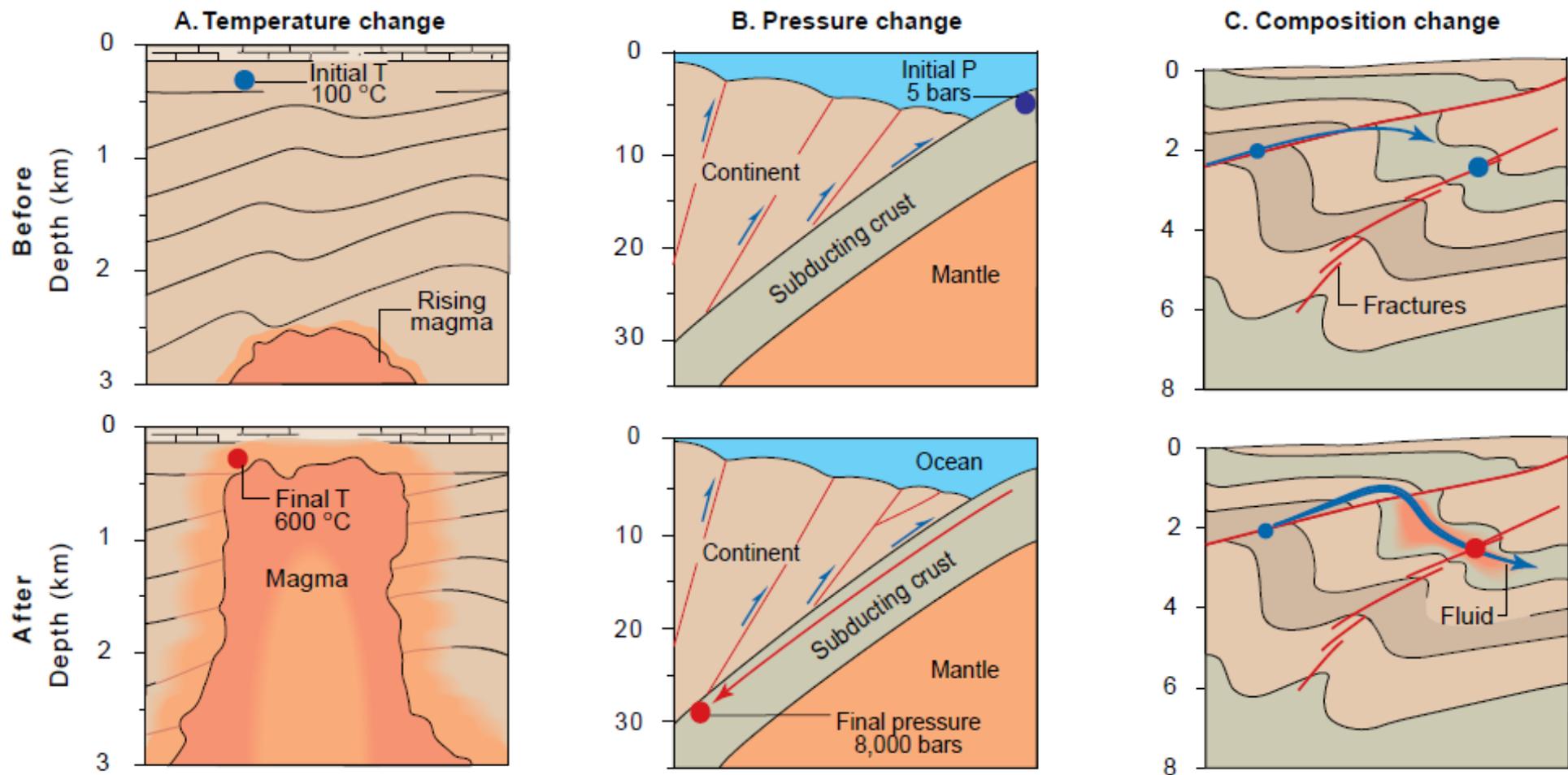
- Metamorphism progresses incrementally from low grade to high-grade
- During metamorphism (transformation) the rock remains essentially solid
- Metamorphism characterized by
 - Growth of new minerals from pre-existing minerals through recrystallization
 - Deformation of existing minerals
 - Change in shape
 - Change in orientation
 - Metamorphic settings

Metamorphic Rocks

- Metamorphic rocks occur because of changes that are caused by high temperatures (above 600 C) and high pressures (500 Mpa) (20 km deep).
- Metamorphic rock type is depended on parent rocks (pre-existing rocks), the process through which a rock's structure is changed by heat and pressure
 - Parent rocks can be Igneous, sedimentary, or other metamorphic rocks.
- Most of the metamorphic changes begin at depths of a few miles of the earth, continuing up to the upper mantle depths with rising temperature and pressure.

metamorphic rocks: controlling factors

- parent rock composition (also called protolith)
- temperature and pressure during metamorphism
- tectonic forces
- fluids



(A) Temperature changes when a magmatic body intrudes the shallow crust and causes recrystallization around the intrusion (region in light orange).

(B) Pressure changes can be caused by the collision of two plates, where minerals at low pressure (blue dot) are dragged to high pressure (red dot) in a subducting plate.

(C) Fluids carrying dissolved ions may flow from one spot (blue dot) to another (red dot), causing minerals along the flow path to recrystallize as they equilibrate with the fluid.

FIGURE 6.4 Metamorphic changes can occur as the result of changes in temperature, pressure, and in the composition of pore fluids, as the rocks attempt to reach equilibrium with the new conditions. These cross sections illustrate some of the changes.

parent rock composition

no new material is added to rock during metamorphism

metamorphic rock will have similar composition to parent rock

if parent material contains only one mineral

resultant metamorphic rock will only have one mineral

--mineral will be recrystallized (texture changes)--

Limestone



Marble

if parent material contains many minerals...

...old minerals will recombine to form new minerals

clay, quartz, mica, and volcanic fragments in a sandstone
will combine to form new metamorphic minerals

example is **garnet**: which grows during metamorphism

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



Photo by C. C. Plummer

garnet growing

garnet schist (metamorphic rock)

temperature during metamorphism

- heat from Earth's deep interior
- all minerals stable over finite temperature range
- higher temperatures than range cause melting
(and therefore generates *igneous* rocks)

heat is essential

think about mixing flour, yeast, water, salt....

*....nothing happens until they have a heat source
and then they make bread*

pressure during metamorphism

pressure in the Earth acts the same in all directions

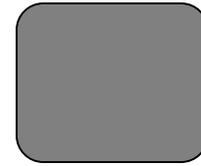
**pressure is proportional
to depth in the Earth**

increases at ~1 kilobar
per 3.3 km

look at example with deep water

*consequence on cube is squeezing
into smaller cube
--grains pack together--*

high pressure minerals: more compact and dense

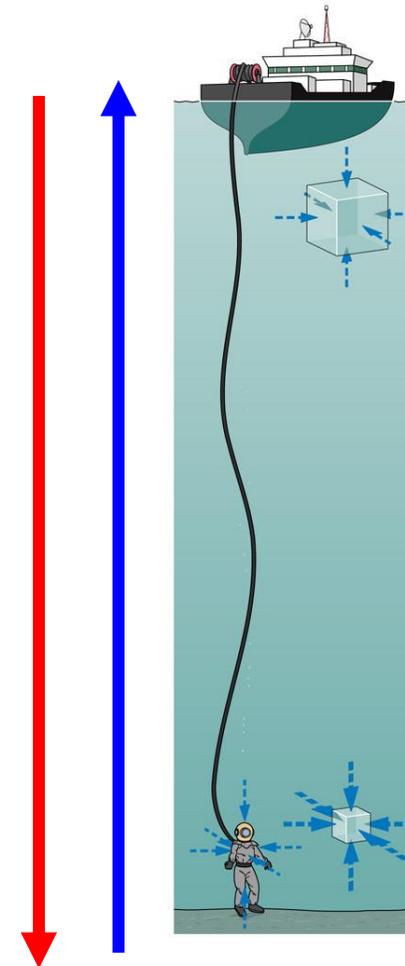


pressure increases
with depth

volume decreases
with depth



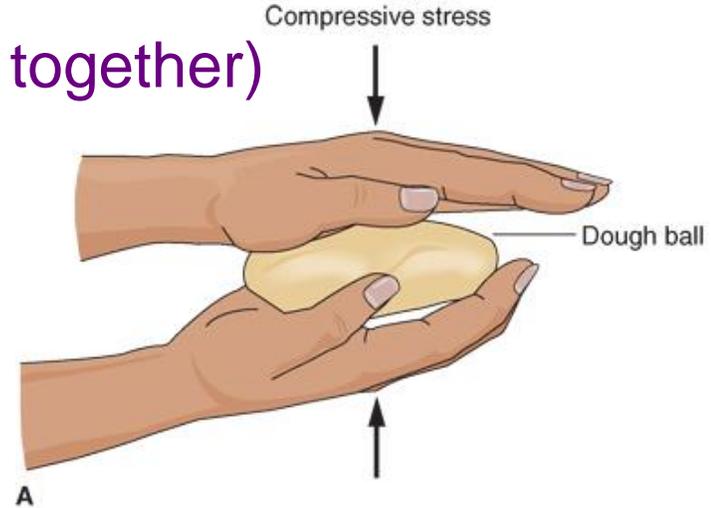
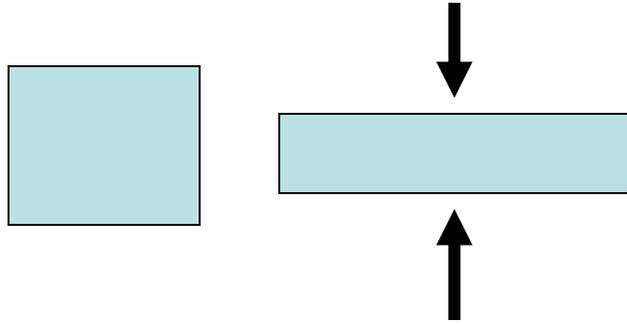
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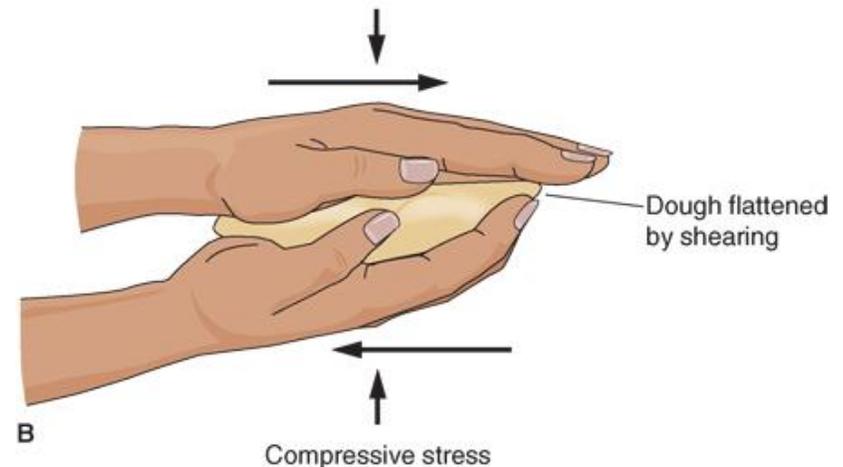
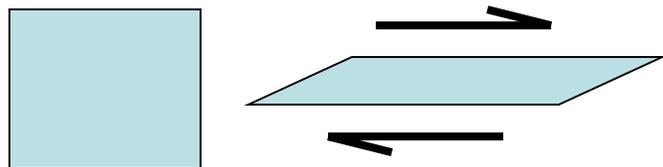
tectonic forces - driven by plate motion!

lead to forces that are not equal in all directions (differential stress)

compressive stress (hands squeeze together)
causes flattening at 90° to stress



shearing (hands rubbing together)
causes flattening parallel to stress



flattened pebbles in metamorphic rock

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Photo by C. C. Plummer

fluids

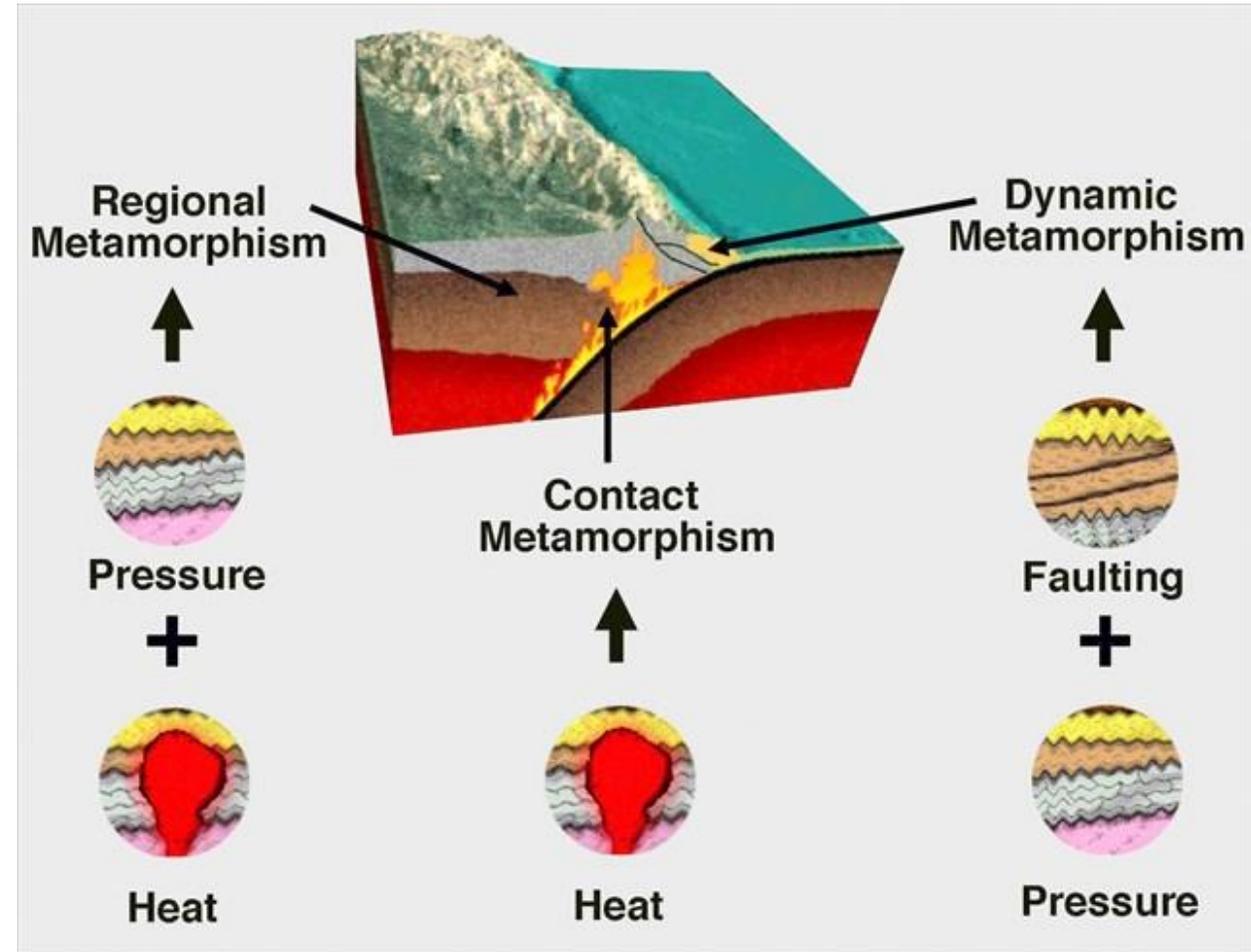
- hot water (water vapor) most important
- heat causes unstable minerals to release water
- water reacts with surrounding rocks
and transports dissolved material and ions

time

- metamorphism may take millions of years
- longer times allow new minerals to grow larger
--coarser grained rocks

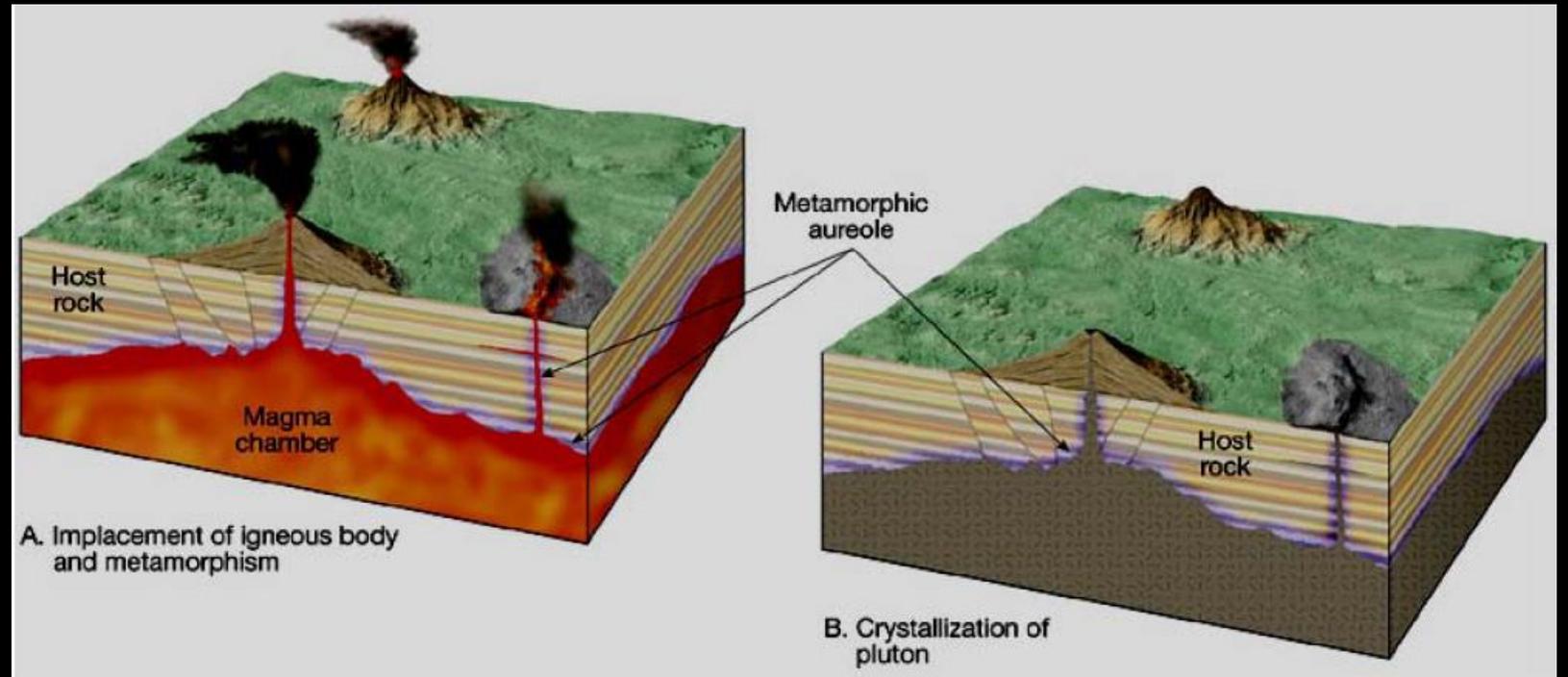
types of metamorphism

- Contact or thermal metamorphism
 - Driven by a rise in temperature within the host rock
- Regional metamorphism
 - Occurs during mountain building
 - Produces the greatest volume of metamorphic rock
- Burial metamorphism
 - Occurs at bottom of thick sedimentary rock piles
- Hydrothermal metamorphism
 - chemical alterations from hot, ion-rich water
- Others



Contact metamorphism

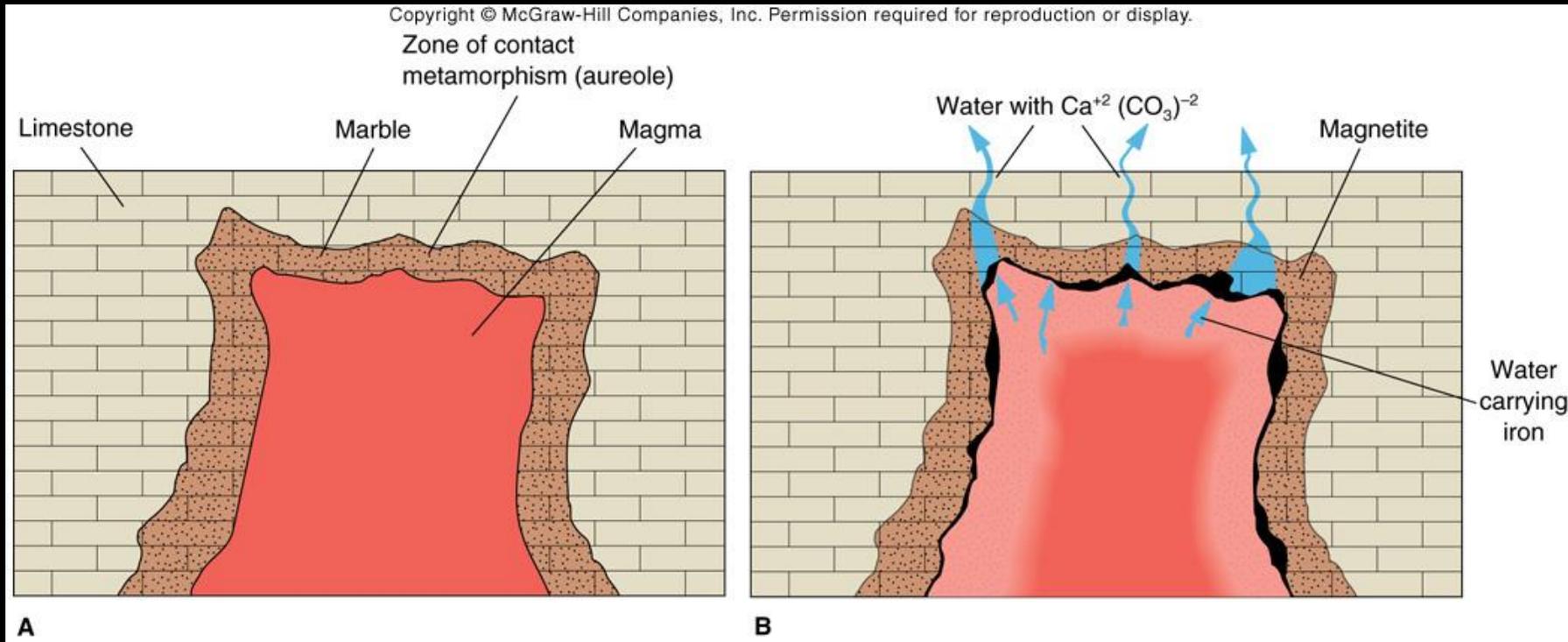
- Occurs due to a rise in temperature when magma invades a host rock
- A zone of metamorphism forms in the rock surrounding the magma
- Most easily recognized when it occurs at the surface, or in a near-surface environment



types of metamorphism

contact metamorphism

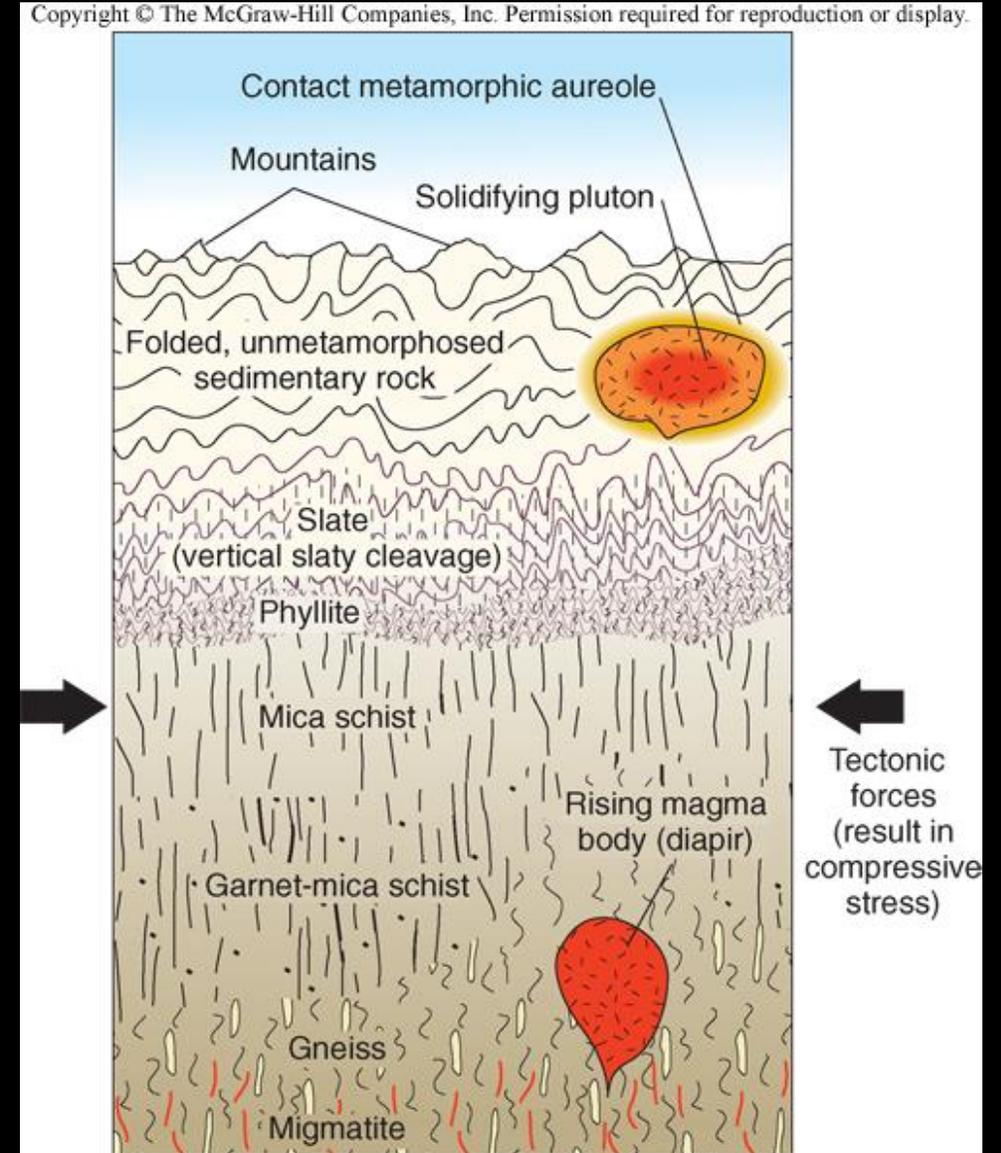
- occurs adjacent to magma bodies intruding cooler country rock -- “contact”
- produces *non-foliated* metamorphic rocks
- happens in a narrow zone of contact (~1 to 100 m wide) known as aureole
- forms fine-grained (e.g. hornfels) or coarse-grained (e.g. marble) rocks

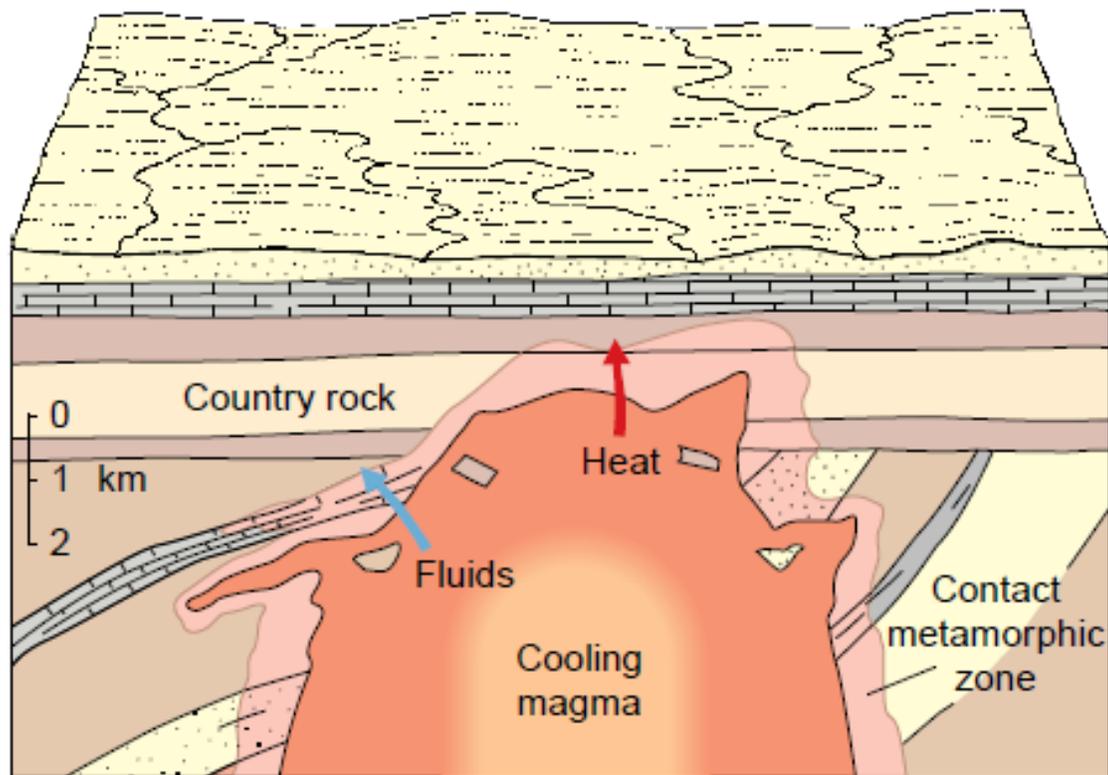


types of metamorphism

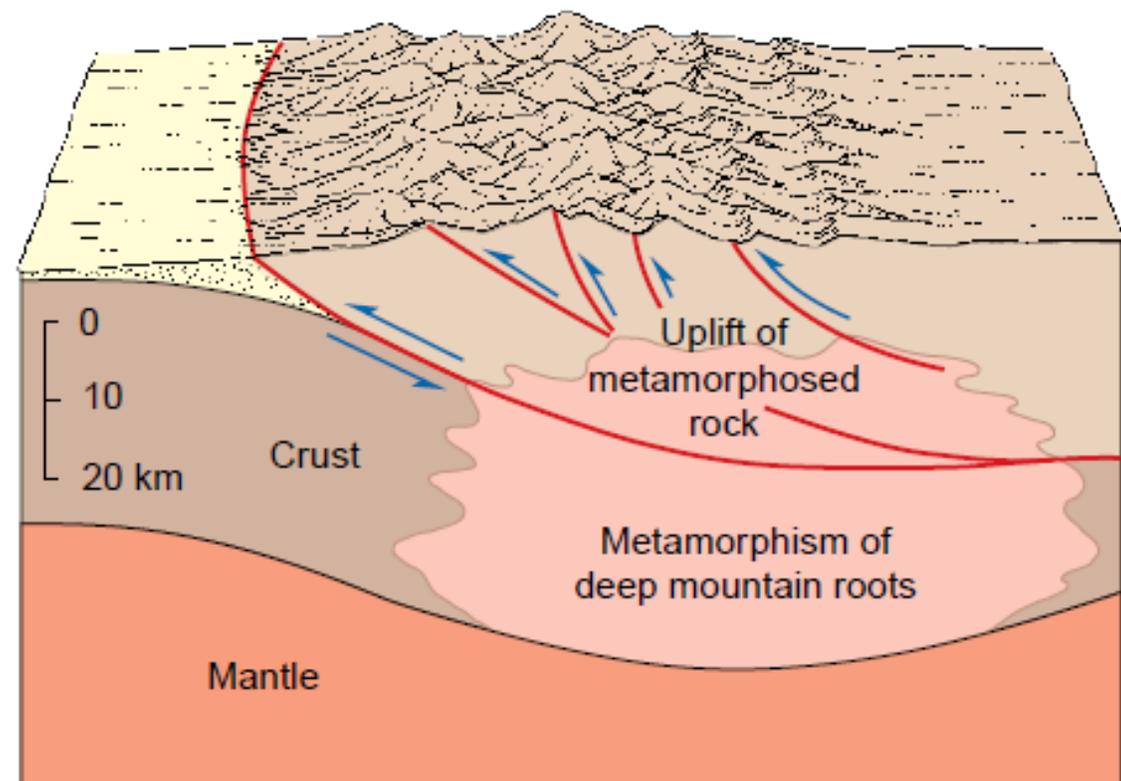
regional metamorphism

- occurs over wide region and mostly in deformed mountain ranges
- produces *foliated* metamorphic rocks
- happens at high pressures and over a range of temperature
- increases in pressures and temperatures forms rocks of higher metamorphic grade





(A) Contact metamorphism occurs around hot igneous intrusions. Changes in temperature and composition of pore fluids cause preexisting minerals to change and reach equilibrium in the new environment. Narrow zones of altered rock extending from a few meters to a few hundred meters from the contact are produced.

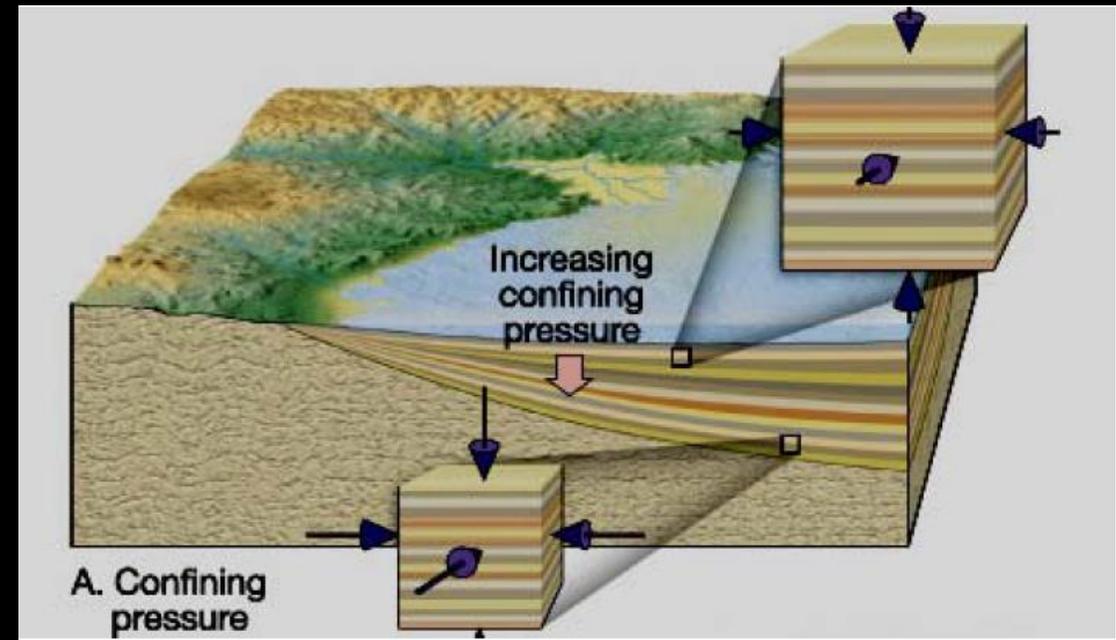


(B) Regional metamorphism develops deep in the crust, usually as the result of subduction or continental collision. Wide areas are deformed, subjected to higher pressures, and intruded by igneous rocks. Hot fluids may also cause metamorphic recrystallization.

FIGURE 6.6 Metamorphic environments are many and varied. Two major examples are shown here.

Burial metamorphism

- Associated with very thick sedimentary strata
- Required depth varies from one location to another
- depending on the prevailing geothermal gradient



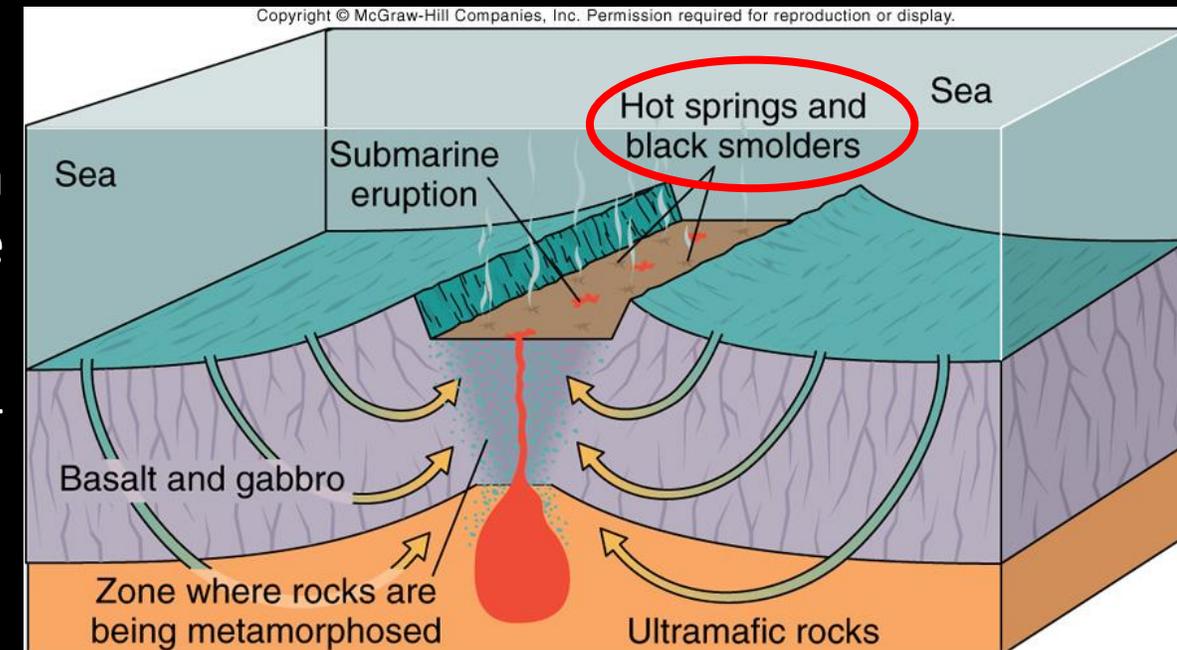
Other types of metamorphism

- Hydrothermal metamorphism

Chemical alteration caused when hot, ion-rich fluids, called hydrothermal solutions, circulate through fissures and cracks that develop in rock

Most widespread along the axis of the mid-ocean ridge system

hydrothermal alteration along mid-ocean ridge



cold sea water encounters hot basalt,
forms steam, alters minerals

other types of metamorphism (less common)

partial melting during metamorphism

- produces migmatites, which have both intrusive and metamorphic textures

shock metamorphism

- occurs during impact events
- yields very high pressures
- forms “shocked” rocks around impact craters

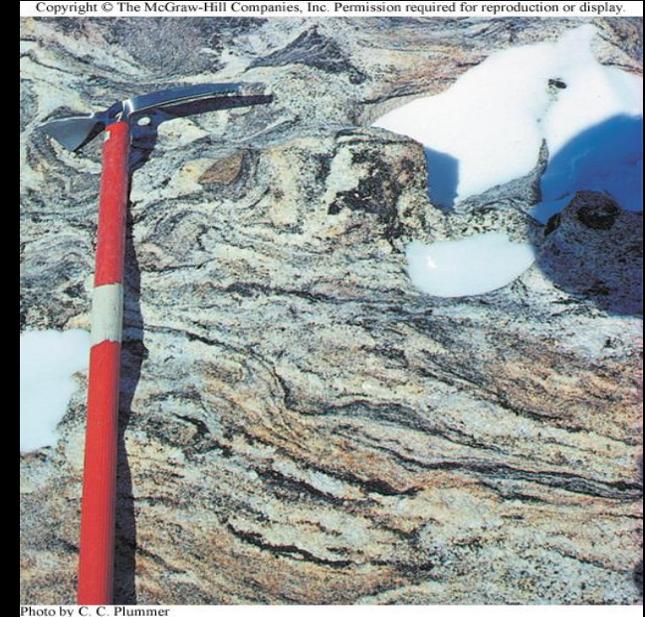
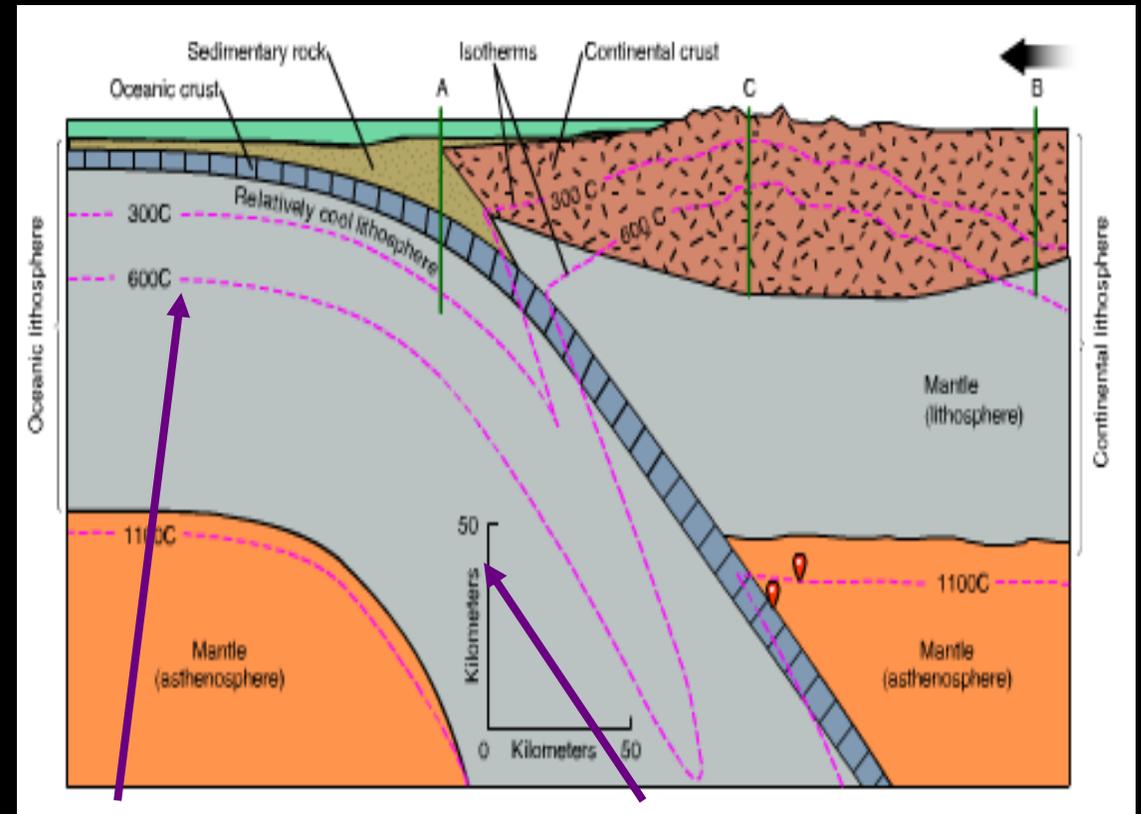


plate tectonics and metamorphism

regional metamorphism associated with *convergent* boundaries

- pressure increases with depth
- temperature varies laterally
- different P, T conditions yield different degrees of metamorphism



temperatures cooler in down-going (subducting) plate
(dashed purple line is *isotherm* -- line of equal T)

Metamorphic rock systematics

Metamorphic rocks are classified on the basis of

- *texture* and
- *composition* (either mineralogical or chemical)

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

Granite
igneous

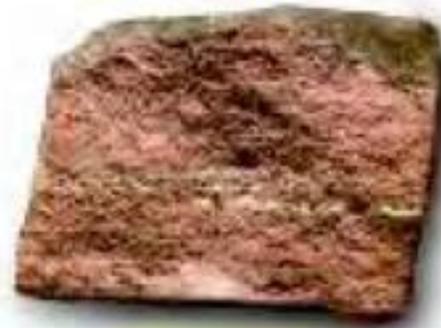


Heat
and
pressure

Gneiss
metamorphic, foliated



Sandstone
sedimentary



Heat
and
pressure

Quartzite
metamorphic, nonfoliated



Shale
sedimentary



Heat
and
pressure

Slate
metamorphic, foliated



With increasing temperature and pressure, metamorphic grade also increases. The higher the metamorphic grade, the more changed the rock will be from its original form. The rocks shown here are (left to right) slate, phyllite, schist and gneiss.

Slate

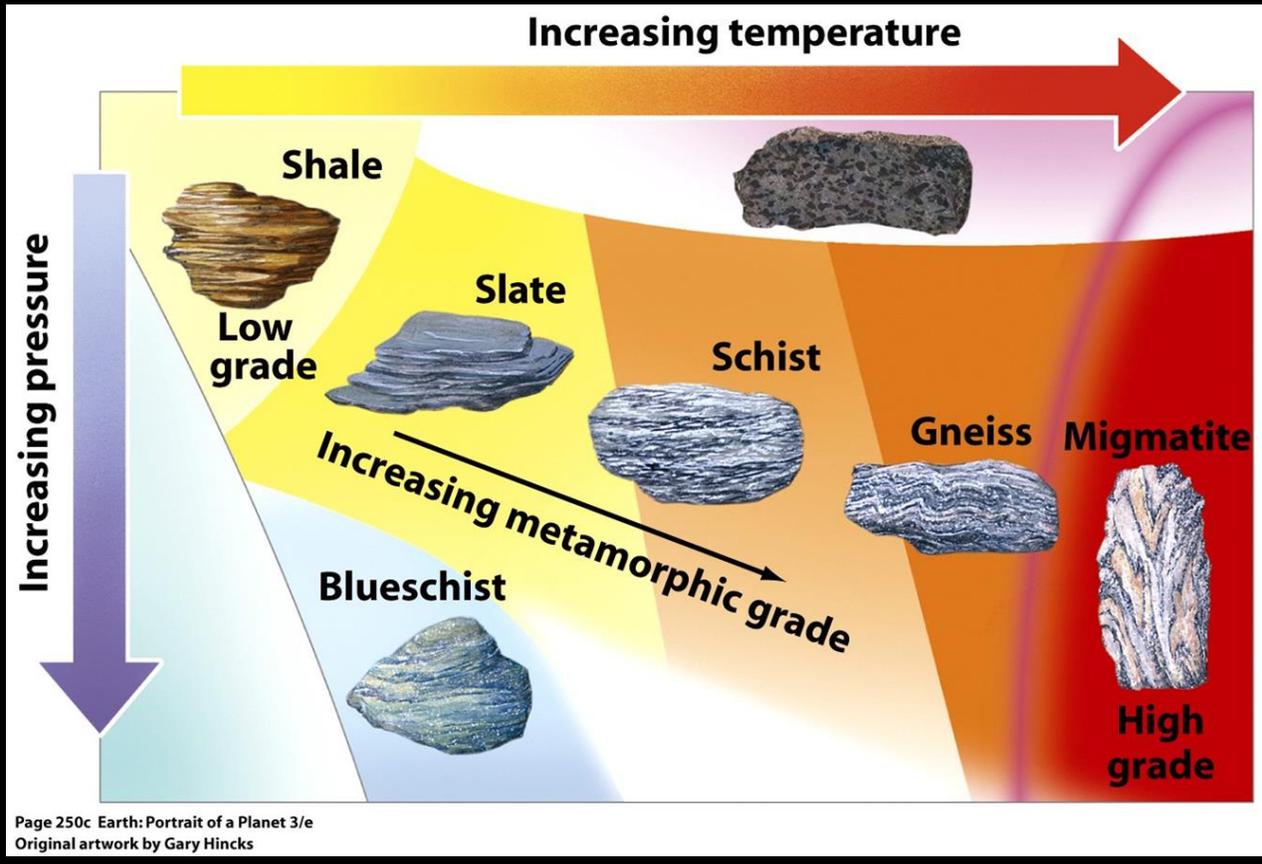
Phyllite

Schist

Gneiss

Increasing Metamorphic Grade

(Photographs by Parvinder Sethi)



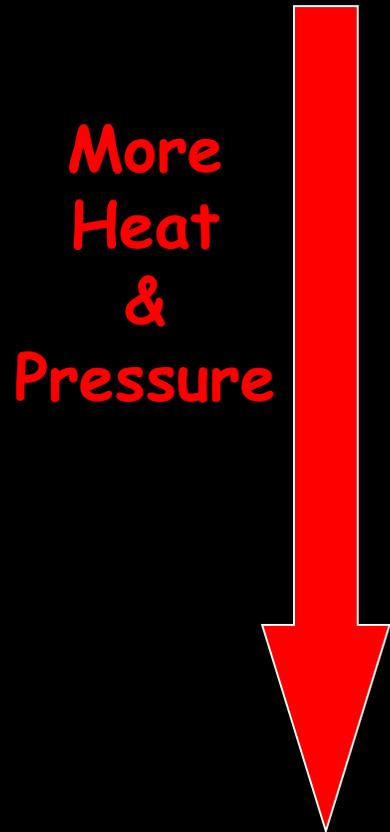
Texture		Composition	Type of Metamorphism	Comment	Rock Name
FOLIATED	MINERAL ALIGNMENT	Mica	Regional ↓ (Heat and Pressure increase w/ depth)	Low-Grade metamorphism of SHALE	Slate
		Mica, Quartz, Feldspar, Amphiboles, Garnet		Foliation surfaces shiny from microscopic mica crystals	Phyllite
		Mica, Quartz, Feldspar, Amphiboles, Garnet, Pyroxene		Platy mica crystals visible	Schist
	BANDING	Mica, Quartz, Feldspar, Amphiboles, Garnet, Pyroxene		Compact, may split easily	Gneiss

Scheme for Metamorphic Rock Identification

Texture	Composition	Type of Metamorphism	Comment	Rock Name
NONFOLIATED	Variable	Contact (Heat)	Various rocks changed by nearby magma/lava	Hornfels
	Quartz	Regional (Heat & Pressure) ↓	Metamorphism of Quartz <u>Sandstone</u>	Quartzite
	Calcite and/or Dolomite		Metamorphism of <u>Limestone</u> or <u>Dolostone</u>	Marble
	Various minerals in particles and matrix		Pebbles may be distorted or stretched	Metaconglomerate

Progression of Metamorphism

Start with a shale and then hit it with heat and pressure!



Rock Name	Rock Type	Grade of Metamorphism
Shale	Sedimentary	-----
Slate	Metamorphic	Low
Phyllite	Metamorphic	Low/Intermediate
Schist	Metamorphic	Intermediate/High
Gneiss	Metamorphic	High
Molten Rock	Cools into Igneous Rock	-----



Shale
(Sedimentary Rock)

Heat
&
Pressure



Slate
(Metamorphic Rock)





Slate
(Metamorphic Rock)

Heat
&
Pressure



Phyllite
(Metamorphic Rock)



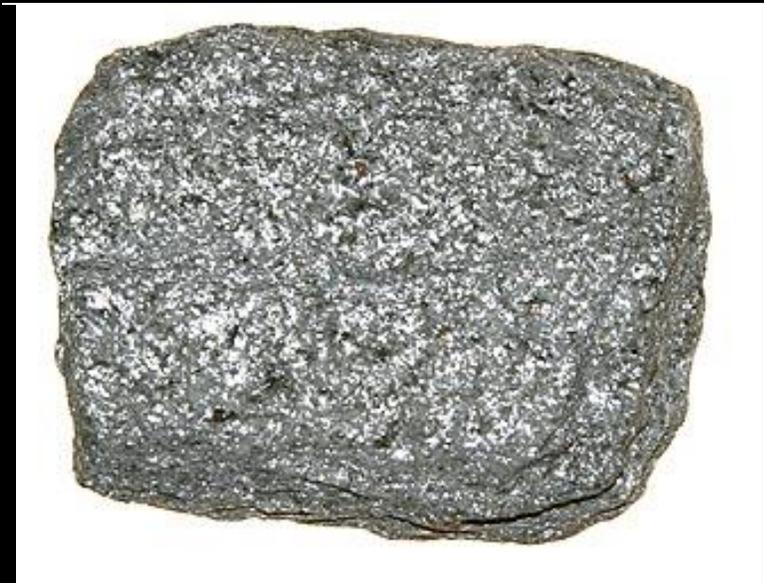


Phyllite
(Metamorphic Rock)

Heat
&
Pressure



Schist
(Metamorphic Rock)

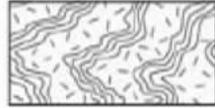
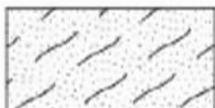


With even more heat & pressure
(High-Grade Metamorphism)



... you end up with something
that is really Gneiss!

Scheme for Metamorphic Rock Identification

TEXTURE		GRAIN SIZE	COMPOSITION	TYPE OF METAMORPHISM	COMMENTS	ROCK NAME	MAP SYMBOL
FOLIATED	MINERAL ALIGNMENT	Fine	<div style="display: flex; flex-direction: column; align-items: center;"> <div style="width: 10px; height: 100px; background-color: #cccccc; margin-bottom: 2px;">MICA</div> <div style="width: 10px; height: 80px; background-color: #cccccc; margin-bottom: 2px;">QUARTZ</div> <div style="width: 10px; height: 80px; background-color: #cccccc; margin-bottom: 2px;">FELDSPAR</div> <div style="width: 10px; height: 80px; background-color: #cccccc; margin-bottom: 2px;">AMPHIBOLE</div> <div style="width: 10px; height: 60px; background-color: #cccccc; margin-bottom: 2px;">GARNET</div> <div style="width: 10px; height: 40px; background-color: #cccccc;">PYROXENE</div> </div>	Regional (Heat and pressure increases) 	Low-grade metamorphism of shale	Slate	
		Fine to medium			Foliation surfaces shiny from microscopic mica crystals	Phyllite	
	BAND-ING	Medium to coarse			Platy mica crystals visible from metamorphism of clay or feldspars	Schist	
		High-grade metamorphism; mineral types segregated into bands			Gneiss		
NONFOLIATED	Fine	Carbon	Regional	Metamorphism of bituminous coal	Anthracite coal		
	Fine	Various minerals	Contact (heat)	Various rocks changed by heat from nearby magma/lava	Hornfels		
	Fine to coarse	Quartz	Regional or contact	Metamorphism of quartz sandstone	Quartzite		
		Calcite and/or dolomite		Metamorphism of limestone or dolostone	Marble		
	Coarse	Various minerals		Pebbles may be distorted or stretched	Metaconglomerate		

Marble	Slate	Gneiss	Quartzite
			
Marble is a strong and beautiful rock. It is most commonly used for countertops because nothing will melt it if you set something on it and it will not be stained.	Slate is a rock that is very similar to shale. Slate is what you would see by lake erie. They are good for skipping stones. This rock is most commonly used for chalkboards.	Gneiss is a foliated rock. It is used for building and paving. You can see the crystals in this rock with the naked eye.	Quartzite can also be used for countertops because of it's hardness. Quartzite can come in a variety of colors. The one in the picture above is pink.

Slate	Serpentine	quartzite	gneiss
a fine-grained gray, green, or bluish metamorphic rock easily split into smooth, flat pieces.	greenish, brownish, or spotted minerals commonly found in serpentinite rocks. They are used as a source of magnesium and asbestos, and as a decorative stone. The name is thought to come from the greenish color being that of a serpent. ...	an extremely compact, hard, granular rock consisting essentially of quartz. It often occurs as silicified sandstone, as in sarsen stones.	a metamorphic rock with a banded or foliated structure, typically coarse-grained and consisting mainly of feldspar, quartz, and mica.
			

Metamorphic Textures

Texture refers to the size, shape, and arrangement of grains within a rock

1. Foliated Rock → Bands of minerals in parallel layers

Foliation – any planar arrangement of mineral grains or structural features within a rock

Parallel alignment of platy and/or elongated minerals

Foliation can form through:

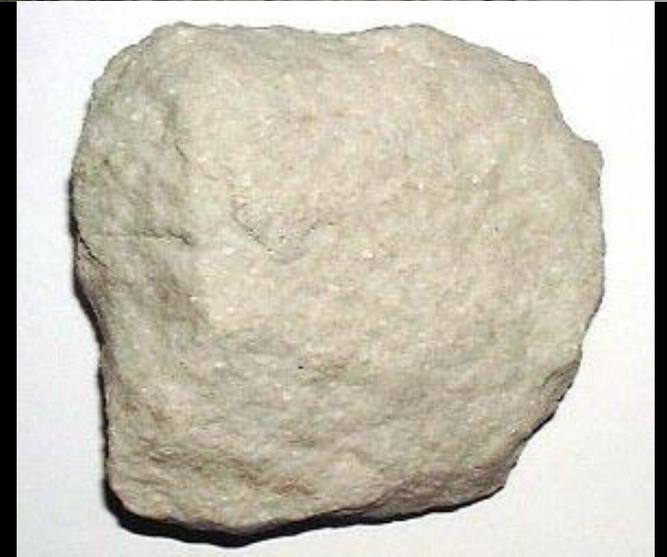
- Rotation of platy and/or elongated minerals
- Recrystallization of minerals in the direction of preferred orientation
- Changing the shape of equidimensional grains into elongated shapes that are aligned

2. Non-foliated Rock → Without bands

Metamorphic rocks that lack foliation are referred to as nonfoliated

Develop in environments where stress (deformation) is minimal

Typically composed of minerals that exhibit equidimensional crystals



Metamorphic Textures

Foliation: The structure is called as foliation when it is ranged as parallel planes of minerals forming metamorphic rocks to each other, collecting in the form of lenses or bands,

It develops planar structures that occur with both planar and elongated flattened mineral grains, and it are repeatedly layered and dyed from a rock under high pressure and heat .

Schistosity: Platy minerals are discernible with the unaided eye and exhibit a planar or layered structure under high pressure and heat.

Lineation: passing there through regardless of their origin rock, repeated, visible linear eye structures of all kinds.

Gneissic texture : Segregation of minerals leads to distinctive banded appearance

Metamorphic Textures

- **Cleavage:** It is called cleavage of wrinkled planes connected by directional pressures, deformed by layering planes, which develops at a certain angle and develops in close proximity to each other, in parallel and in more than one direction. Cleavage is a secondary texture that allows a rock to separate into planes.
- **Mylonite:** Rock in the deep portions of faults undergoes dynamic metamorphism and creates a fine-grained metamorphic rock called a mylonite. Rock in the deep portions of faults undergoes dynamic metamorphism and creates a fine-grained metamorphic rock called a mylonite. During the deformation occurring in the fault zone, the primary grains of the rock are broken and crushed to form the mylonitic zone, which forms again smaller rocks, smaller than 0.5 mm, forming the mylonite.

metamorphic rocks: basic classification

based on *rock texture*

foliated (layered)

type of foliation -- e.g. slaty

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non-foliated (non-layered)

composition -- e.g. marble

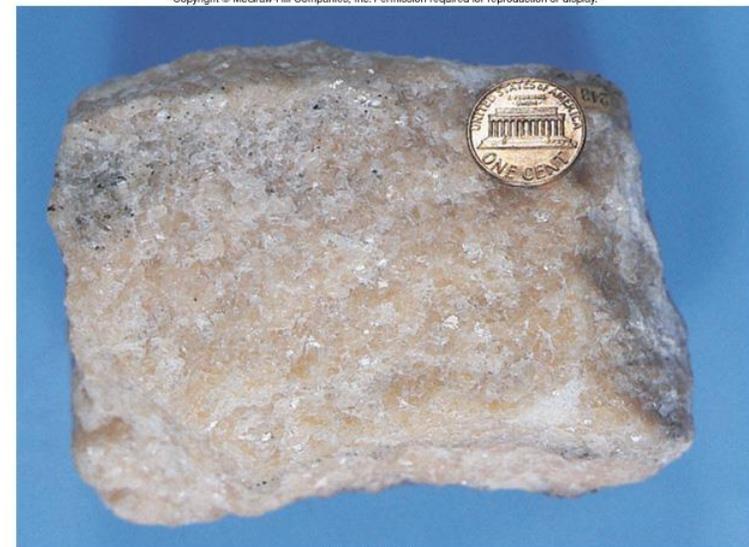
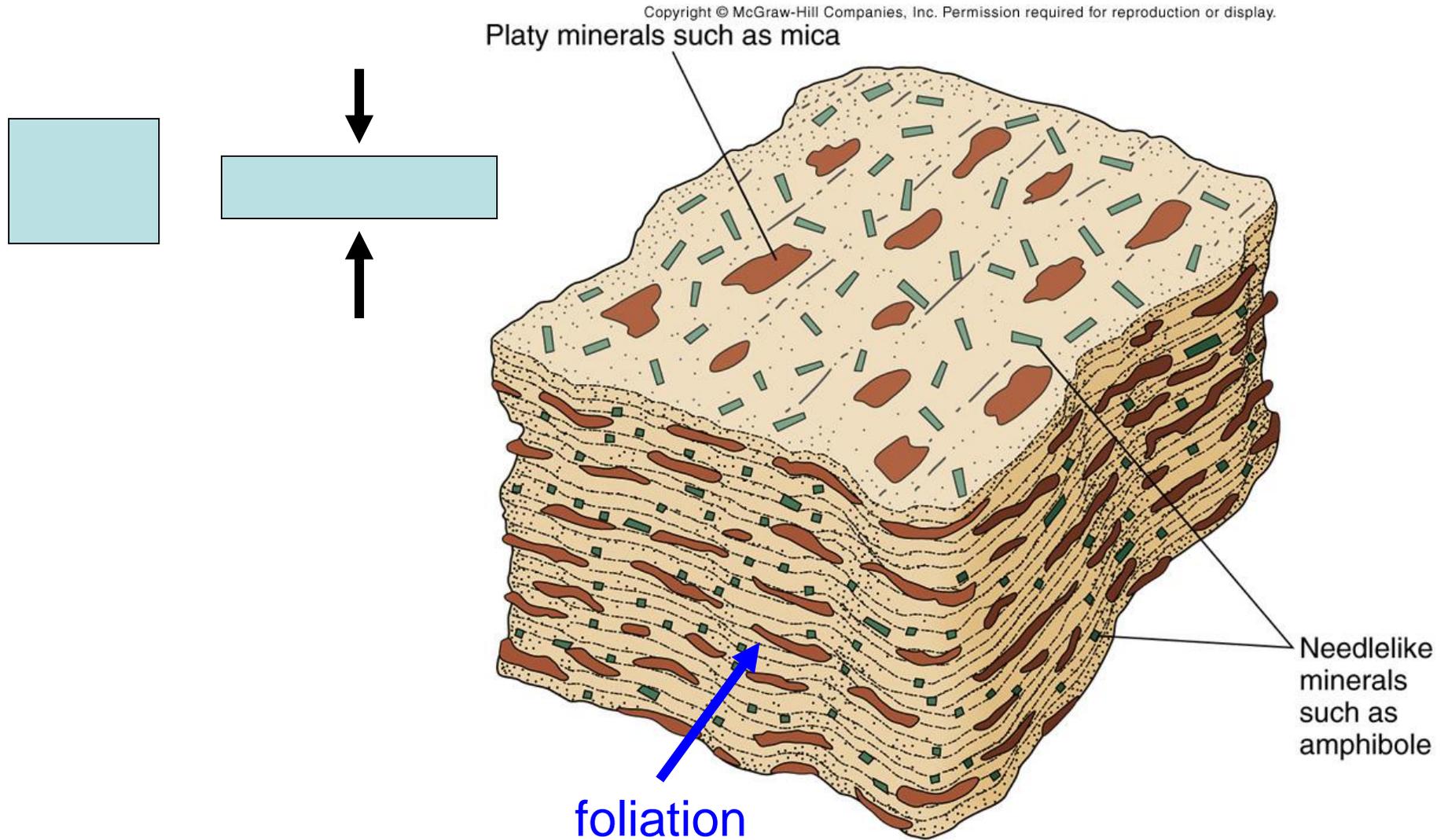


Photo by C. C. Plummer

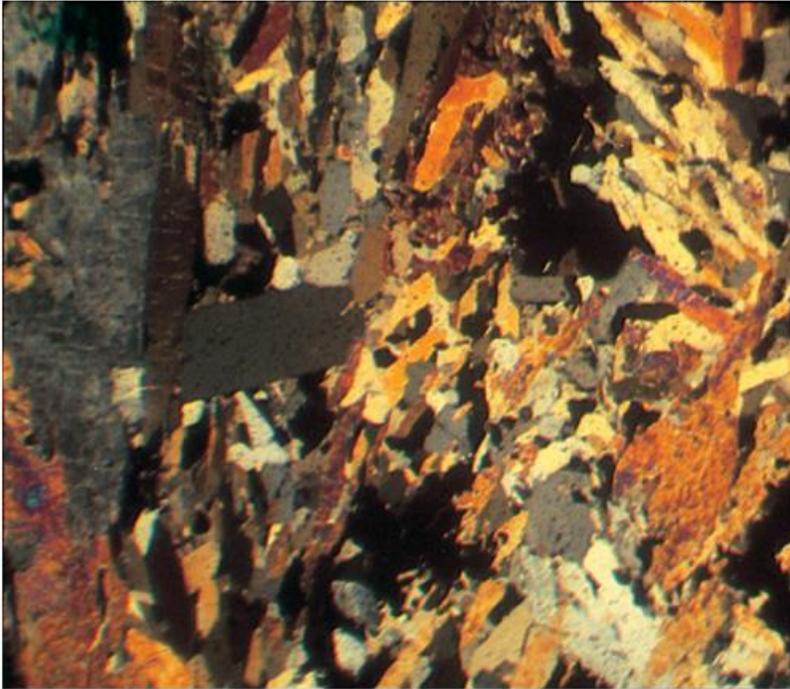
foliated (layered) metamorphic rocks

results from differential stress (not equal in all directions)



appearance under microscope

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A

Photo by C. C. Plummer

non-foliated

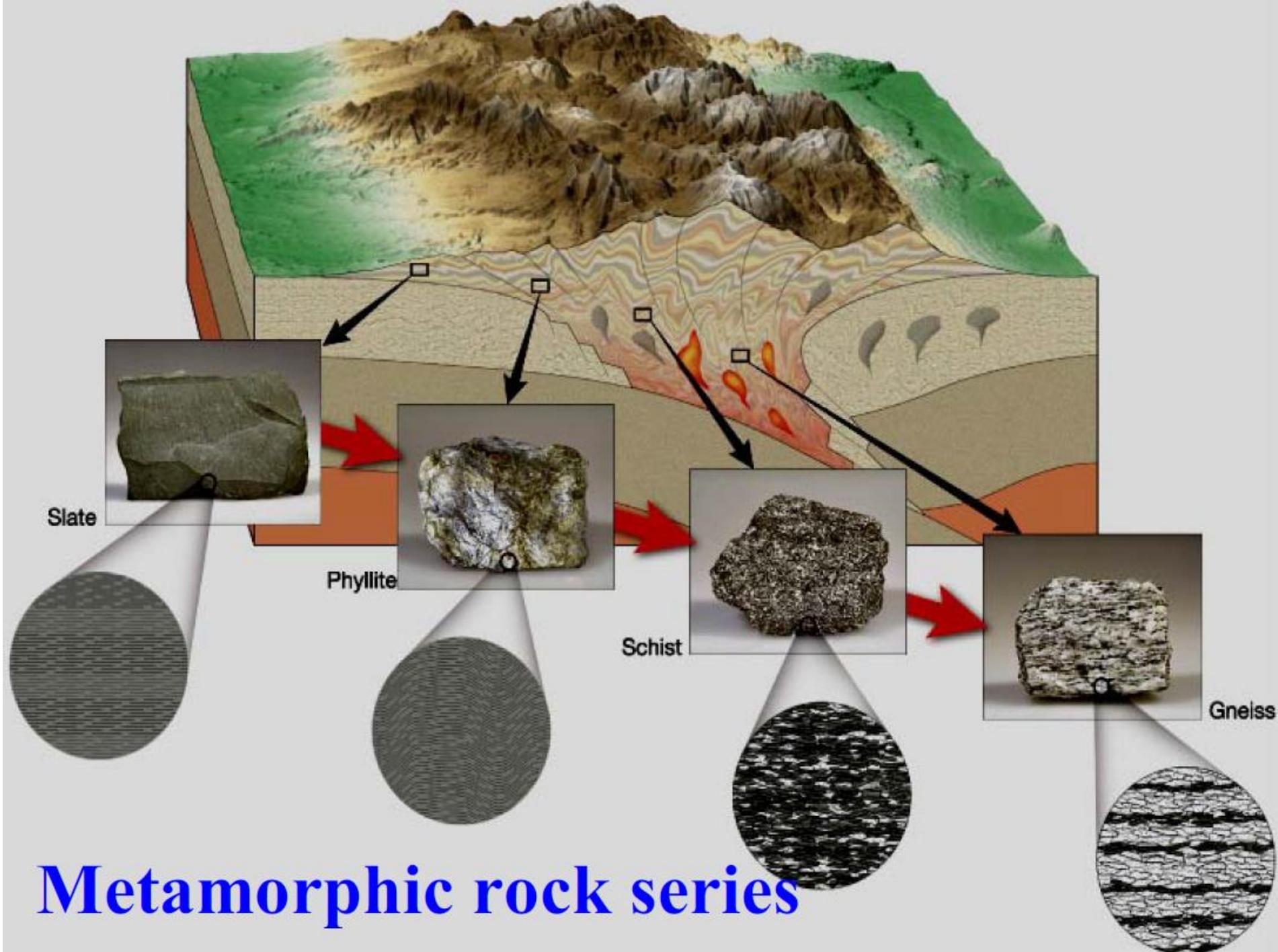
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B

Photo by C. C. Plummer

foliated



Engineering Properties of Metamorphic Rocks

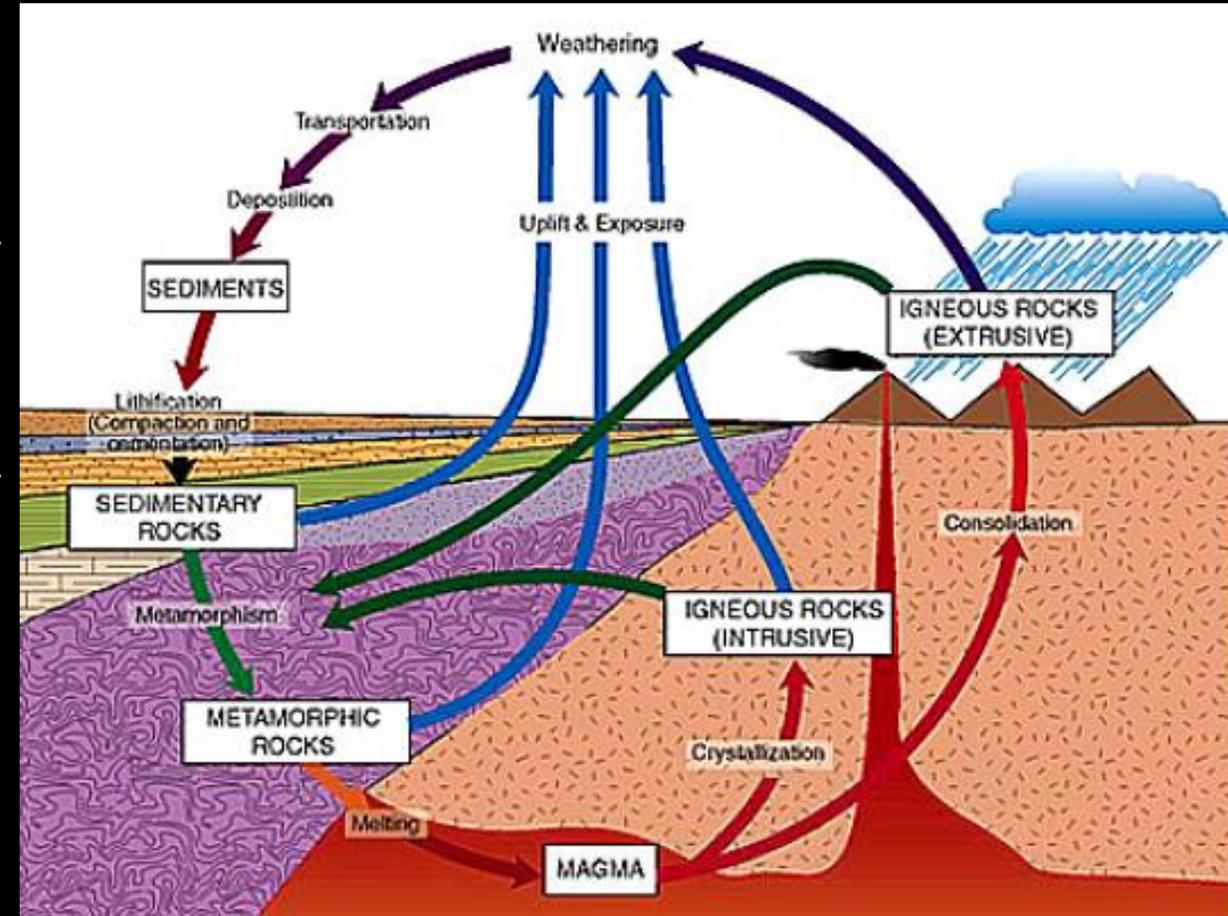
- Rocks showing foliation should not be preferred as construction materials in terms of strength.
- The strengths of the foliated metamorphic rocks, along with the leavening and foliations that develop as a result of the metamorphism, are decreasing along the foliage planes due to clay minerals that swell in water like chlorite and epidote.
- Marbles from metamorphic rocks are preferred as a good building material. It is the building material that is required in the building coverings.
- The metamorphic masses provide a solid structure for the foundation of the building, if it is not separated. Some slip planes can be used without any support if the slip gaps are not full with clays.

Engineering Properties of Metamorphic Rocks

- Metamorphics can be exposed to change immediately under favorable climatic conditions. Due to the changing construction, volume increases and pressure increases. Such features should be observed in tunnels and dam constructions and other constructions.
- Schist rocks along the schistosity plane cause shifts in the excavations. This is especially the case for the dissociated regions where the schistose and cleavage are opened and weakened and the rock resistance is greatly reduced.
- Schists and similar rocks create landslide hazards in road constructions, dam abrasions and reservoir slopes.
- Massive gneisses provide very good conditions for large underground openings. Facilities for swimming pools, theaters, skating rinks, industrial warehouses, production plants and many other activities have been created economically and safely in large openings to such rocks.
- Schistosized and competing gneisses can create stability problems in underground openings. Even in the ravaged schist and the small tunnels opened in the phyllite, the ceiling may collapse. As the metamorphic rocks are cracked and contested on the surface, excavations cause the rock blocks to move.

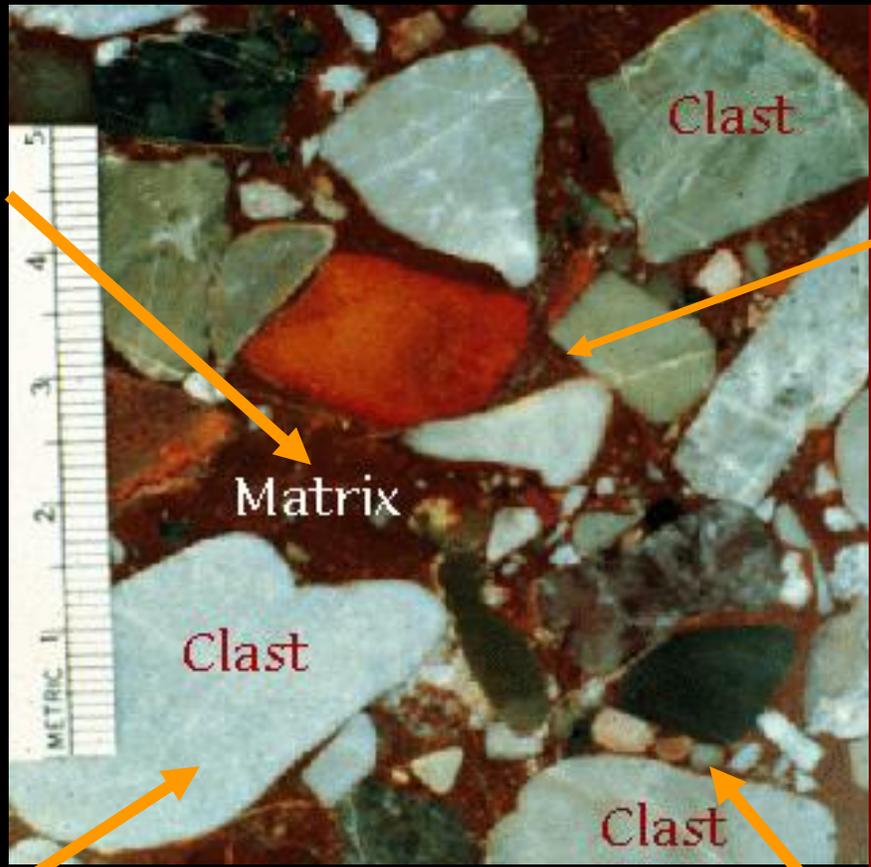
Sedimentary Rocks

- Materials which are derived by all kinds of rocks (magmatic, metamorphic, sedimentary) are subject to physical chemical and biological disruption and dispersion under all kinds of conditions, then they stay in place or are transported in different ways and settled in a certain place. It is called as «sediment»
- Sedimentary rocks are formed by the accumulation of inorganic and organic sediments which undergo compaction and cementation to form rock.



Matrix:
is the finer grains or material that surrounds the larger clasts. It consist of either clay, silt and sand.

Cement:
dissolved substance that bounds the sediments.
1. Calcareous
2. siliceous



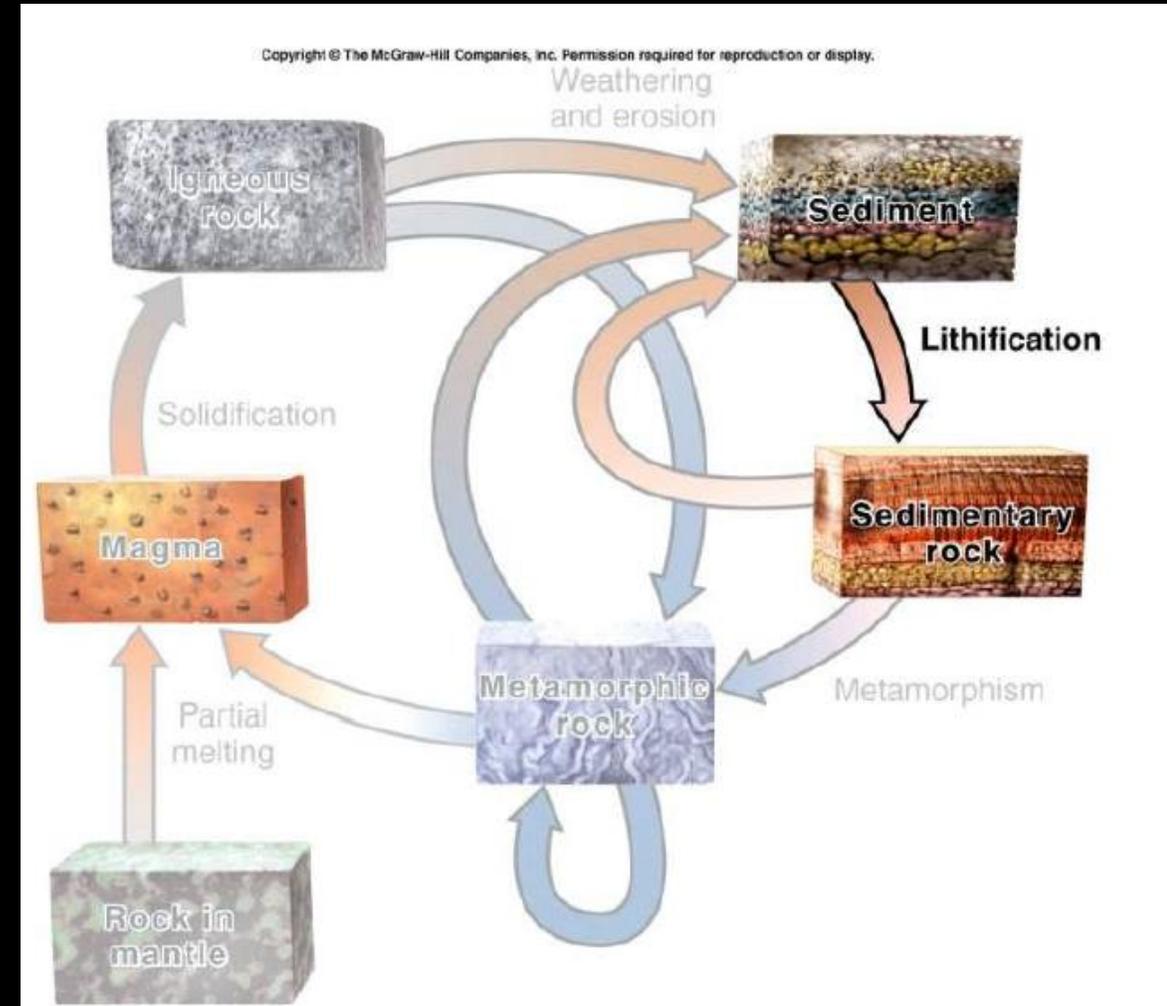
**Any rock fragment
(size is > 4 mm=Pebble)**

**Fine-gravel/
Granule
(size <4mm)**

Sediment

loose, solid particles originating from:

- Weathering and erosion of preexisting rocks
- Chemical precipitation from solution, including secretion by organisms in water

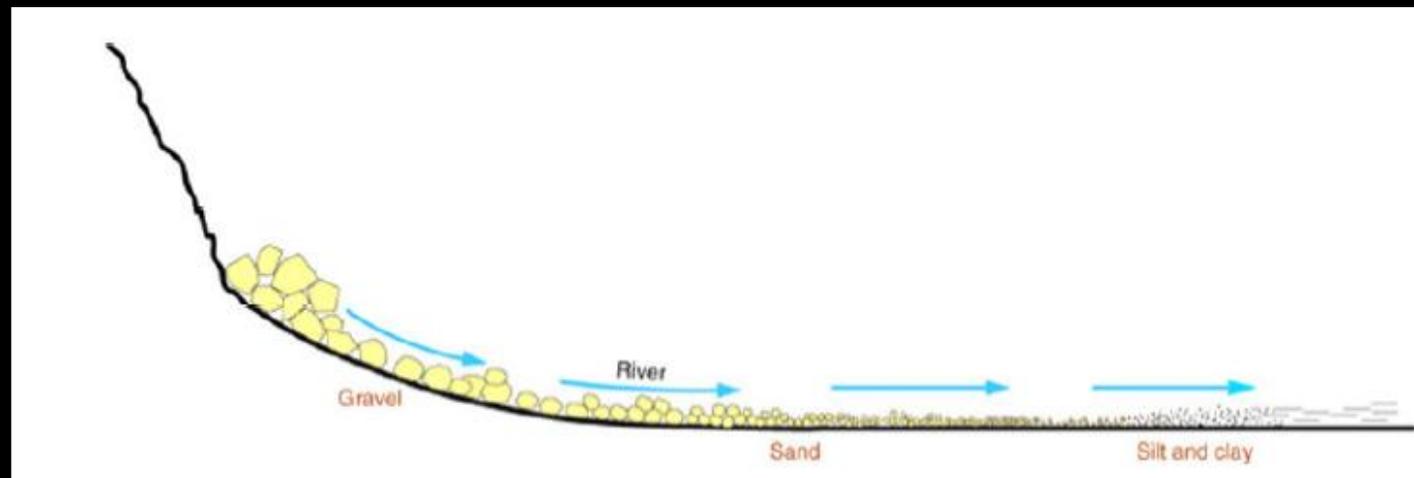


Sedimentary Rocks

- There are at least four phases in the generation of sedimentary rocks; These phases;
 1. Weathering and erosion
 2. Transportation: Movement of the material coming from the decay of the rocks in various ways
 3. Deposition: Storage or sedimentation of transported material in certain places,
 4. Lithification: Compaction and consolidation of stored or deposited sediments after diagenesis

Transportation

- Movement of sediment away from its source, typically by water, wind, or ice
- Rounding of particles occurs due to abrasion during transport
- Sorting occurs as sediment is separated according to grain size by transport agents, especially running water
- Sediment size decreases with increased transport distance



Deposition

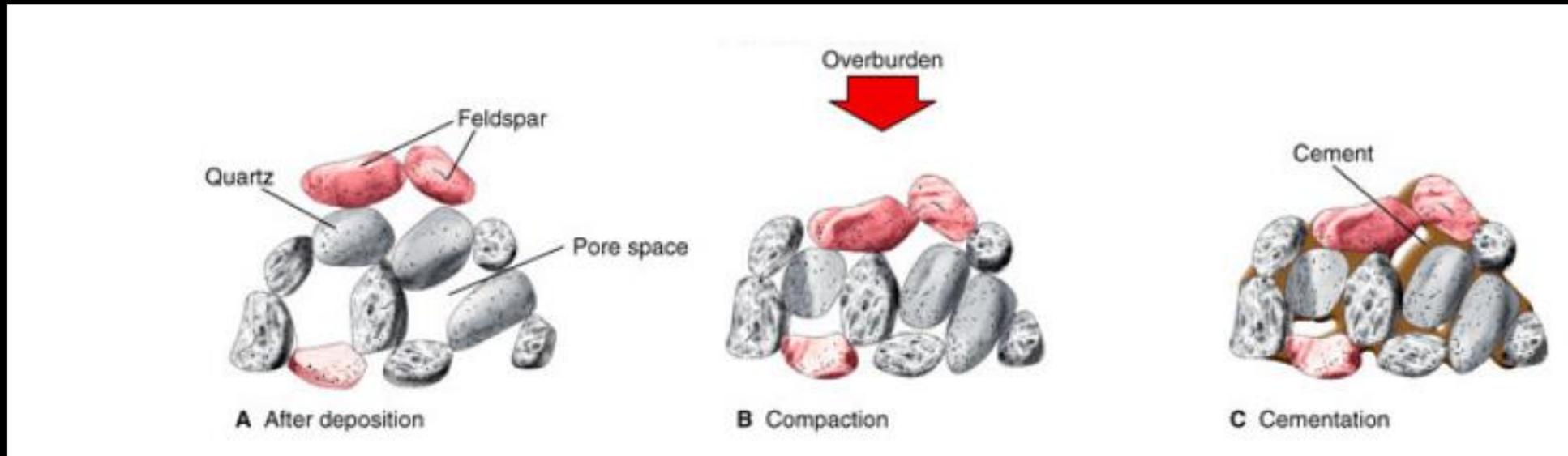
- Settling and coming to rest of transported material
- Accumulation of chemical or organic sediments, typically in water
- Environment of deposition is the location in which deposition occurs
 - Deep sea floor
 - Beach
 - Desert dunes
 - River channel
 - Lake bottom

Preservation

- Sediment must be preserved, as by burial with additional sediments, in order to become a sedimentary rock

Lithification

- General term for processes converting loose sediment into sedimentary rock
- Combination of *compaction* and *cementation*



Sedimentary Rocks

- Diagenesis is the term used for all of the changes that a sediment undergoes after deposition and before the transition to metamorphism. The multifarious processes that come under the term diagenesis are chemical, physical, and biological.

Diagenesis

Compaction

Cementing

- Quartz
- Calcite
- Iron Oxide
- Clay
- Glauconite
- Feldspar

Alteration

- Limestone - Dolomite
- Plagioclase – Albite

Recrystallization

- Limestone

Sedimentary Rocks

Some of the criteria that distinguish sediments from sedimentary rocks are:

Sediments are loose because they do not bond to one another and do not undergo diagenesis.

In sedimentary rocks, granules are connected to each other by an intermediate material, namely cement. They are also diagenetic and petrified. Contrary to sediments, they are consolidated and hardened.

Sedimentary rocks show stratification and provide different shapes when stratified (Graded stratification, cross stratification, etc.) Sediments are usually found in mass. They do not show stratification.

Sedimentary rocks contain organic residues. Organisms leave behind organic and inorganic materials after their deaths. Inorganic wastes become fossilized and organic materials leave their places to organic minerals such as petroleum and coal.

Sedimentary rocks may undergo some changes after their formation. This is called deformation. As a result of deformation are folded, bent, broken, or even are displaced.

IMPORTANCE OF SEDIMENTARY ROCK

“Present is the key to the past”

- Helps in knowing depositional environment viz. marine (ocean deposits), fluvial (river deposits), aeolian (wind deposits), glacial, estuarine, Lacustrine (lake deposits) etc.
- Helps in knowing the provenance (i.e. source area of the sediments); change in climatic conditions i.e. in knowing and understanding old climate=*paleoclimate*.

TYPES OF SEDIMENTARY ROCKS

Clastic rocks

- Sandstones
- Conglomerates
- Breccia
- Shale/mudstones

Chemical

Carbonate rocks

Form basically from CaCO_3 – both by chemical leaching and by organic source (biochemical) eg. Limestone; dolomite

Evaporitic rocks

These rocks are formed due to evaporation of saline water (sea water) eg. Gypsum, Halit (rock salt)

Organic rocks

Organic rocks

Form due to decomposition of organic remains under temperature and pressure eg. Coal/Lignite etc.

Sedimentary Rocks are classified based on their components.

Clastic



1.) Conglomerate



2.) Sandstone



3.) Shale

Organic



1.) Coal



2.) Fossiliferous Limestone

Chemical

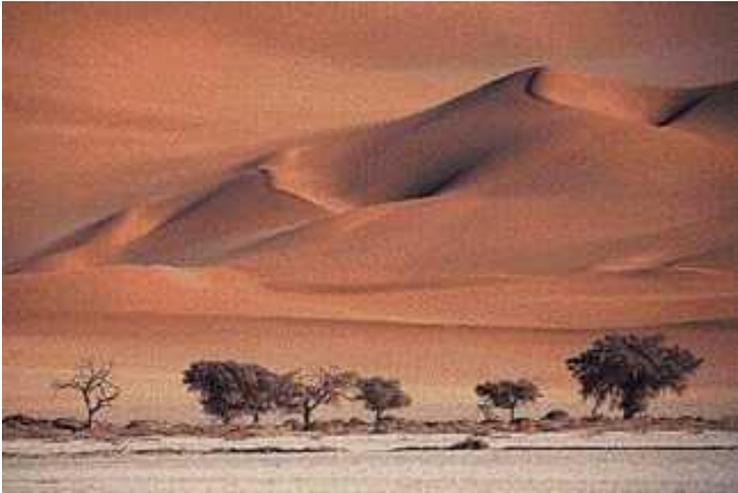


1.) Limestone

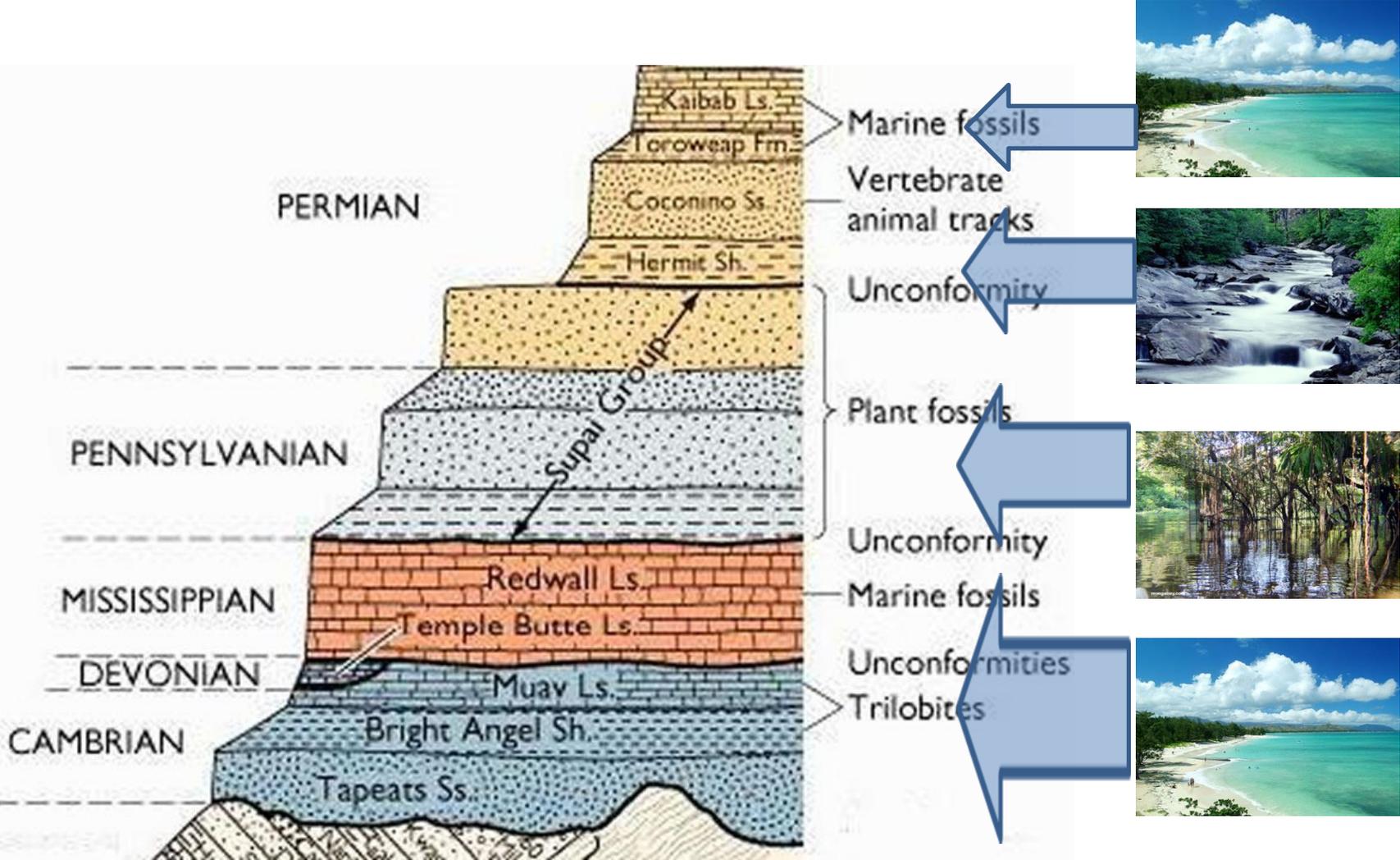


2.) Salt

Environments affect the type of sediment.



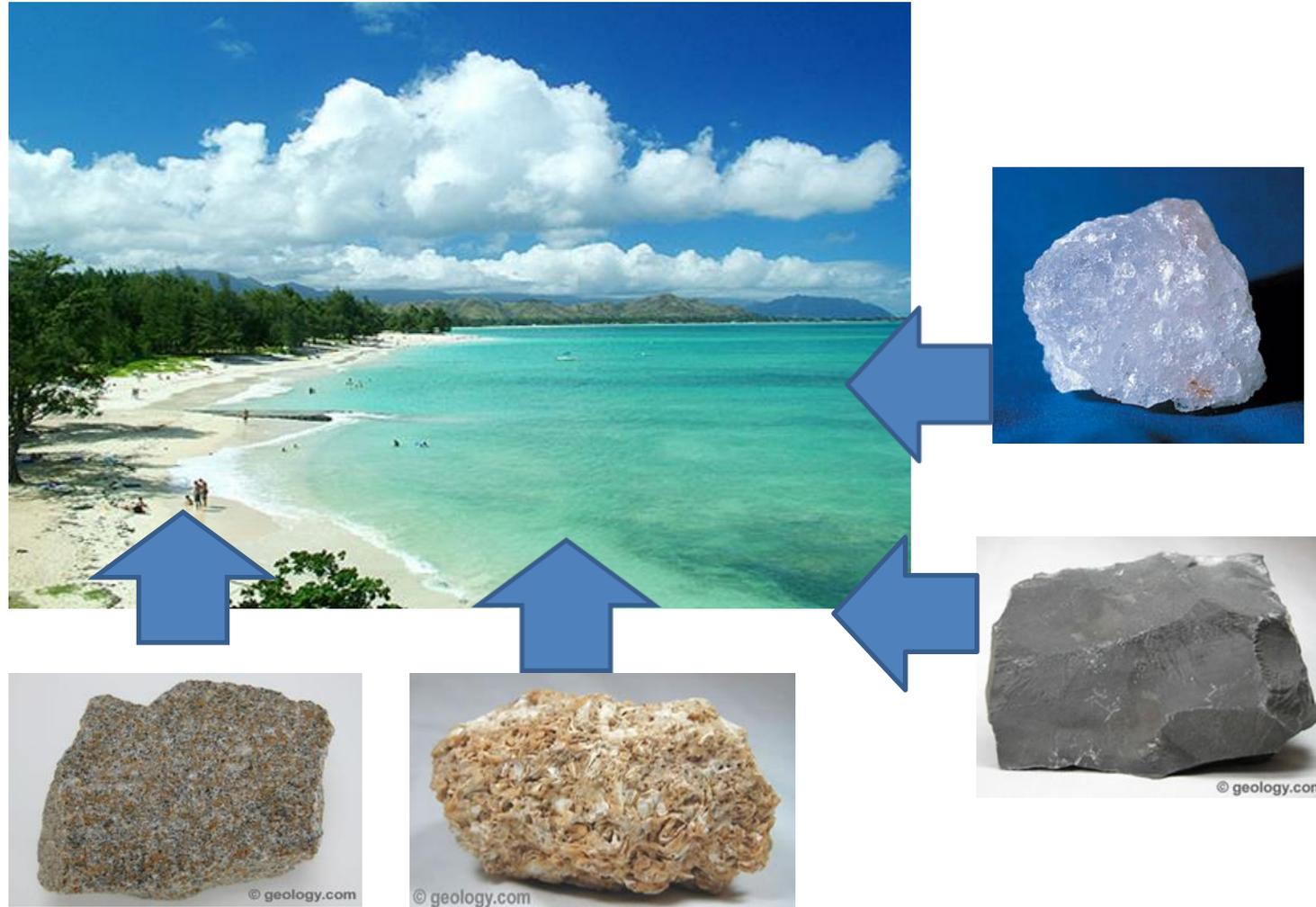
Environments change throughout geologic time.



Where do you think these rocks are from?

GRAND CANYON!!!

Different environments produce different sedimentary rocks.



Different environments produce different sedimentary rocks.



Different environments produce different sedimentary rocks.



Different environments produce different sedimentary rocks.



Sedimentary Rocks

Clastic Sedimentary Rocks; formed from broken rock fragments weathered and eroded by river, glacier, wind and sea waves. These clastic sediments are found deposited on floodplains, beaches, in desert and on the sea floors.

These rocks usually form in water environments such as, rivers, lakes, oceans, but can also form in deserts.

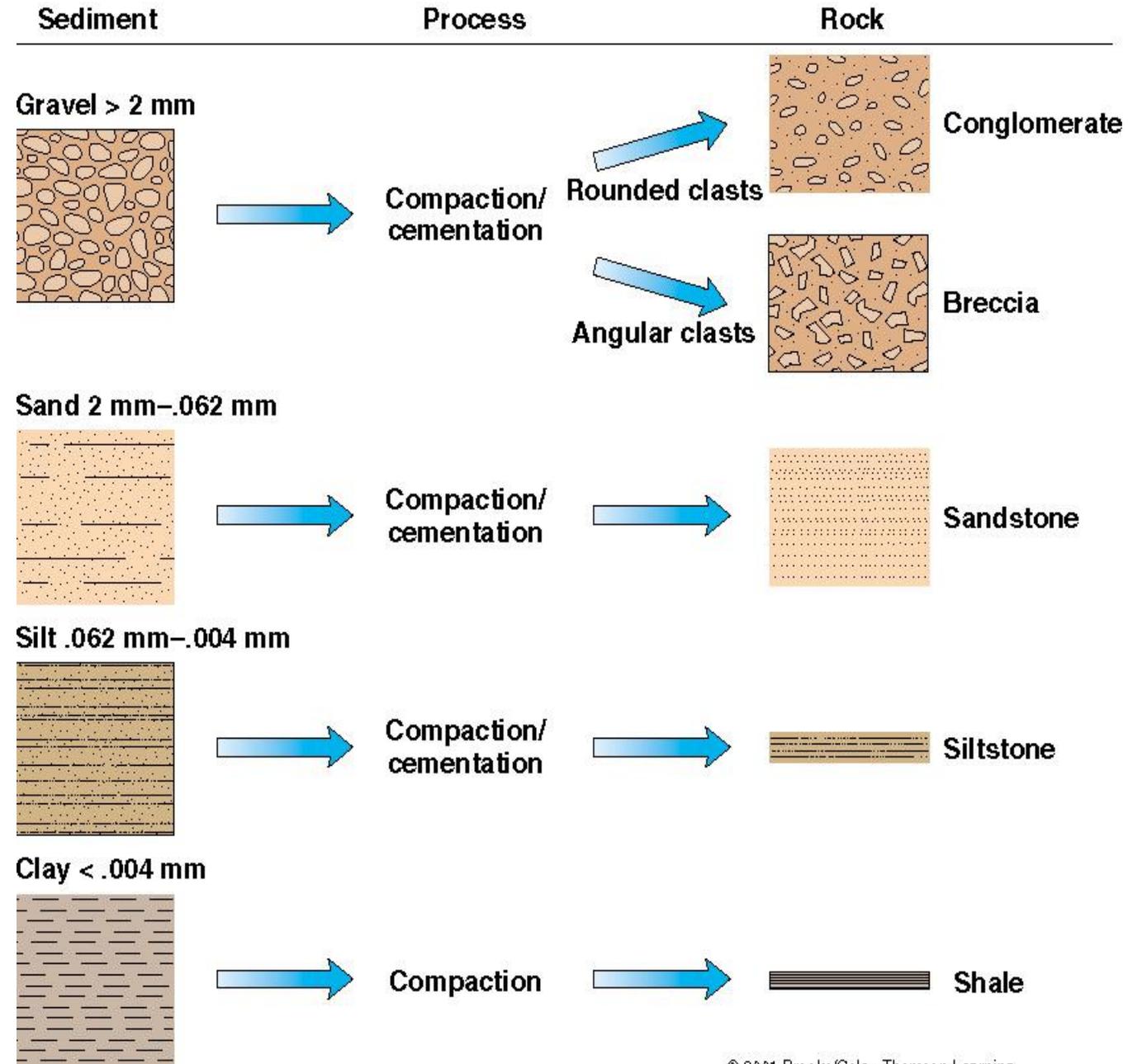
Consist of solid particles from weathered rocks. These rock fragments include pebbles, sand, silt and clay.

Diameter (mm)	Sediment		Sedimentary Rock
256	Boulder	Gravel	Breccia (angular particles) or Conglomerate (rounded particles)
64	Cobble		
2	Pebble		
$\frac{1}{16}$	Sand		Sandstone
$\frac{1}{256}$	Silt	"Mud"	Siltstone (mostly silt) Shale or mudstone (mostly clay)
	Clay		

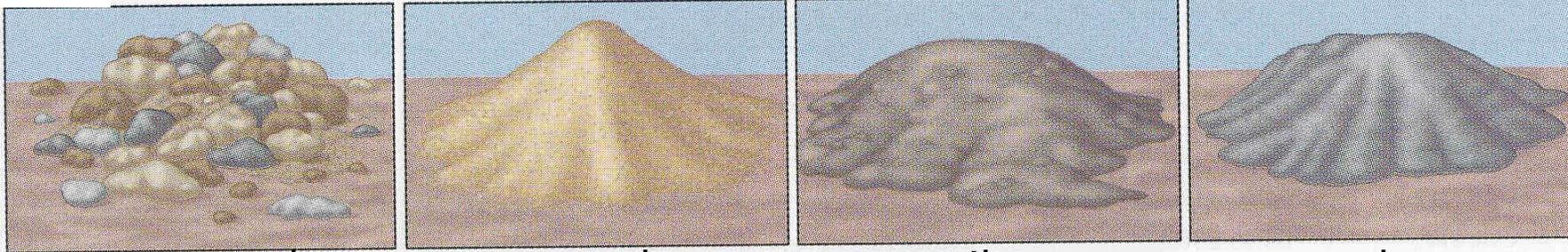
Sandstone and shale are quite common; the others are relatively rare.

This figure shows how clastic sediment of various sizes will, after compaction and cementation, form different types of **detrital sedimentary rocks**.

The process of sediment turning into rock is called **lithification**.



sediments



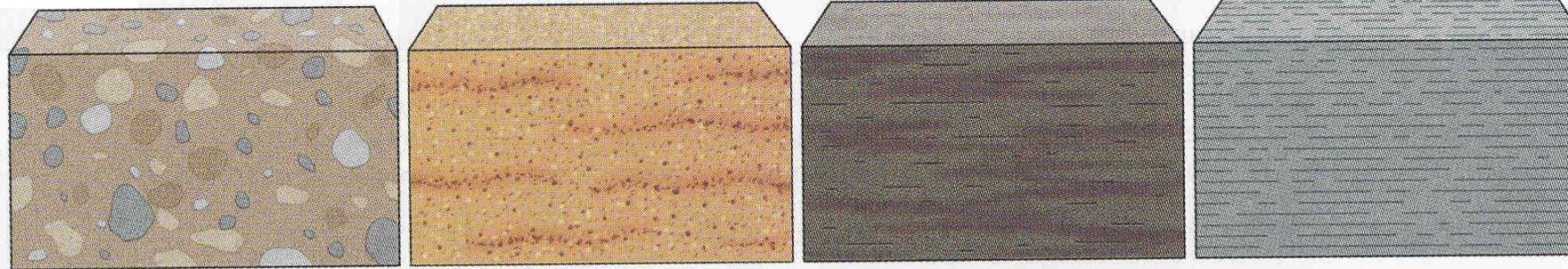
gravel

sand

silt

clay

sedimentary rocks

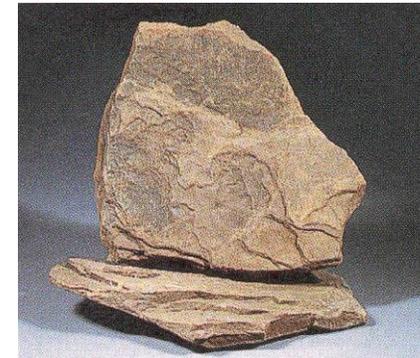
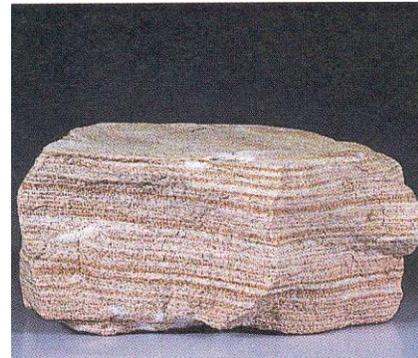
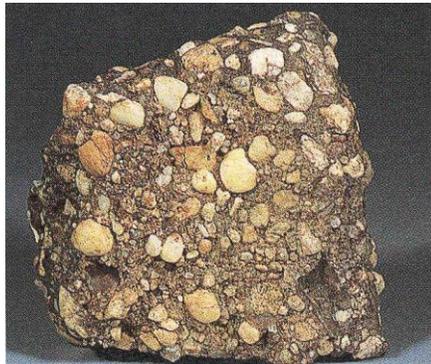


conglomerate

sandstone

siltstone

shale



**Table 8.3****Major Classes of Clastic Sediments and Sedimentary Rocks**

Particle Size	Sediment	Rock
COARSE	GRAVEL	
Larger than 256 mm	Boulder	Conglomerate
256–64 mm	Cobble	
64–2 mm	Pebble	
MEDIUM		
2–0.062 mm	SAND	Sandstone
FINE	MUD	
0.062–0.0039 mm	Silt	Siltstone
Finer than 0.0039 mm	Clay	{ Mudstone (blocky fracture) Shale (breaks along bedding) Claystone

Chemical Sedimentary Rocks

These rocks form as a result of chemical weathering dissolving chemicals and transporting it in solution. When conditions are right, these dissolved chemicals change back into a solid through the processes of **precipitation** and **evaporation**.

Precipitation: Process where chemicals dissolved on solution, fall out of solution and forms a solid material. Most common in shallow water environments.

Evaporation: Process where there is a change in state from a liquid to a gas. Chemicals dissolved in the liquid (water) are left behind as a solid material.

Chemical Sedimentary Rocks

These rocks usually form in water environments such as lakes and shallow seas or oceans.

Some examples of chemical sedimentary rocks include;

- 1) Limestone (Calcite) - (form by precipitation)**
- 2) Rock Gypsum - (form by precipitation and evaporation)**
- 3) Rock salt (Halite) – (from by evaporation)**
- 4) Coquina - (form by biochemical processes)**



Organic Sedimentary Rocks

These rocks form as a result of once living material accumulating to form solid rock.

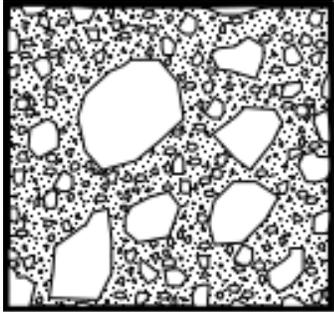
The most common organic rock is [coal](#), which forms when plant material in water saturated environments (swamps) die and accumulate to form peat. As peat is buried it compresses and eventually changes to form coal.

Textures of Sedimentary Rocks

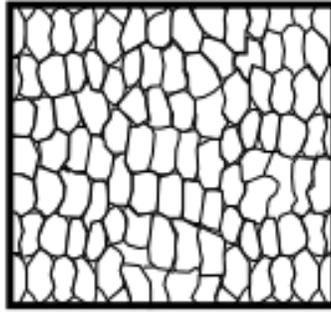
- Most sedimentary rocks are derived by processes of weathering, transportation, deposition, and diagenesis. The final texture (grain size, shape, sorting, mineralogy, etc.) in a sediment or sedimentary rocks is dependent on process that occur during each stage. The points below summarize the basic factors affecting rock texture.
 - The nature of the source rocks (the rocks that were eroded to create the sediments). This determines the original shape of the grains and the mineralogical composition of the original sediment.
 - The strength of the wind or water currents that carry and deposit the sediment. This determines whether or not grains are transported or deposited. The deposition process also controls structures (see sedimentary structures below) that could be preserved in the sediment and thus give clues to the environment of deposition.
 - The distance transported or time in the transportation process. The longer grains are in the transportation process the more likely they are to change shape and become sorted on the basis of size and mineralogy. This also controls extent to which they break down to stable minerals during the transportation process.
 - Biological activity with the sediment prior to diagenesis. Burrowing organisms can redistribute sediment after it has been deposited, thus erasing some of the clues to the original environment of deposition.
 - The chemical environment under which diagenesis occurs. During diagenesis grains are compacted, new minerals precipitate in the pore spaces, some minerals continue to react to produce new minerals, and some minerals recrystallize. What happens depends on the composition of fluids moving through the rock, the composition of the mineral grains, and the pressure and temperature conditions attained during diagenesis.

Textures of Sedimentary Rocks

Grain sorting: Sorting refers to the uniformity of grain size in a sediment or sedimentary rock.

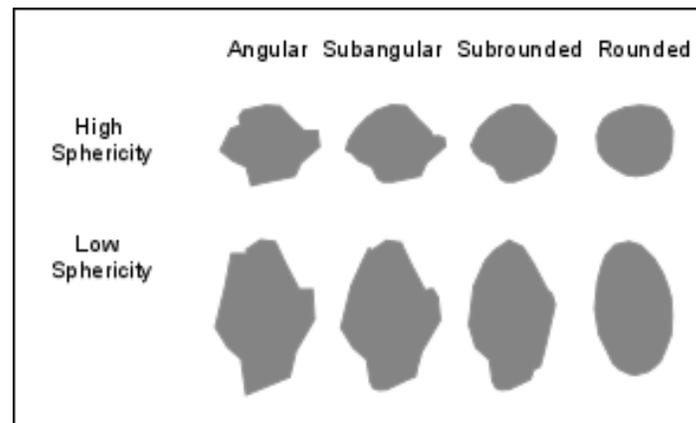


Poorly Sorted Sediment



Well Sorted Sediment

Rounding: During the transportation process, grains may be reduced in size due to abrasion. Random abrasion results in the eventual rounding off of the sharp corners and edges of grains. Thus, the degree of rounding of grains gives us clues to the amount of time a sediment has been in the transportation cycle.



Textures of Sedimentary Rocks

- Sphericity is controlled by the original shape of the grain. The longer the sediment is transported, the more time is available for grains to lose their rough edges and corners by abrasion

Layering (bedding)

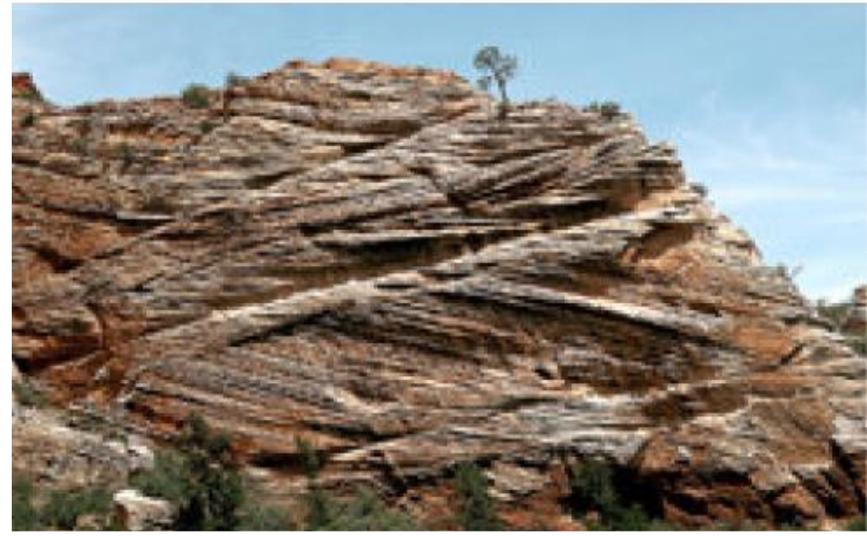
One of the most obvious features of sedimentary rocks and sediment is the layered structure which they exhibit. The layers are evident because of differences in mineralogy, clast size, degree of sorting, or color of the different layers. In rocks, these differences may be made more prominent by the differences in resistance to weathering or color changes brought out by weathering.

Cross Bedding

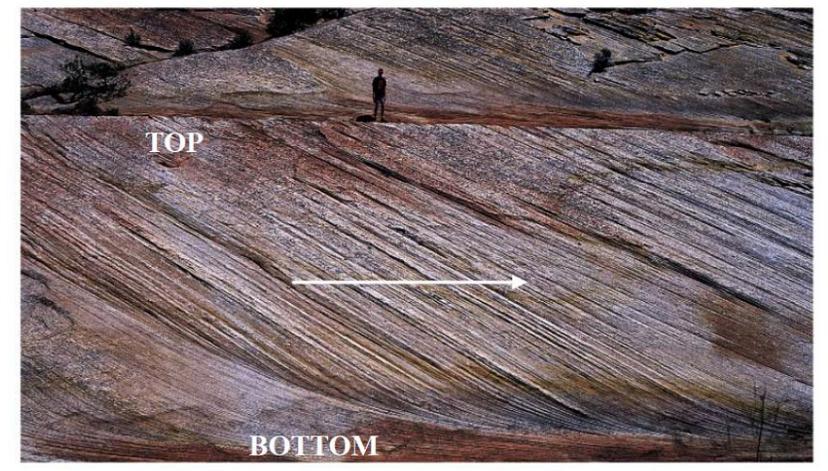
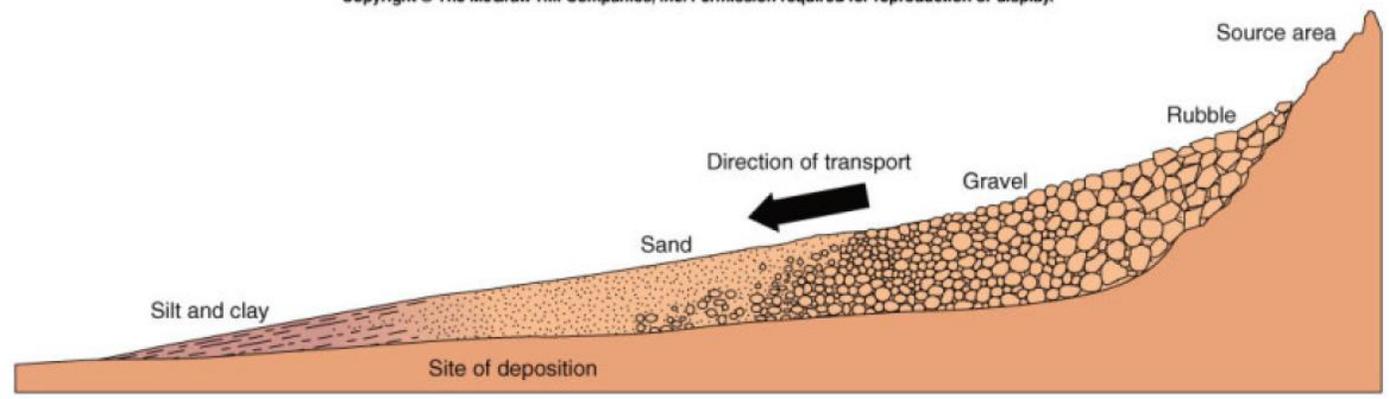
Consists of sets of beds that are inclined relative to one another. The beds are inclined in the direction that the wind or water was moving at the time of deposition. Boundaries between sets of cross beds usually represent an erosional surface. Cross bedding is very common in beach deposits, sand dunes, and river deposited sediment. Individual beds within cross-bedded strata are useful indicators of current direction and tops and bottoms. Note how the beds become asymptotic to the lower boundary on which they were deposited

Graded Bedding

As current velocity decreases, the larger or more dense particles are deposited first, followed by smaller particles. This results in bedding showing a decrease in grain size from the bottom of the bed to the top of the bed. This gives us a method for determining tops and bottoms of beds, since reverse grading will not be expected unless deposition occurs under unusual circumstances. Note that reverse graded bedding cannot occur as current velocity increases, because each layer will simply be removed as the current achieves a velocity high enough to carry sediment of a particular size.



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Engineering Properties of Sedimentary Rocks

Physical and especially mechanical properties of the existing rocks should be determined by laboratory tests and tests. The results should be numbered and used in basic and static calculations.

The rocks have a certain carrying power. Rocks that are overloaded by forces change structure and shape, so the upper structures can be damaged.

The ground that is overloaded on the surface shows different physical and chemical properties.

The factors affecting the cost and safety of the construction which are known as the engineering properties of the rocks are the specific gravity, porosity, water absorption, unit volume weight, resistance corresponding to the press, resistance to atmosphere effect, wear, fragmentation,

Engineering Properties of Sedimentary Rocks

With laboratory experiments;

It should be determined whether they are essential or not according to various rock and soil conditions. Stability and resistance to depression should be determined.

The properties of storage (S) or permeability (K) and transmissibility T of groundwater of various rocks and soils should be determined.

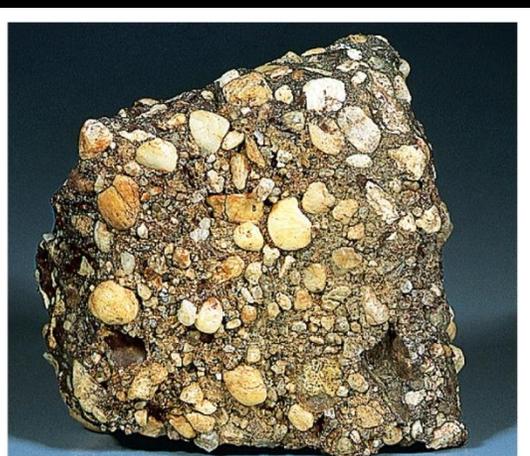
Whether or not the rocks are suitable for building materials should be determined.

Engineering Properties of Sedimentary Rocks

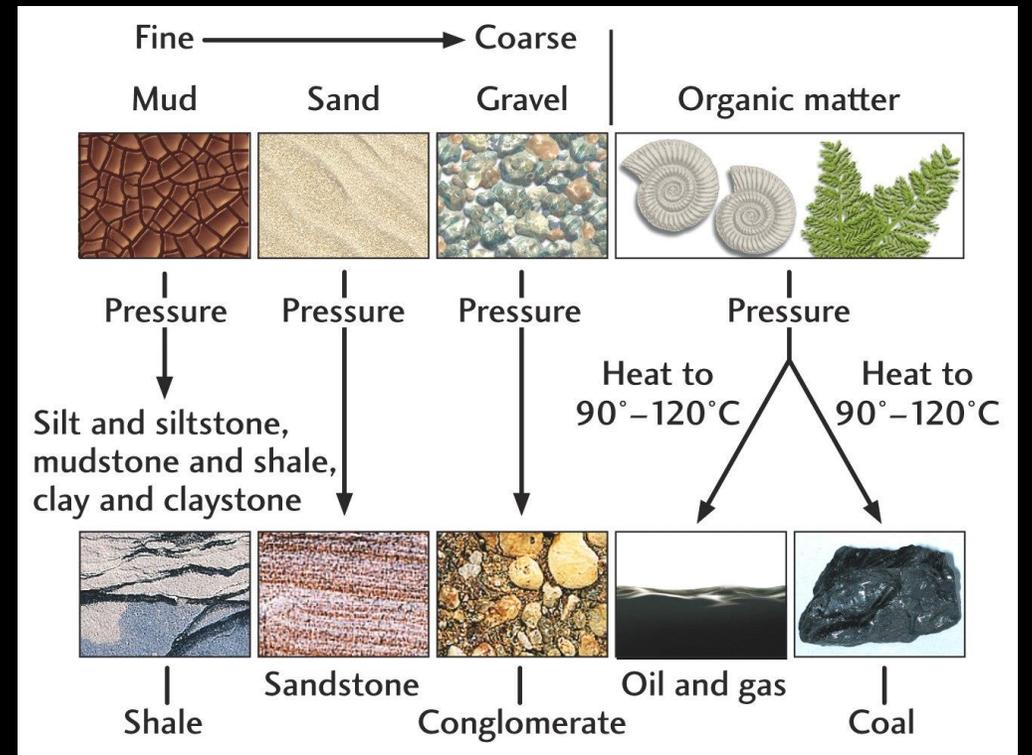
- The resistance of the sedimentary rocks to breakage and pressures varies depending on the hardness grades and the susceptibility of the minerals to water. For example; Clay, marl, gypsum and limestone cemented sandstones and conglomerates show little resistance to water pressures. Silica cemented ones are more resistant, like granite and basalt. Good cemented rocks have high porosity and permeability ratings, so their water storage capacities are high, while their resistance is low.
- Sedimentary rocks containing clay minerals such as clay and shale contain water in a small or large amount depending on the type of minerals they contain. Their indentations loosen or degrade according to the water content. As a result, resistance and handling power are reduced.
- Limestones are used as building material for producing lime, aggregate, gravel and building stone. The resistance of the limestones to be used in this area must be at least 200 kg / cm² with respect to water absorption, less abrasion, and pore and porosity
- The resistance of the limestones is low and high, so the stratification of the limestones is effective.
- Cracking systems and melting gaps should be avoided or minimized in limestones if they are used in foundation and dam construction.
- Limestones must be cracked and melting space at groundwater investigations. Limestones which have high porosity and cracked provides to generate high discharges karstic springs.



(b) Sandstone



(a) Conglomerate



Flatirons, Boulder, Colorado



Garden of the Gods, Colorado



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MAGMA



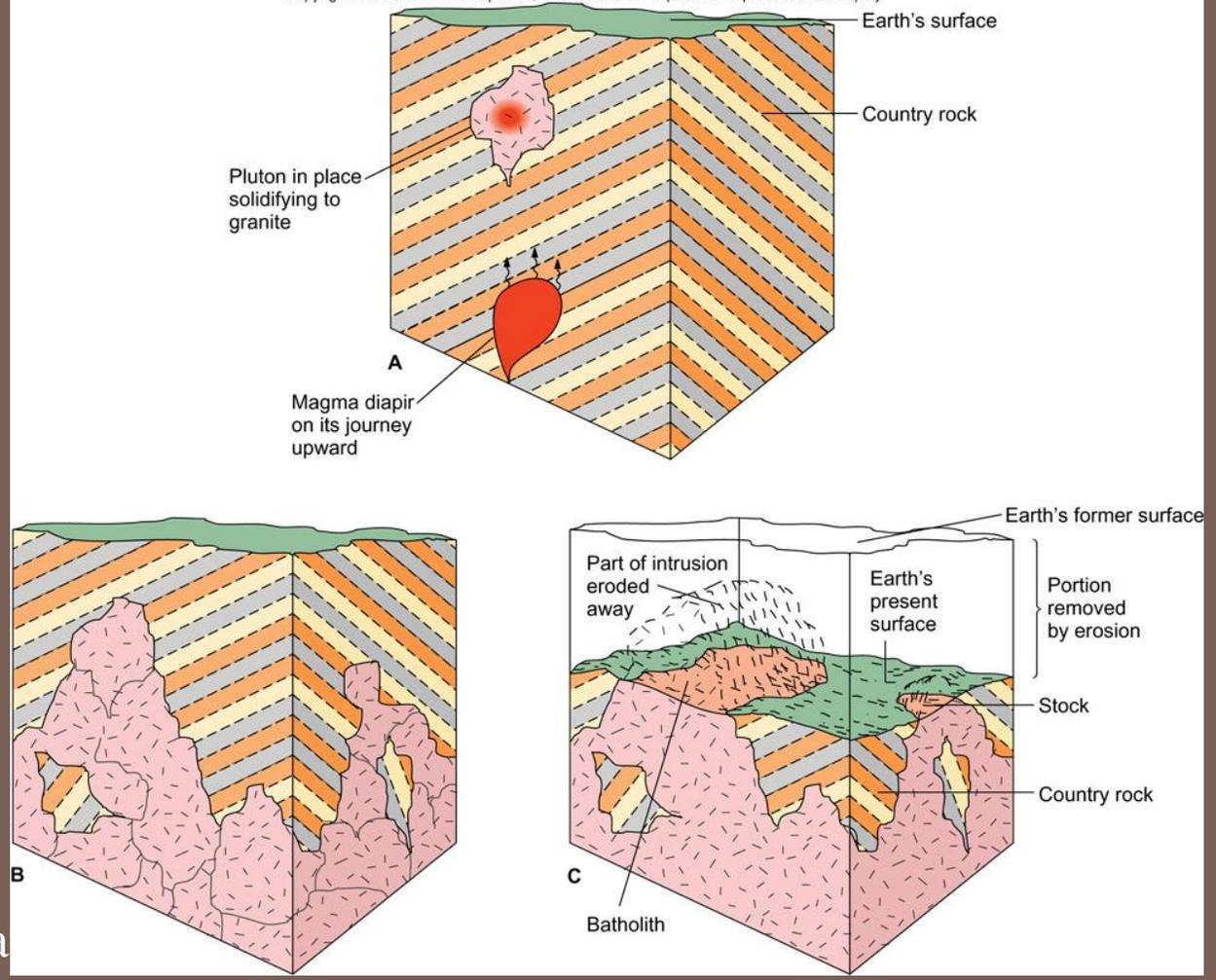
IGNEOUS

Solidification

MAGMA



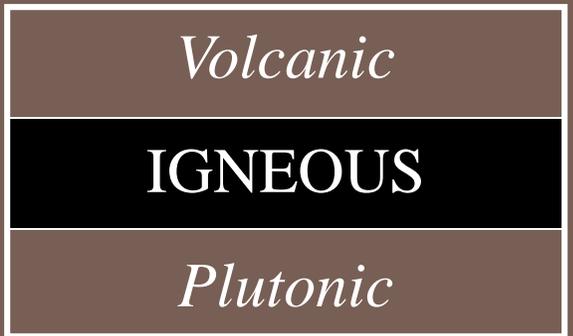
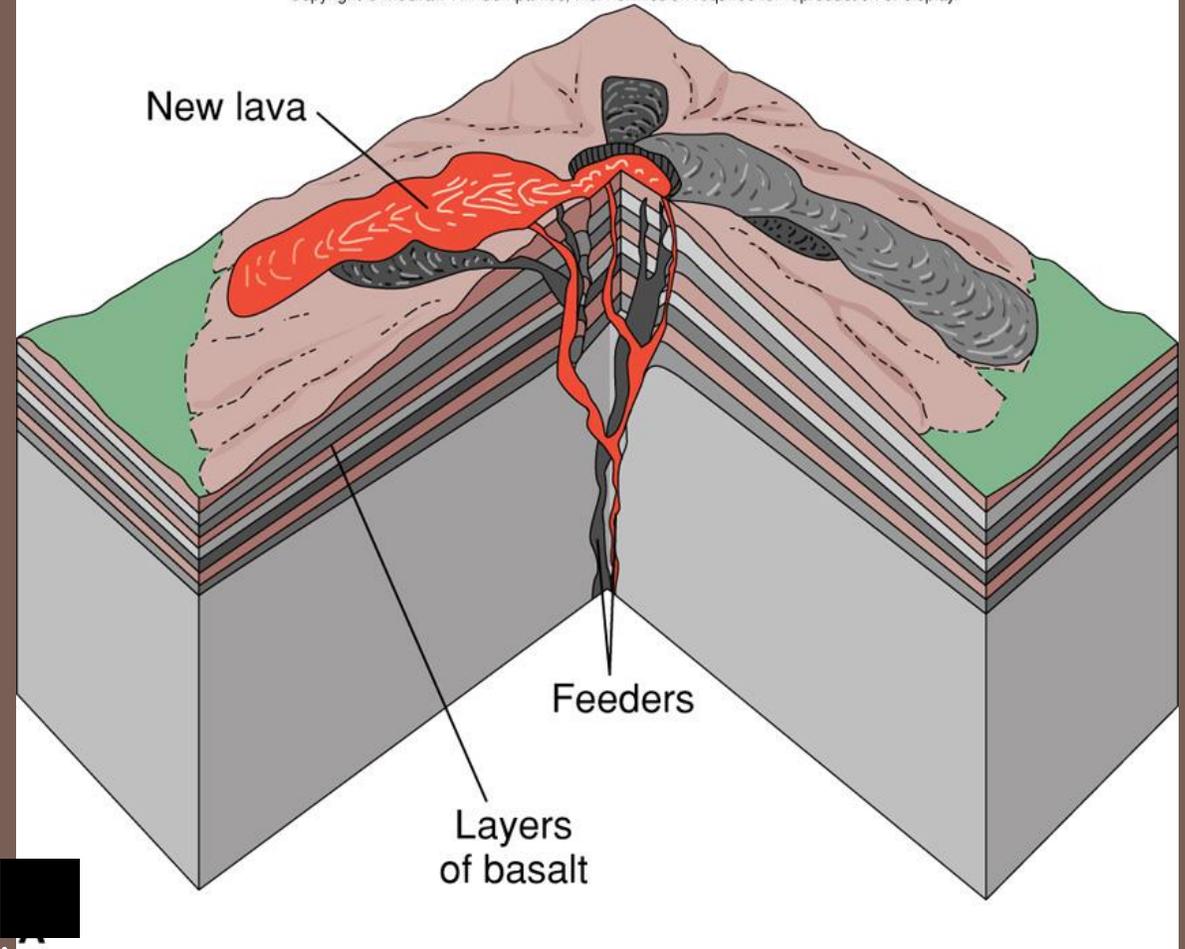
IGNEOUS
Plutonic

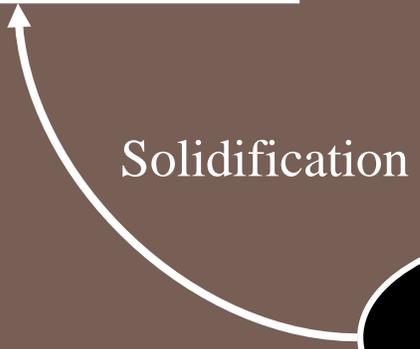
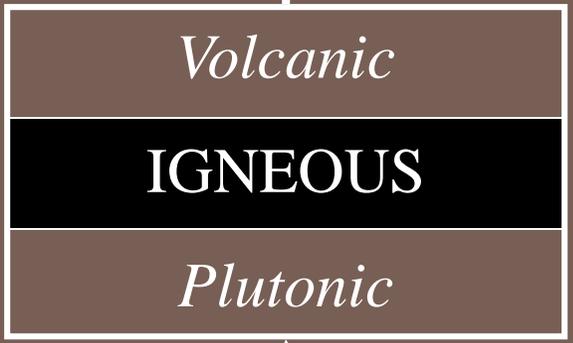
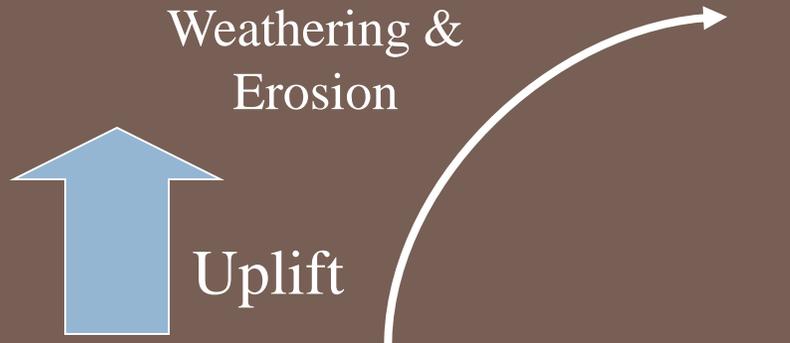


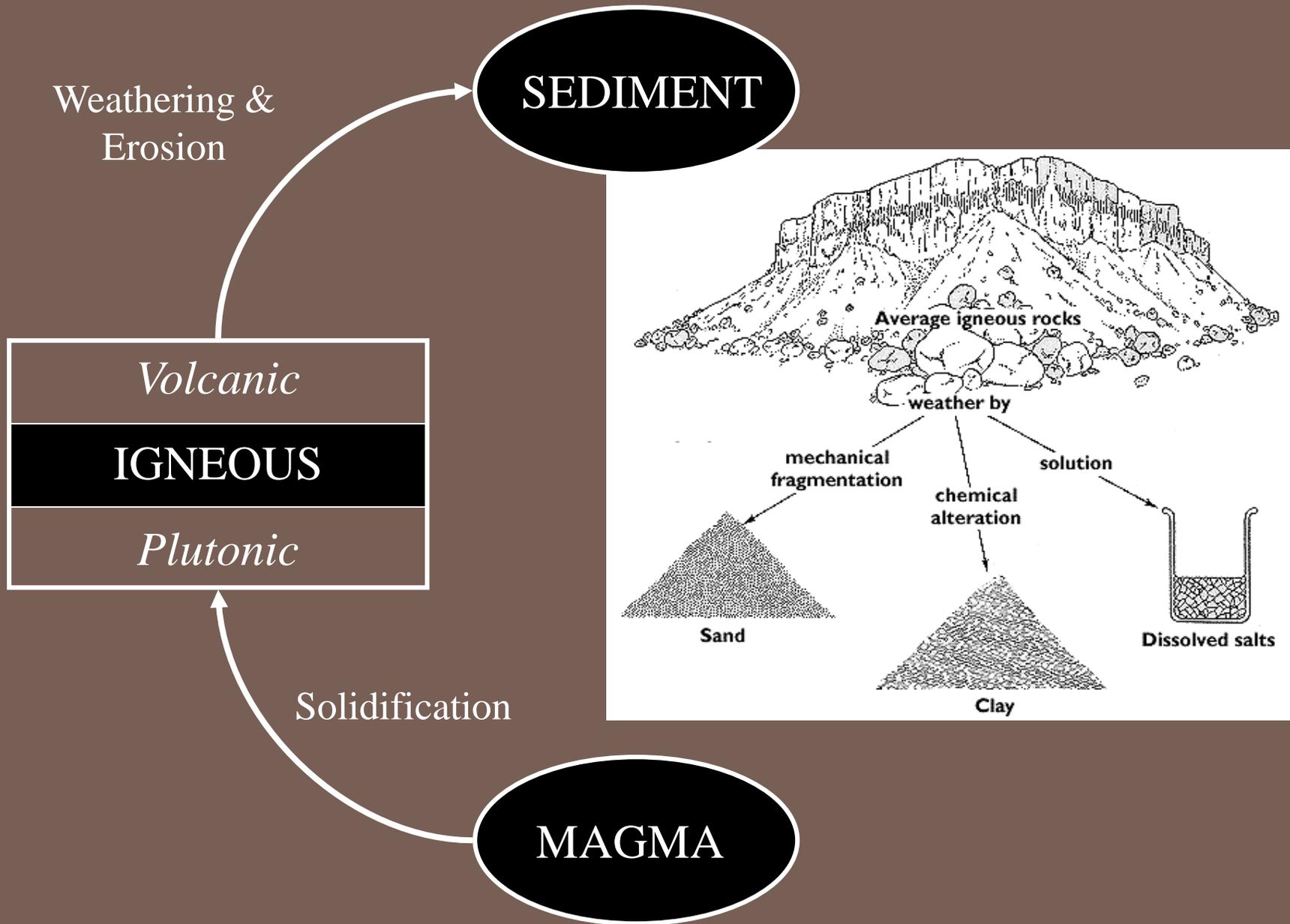
Solidifica

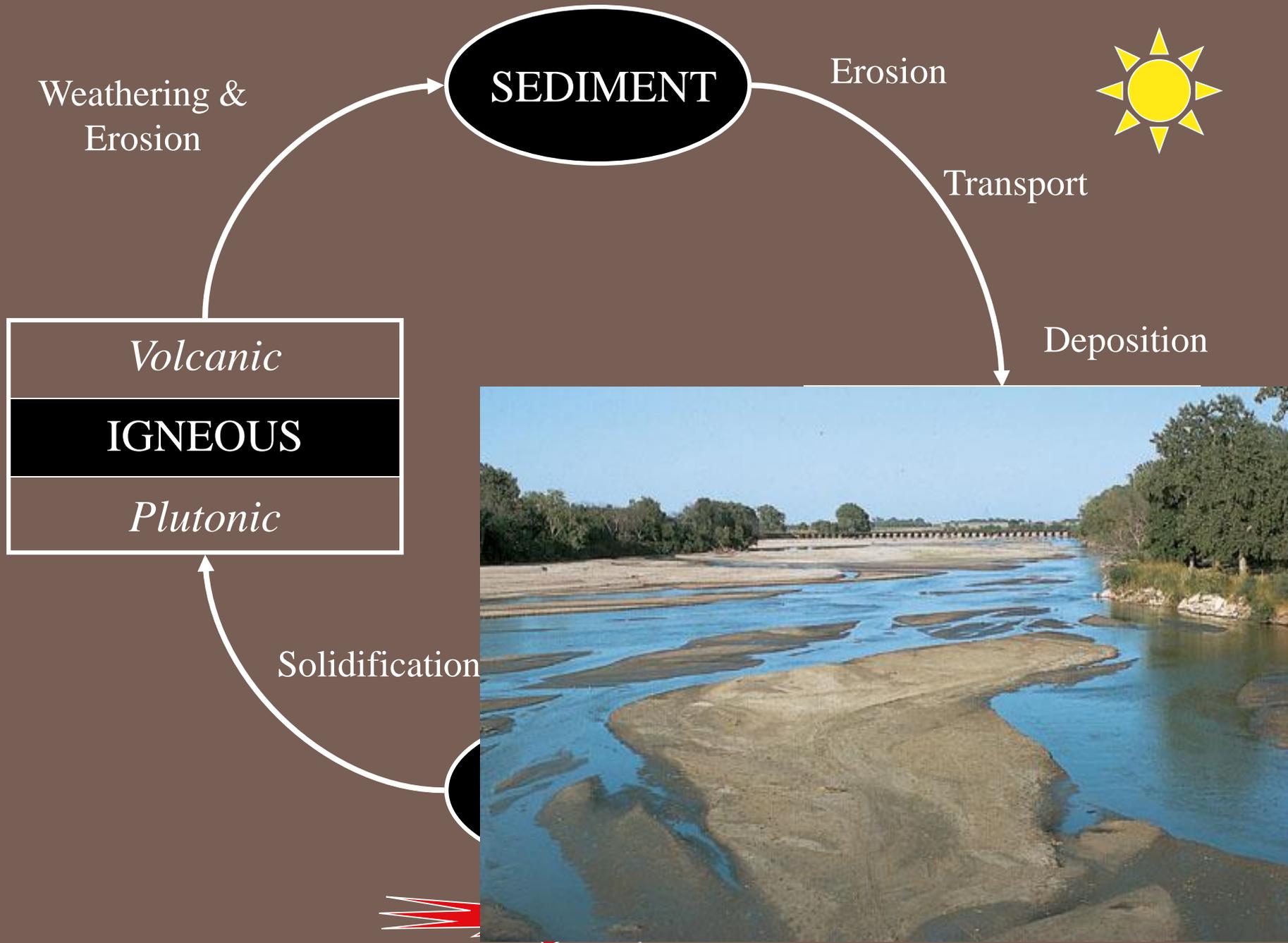
MAGMA

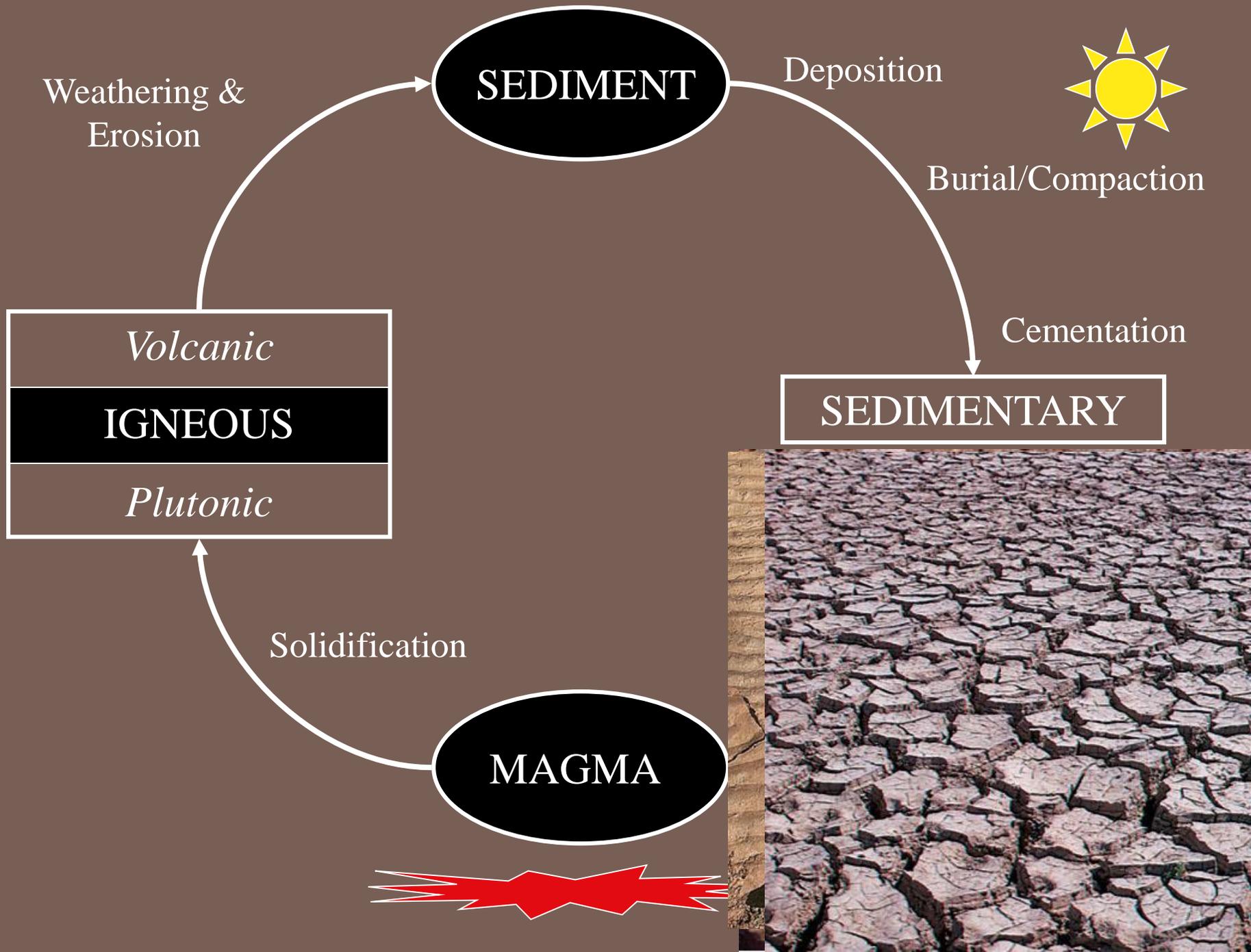


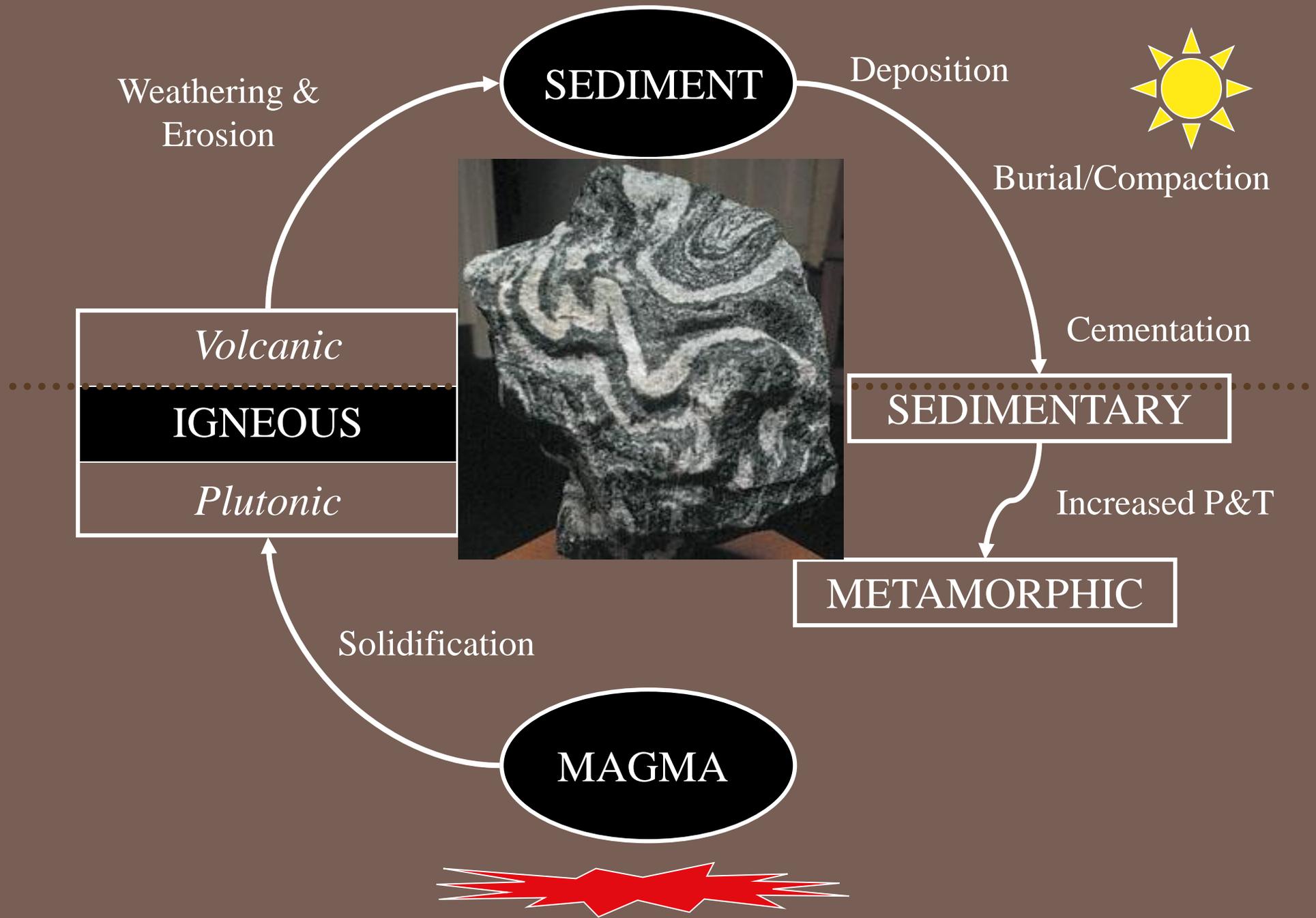


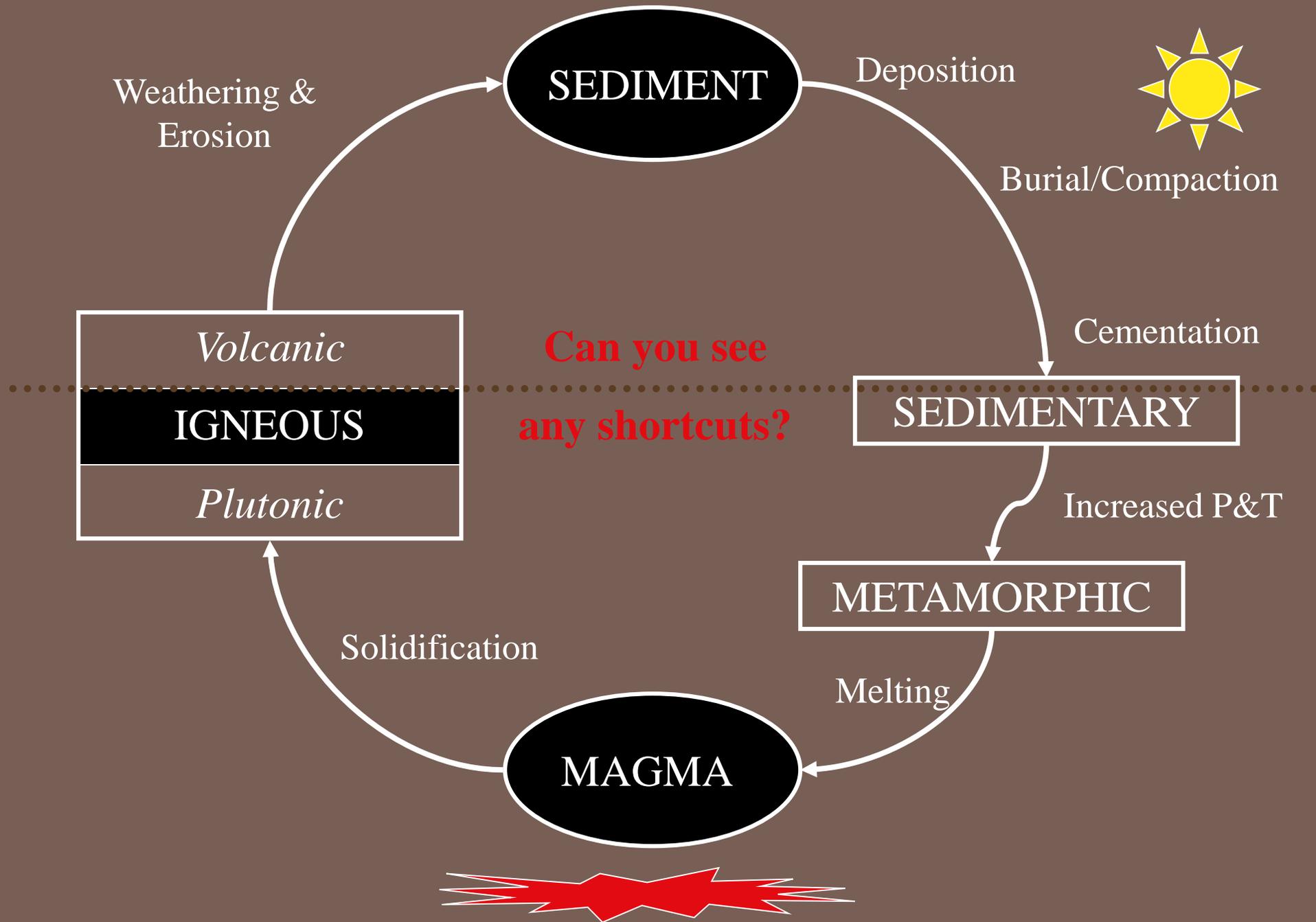


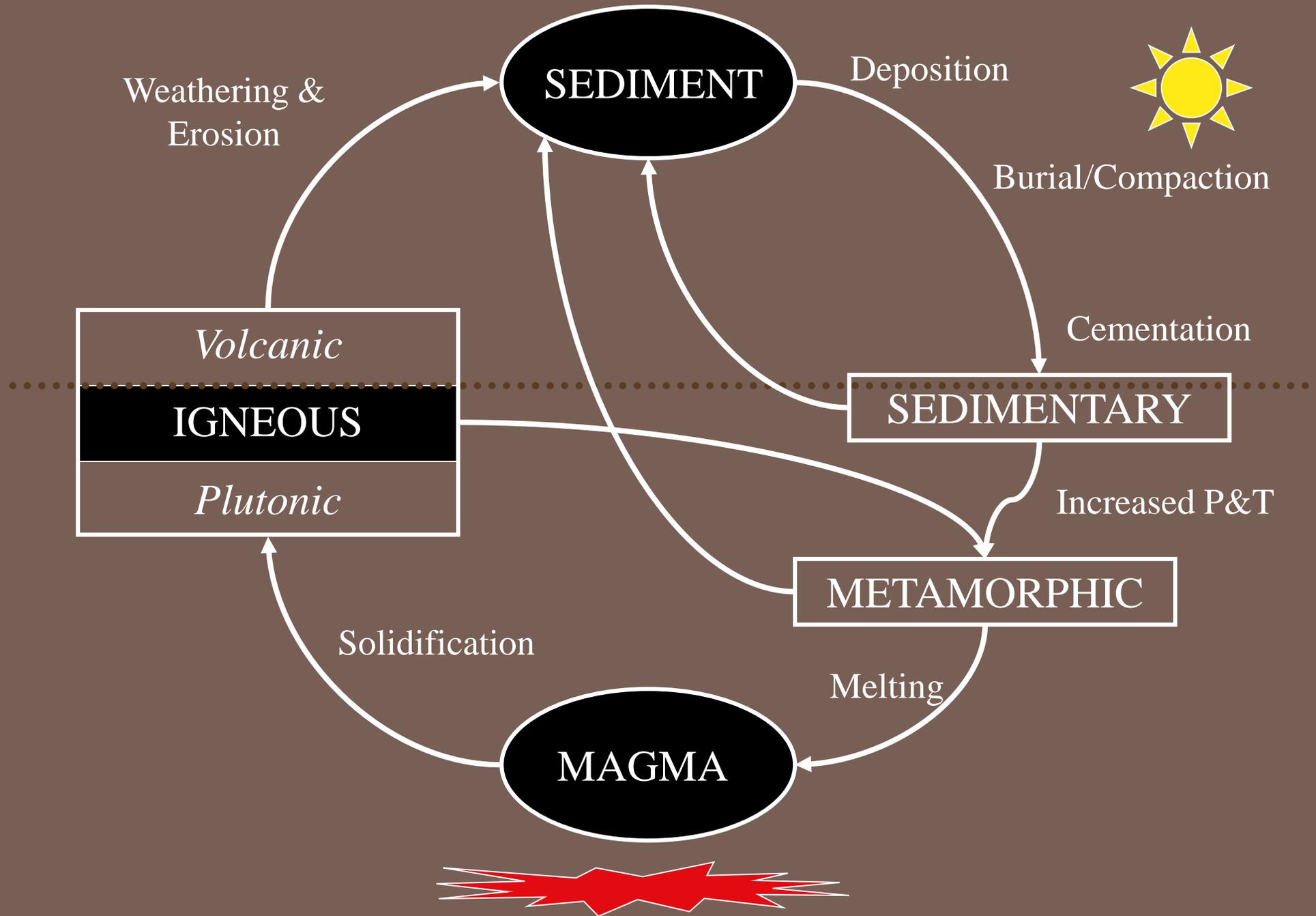


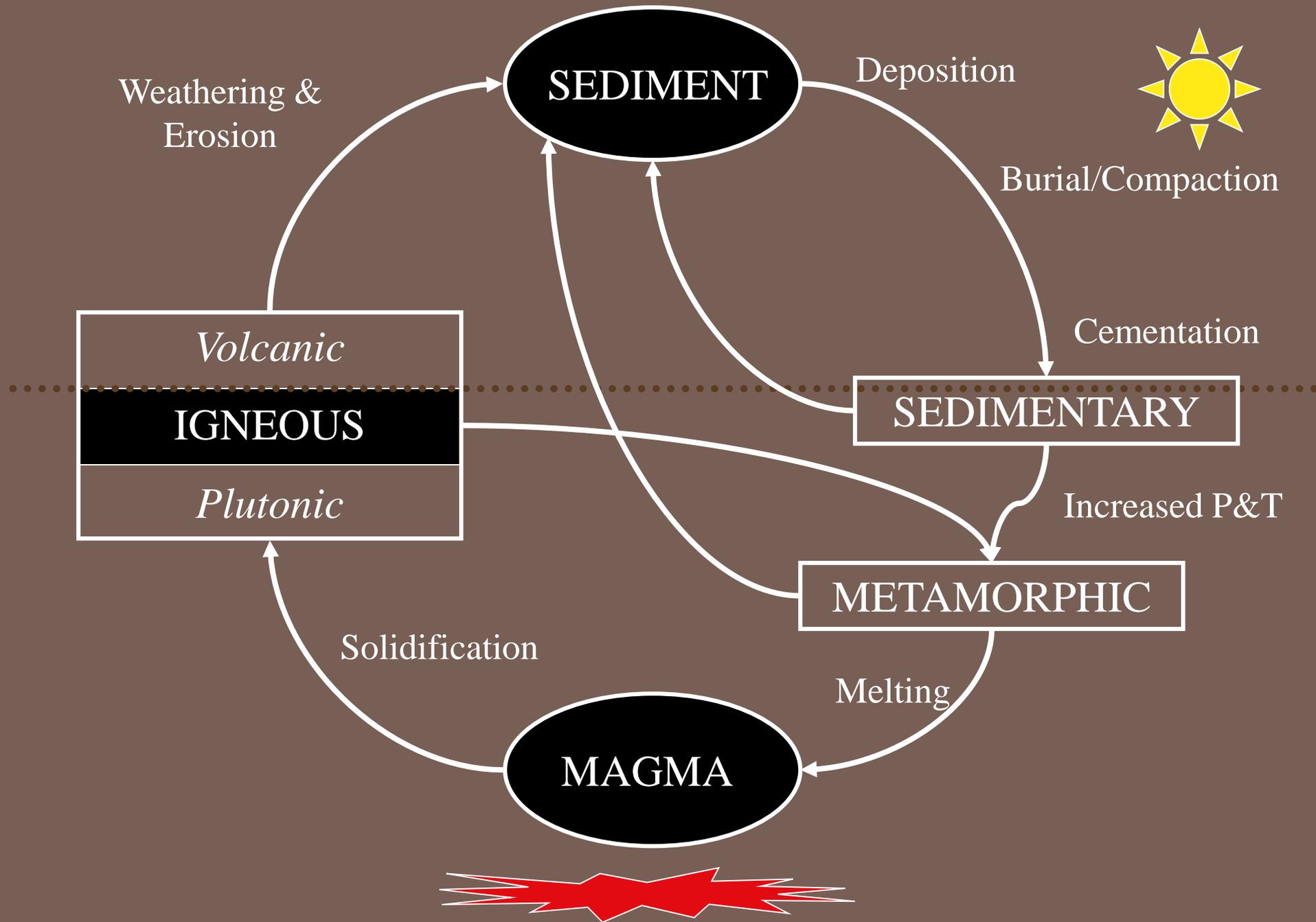












IGNEOUS ROCKS



GRANITE



DIORITE



FELSITE



BASALT



OBSIDIAN

SEDIMENTARY ROCKS



CONGLOMERATE



SANDSTONE



SHALE



LIMESTONE



DOLOMITE

METAMORPHIC ROCKS



SLATE



SCHIST



SERPENTINE

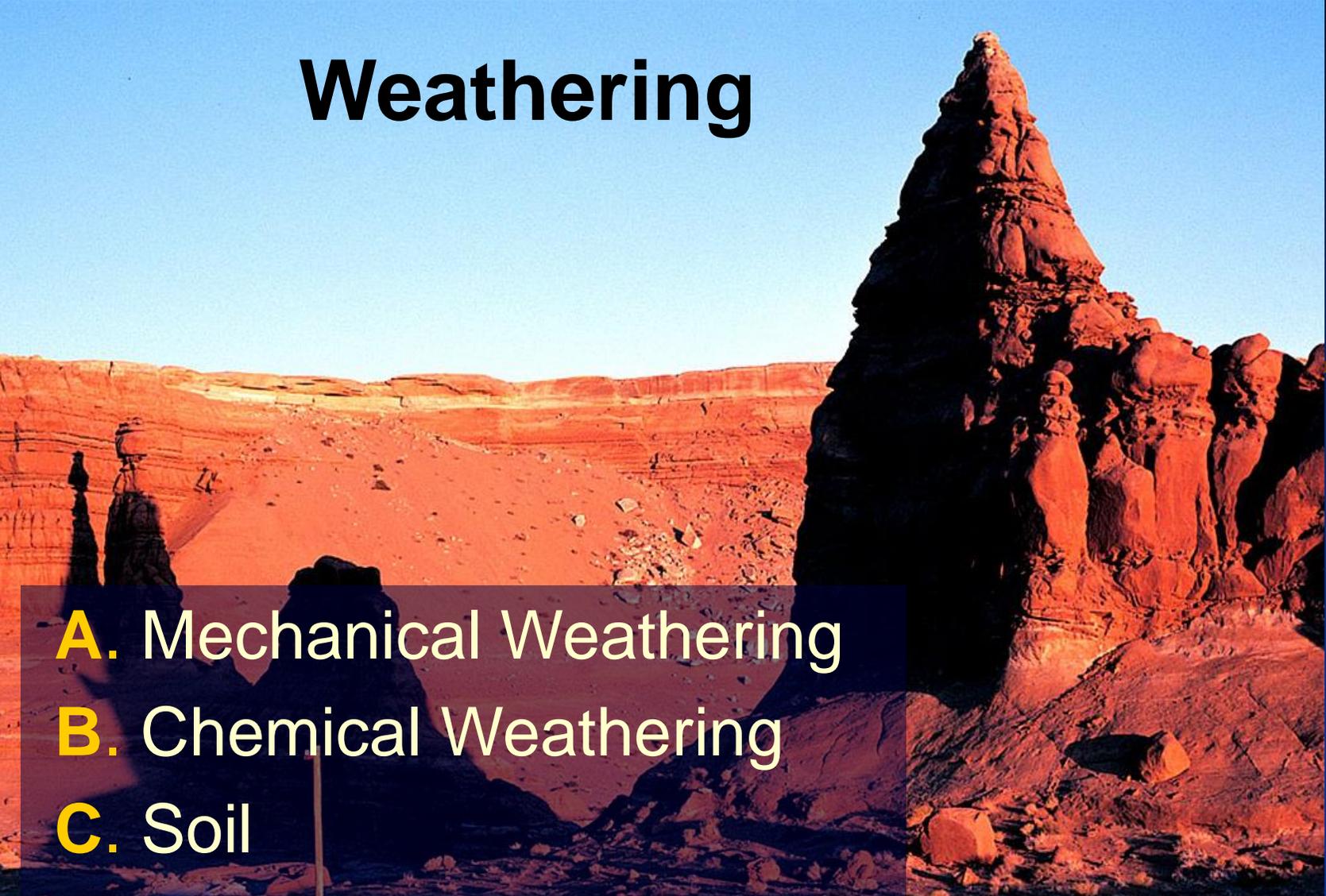


QUARTZITE



MARBLE

Weathering



- A.** Mechanical Weathering
- B.** Chemical Weathering
- C.** Soil

Weathering

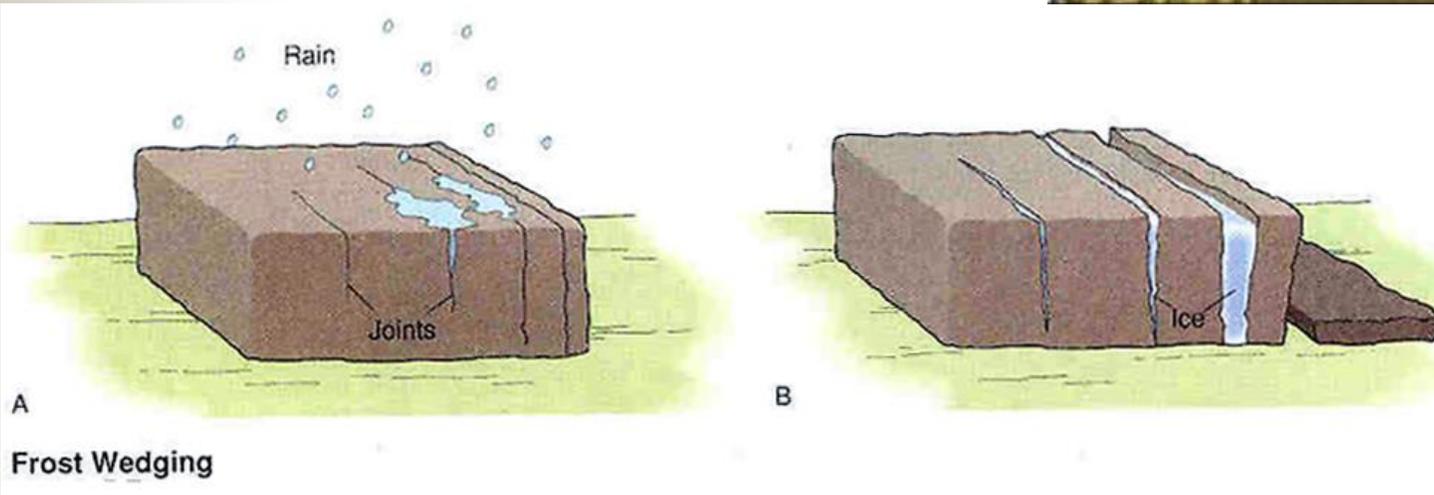
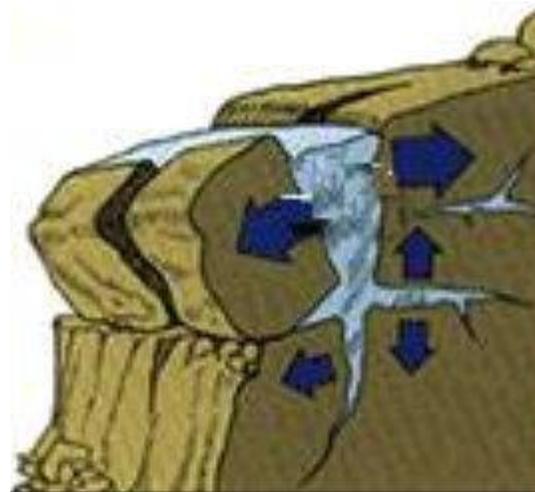
- Mechanical Weathering
 - Physical disintegration of rock (with no chemical alteration)
- Chemical Weathering
 - Chemical alteration of minerals within the rock
 - Usually softening or dissolving the minerals
 - Forming clays, oxides and solutes



AGENTS OF PHYSICAL WEATHERING

1. Frost Action - The freezing and thawing causes alternate expansion and contraction of rocks eventually breaking them apart.

- Dominate in mountain or polar regions.
- More likely to occur in winter

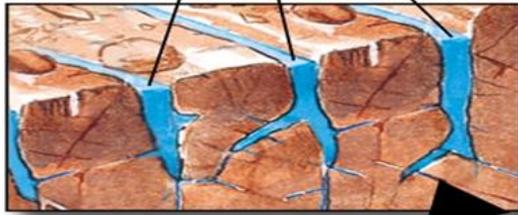


A

Frost Wedging

B

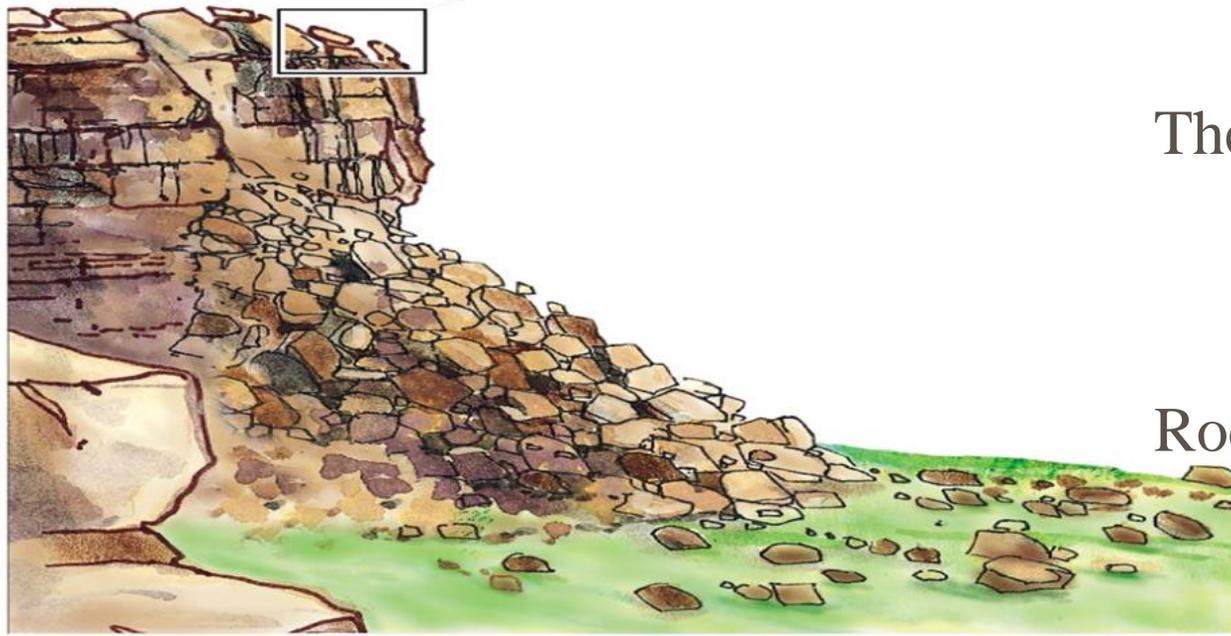
1 Water enters cracks in rock



2 Water freezes as temperature drops; expands against walls of rock



3 Cracks are enlarged; intervening rock is dislodged

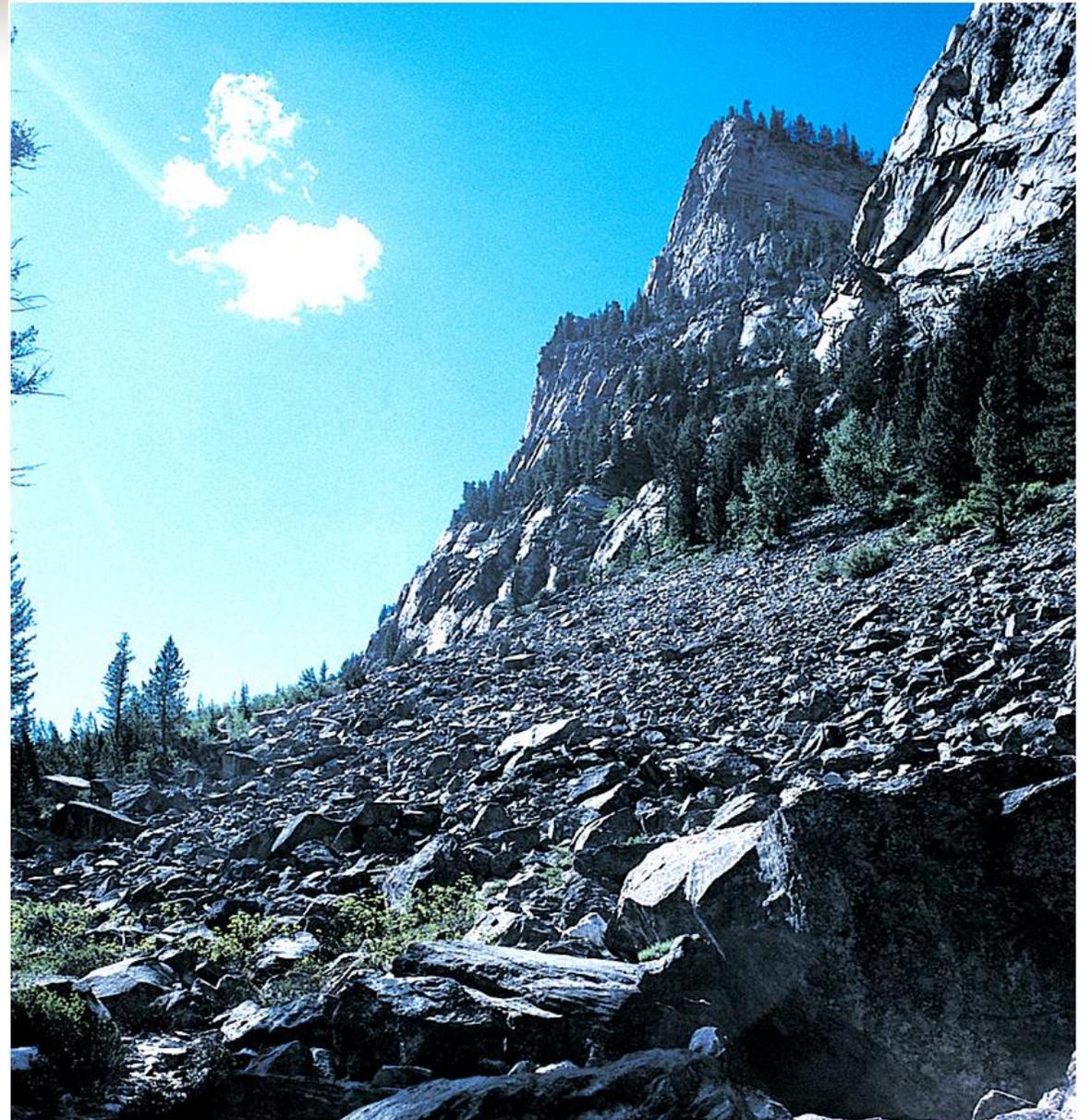


The result of
Mechanical weathering
Rock falls and slides
Crushing and abrasion (more mechanical weathering)

Rock Avalanches
Slopes of rock fragments may let go and careen downhill as a very fast flow

Talus Slopes

- The result of
 - Mechanical weathering
 - Rock falls and slides
 - Crushing and abrasion (more mechanical weathering)
- Rock Avalanches
 - Slopes of rock fragments may let go and careen downhill as a very fast flow



MECHANICAL WEATHERING

Ice

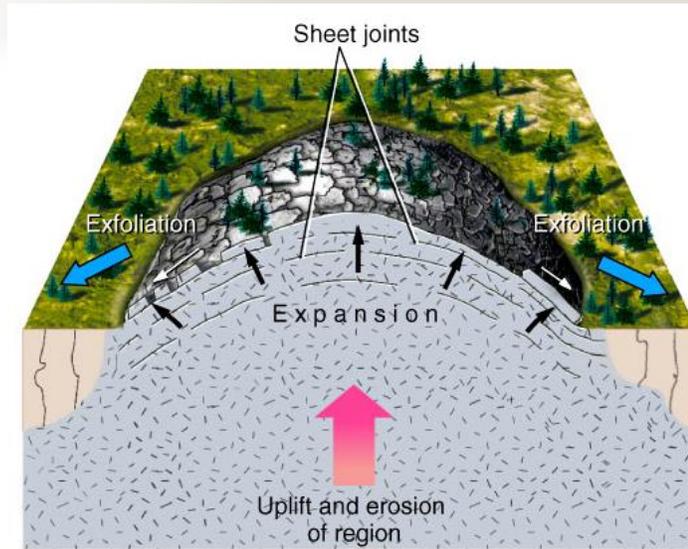


Zach Smith, TERC

Water in the ground below paved roads freezes and expands, lifting the pavement unevenly and allowing sections to collapse after the ice melts.

Salt crystal growth

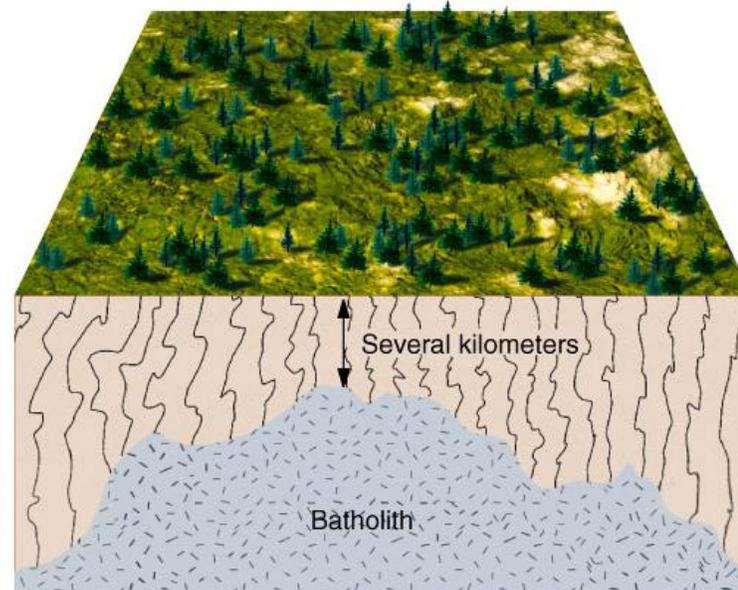
As salt crystals gradually grow larger, they weaken the rock by pushing apart surrounding grains or enlarging tiny cracks



B

Unloading

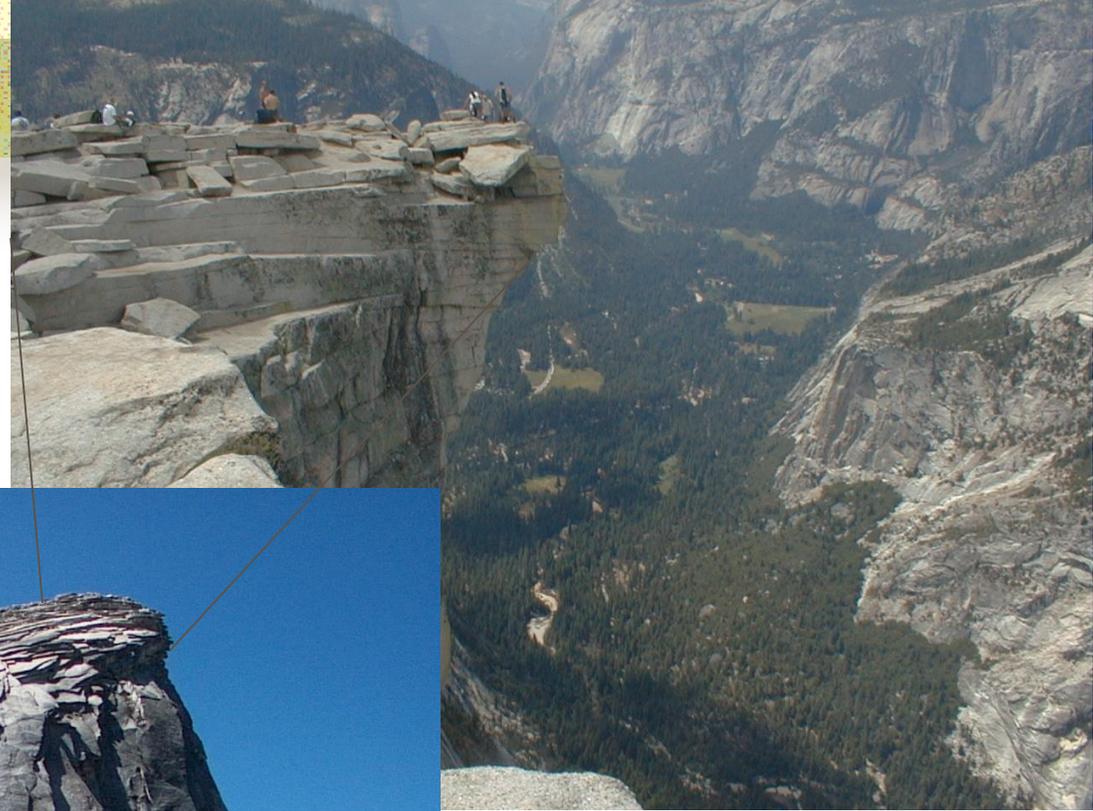
Pressure release forms sheet joints and exfoliation
Sheeting is caused by the expansion of crystalline rock as erosion removes the overlying material, a process termed unloading



A

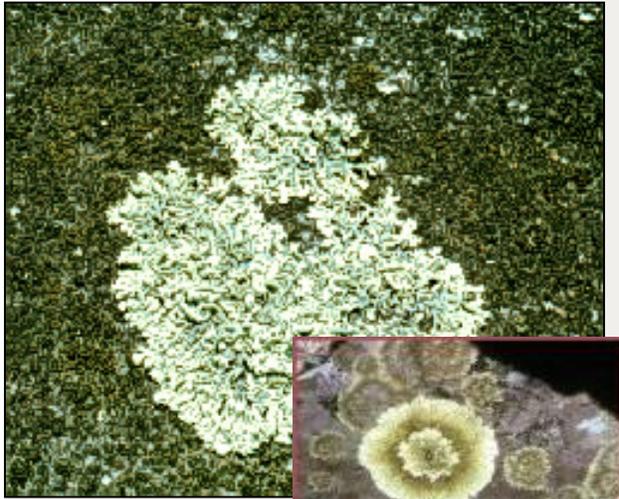


Mechanical Weathering

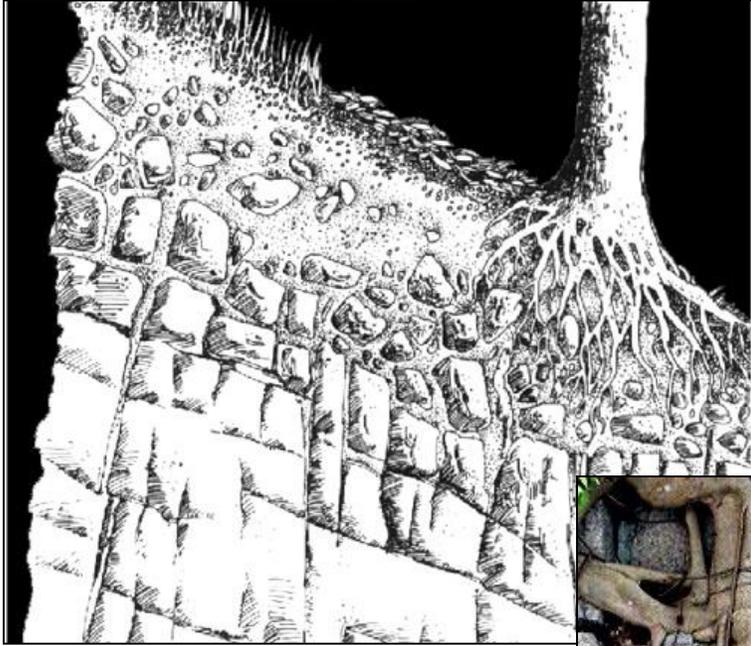


■ An exfoliation dome in Yosemite, CA (Half Dome)

2. Biological Action - With plant growth the root system will increase in volume and cause cracks in the rock to expand.



- Lichens are primary soil producers creating conditions for larger plant growth.



Chemical Weathering - when agents of weathering chemically change the composition of a rock.

II. AGENTS OF CHEMICAL WEATHERING

1. Oxidation - Oxygen combines with minerals to form oxides.
(iron + oxygen = Rust)



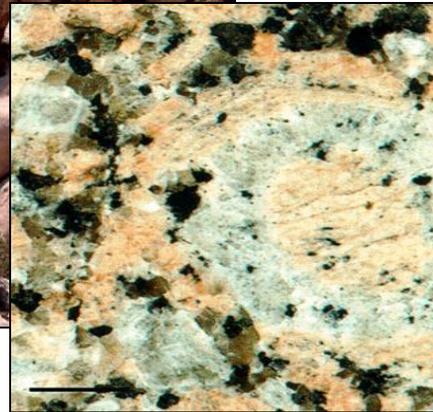
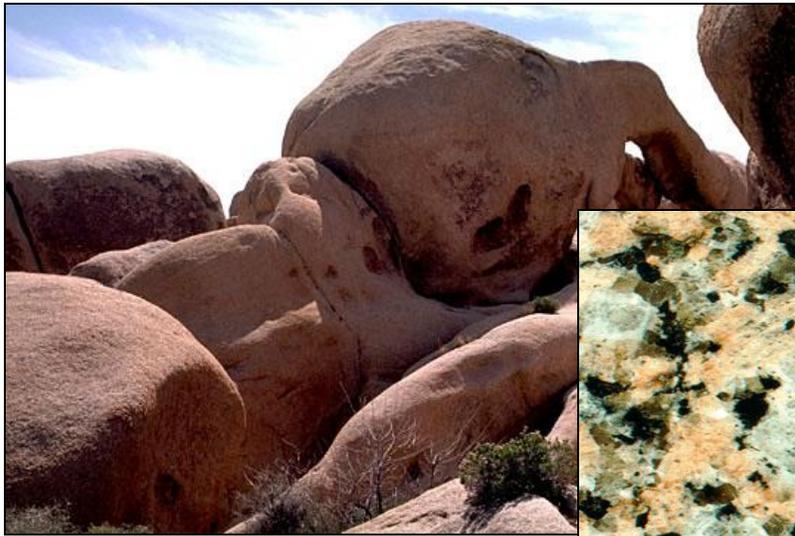
- Oxidation weakens the bedrock making it softer.



■ Chemical Weathering

- Dissolving → Dissolved ions
- Oxidation → Iron in Ferromag. Minerals → Iron Oxides (e.g., Hematite)
- Formation of Clays from silicates (e.g., Feldspar)

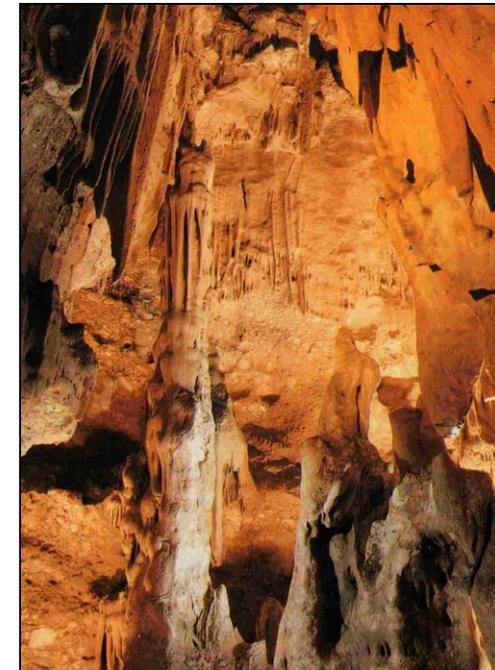
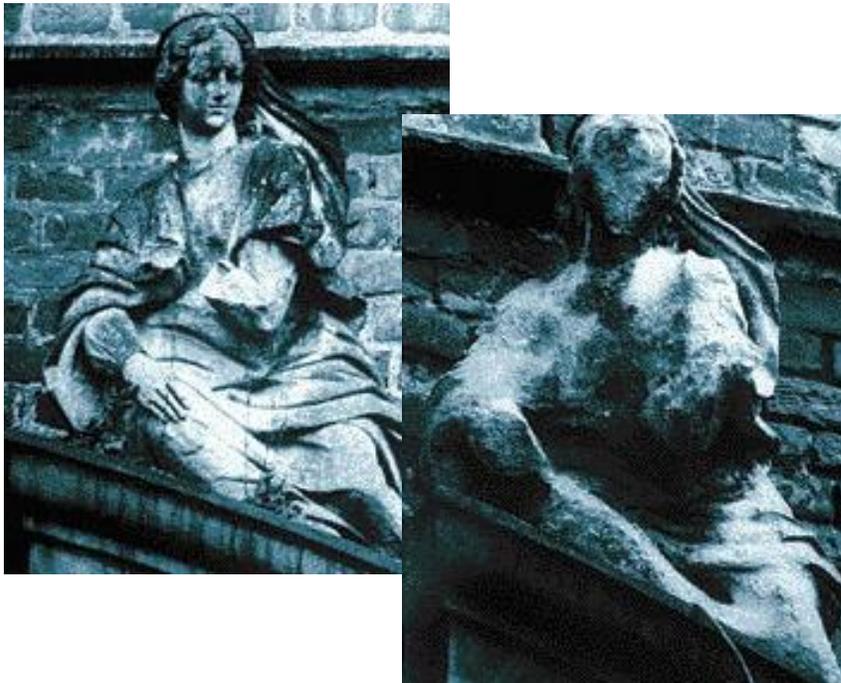
2. Hydration- minerals absorb water and chemically change the composition of the material



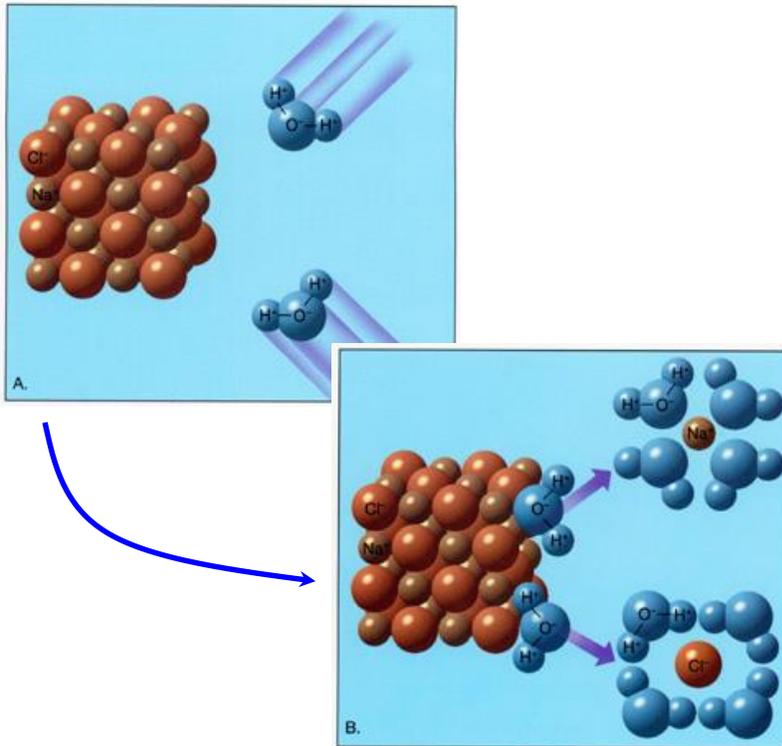
- Ex. granite contains mica.
- Mica has a weak chemical composition and absorb water.
- Turns into clay

3. Carbonation - When pollutants like Carbon Dioxide, Nitrogen & Sulfuric Oxides mix with rain water creating acid rain, which can dissolve limestone and harm the living environment.

- Coal Burning For Electricity
- Fossil Fuel Consumption for Cars



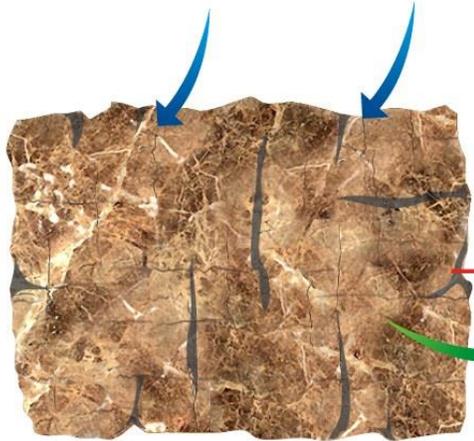
4. Water - Is unique and dissolves most minerals and metals in our environment.
- (universal solvent).



Chemical weathering:

ion exchange and the chemical breakdown of feldspar

1 Acidified water containing hydrogen ions (H^+) enters feldspar crystal along existing fractures.

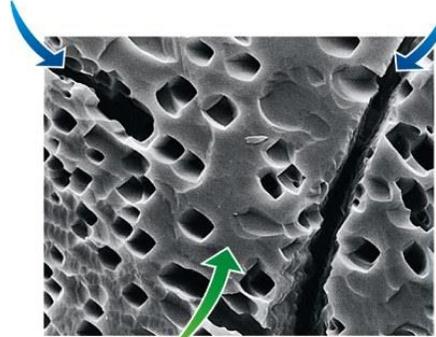


Potassium ion (K^+) leaves in solution.



2 Where potassium has washed away, an insoluble residue of clay remains.

Clay residue forms along cleavage planes



Unaltered feldspar

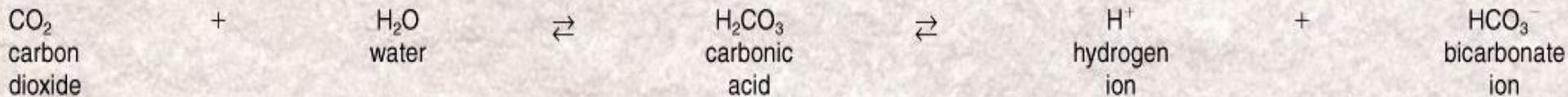
Unaltered feldspar

Alteration products (clay)

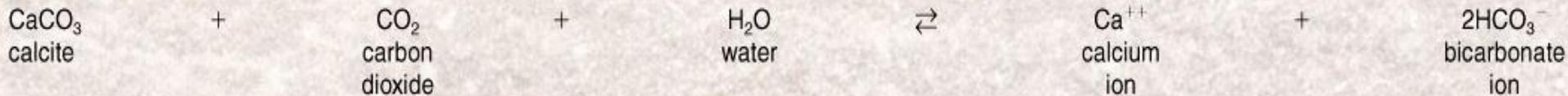
Chemical Weathering

Chemical Equations Important to Weathering

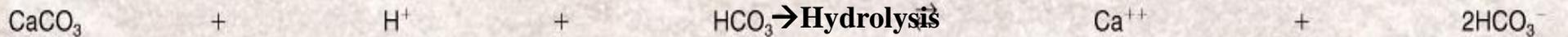
A. Solution of Carbon Dioxide in Water to Form Acid



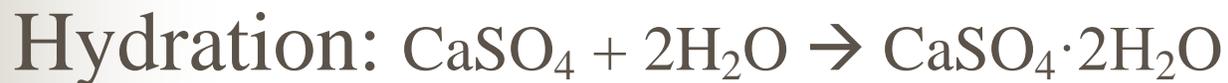
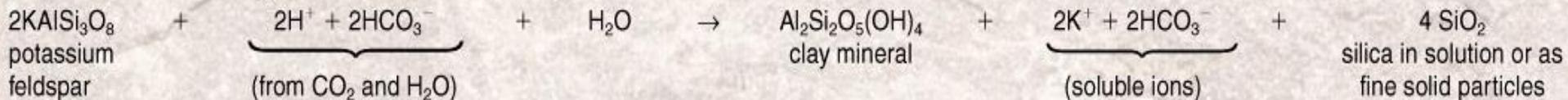
B. Solution of Calcite



C. Solution of Calcite



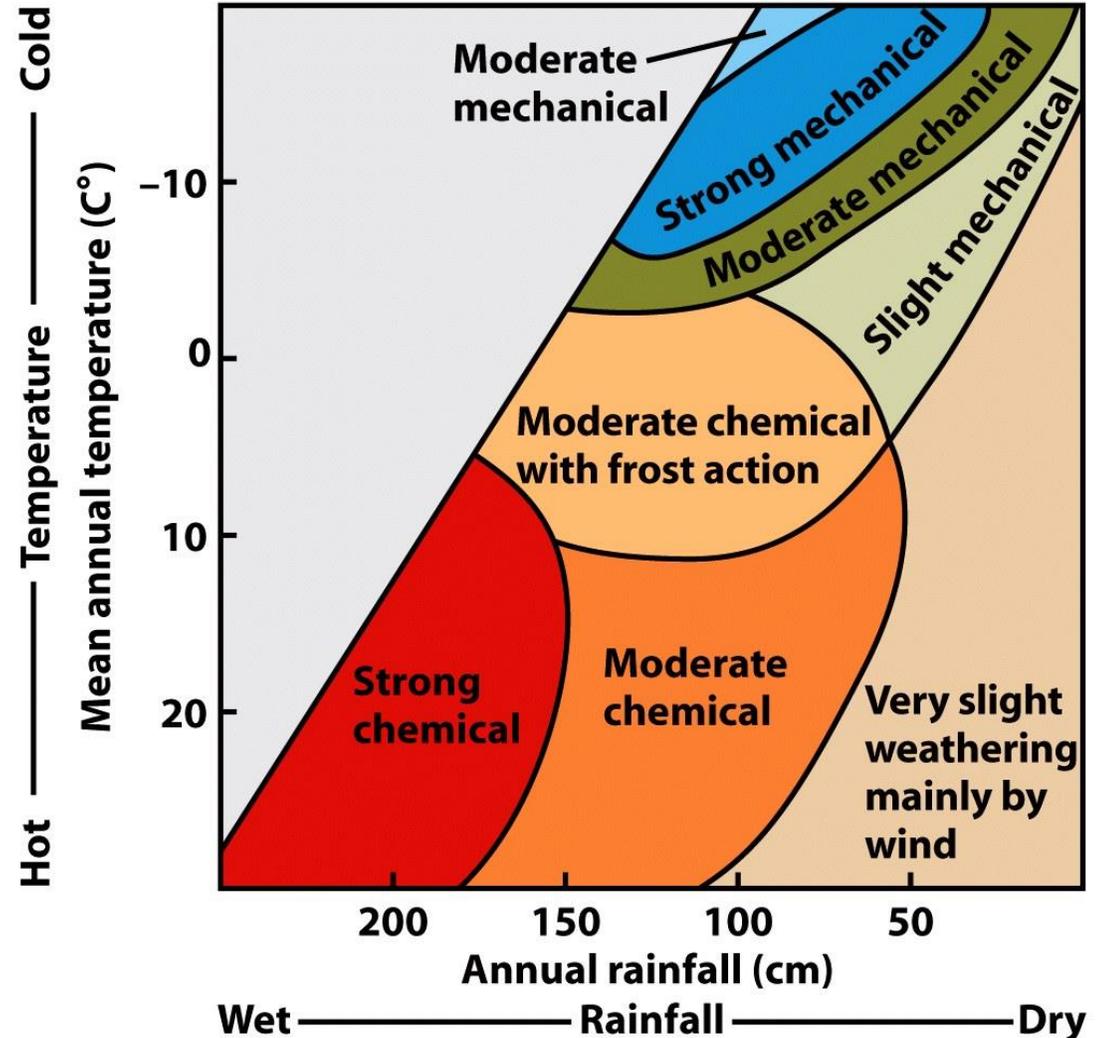
D. Chemical Weathering of Feldspar to Form a Clay Mineral



Factors affecting weathering

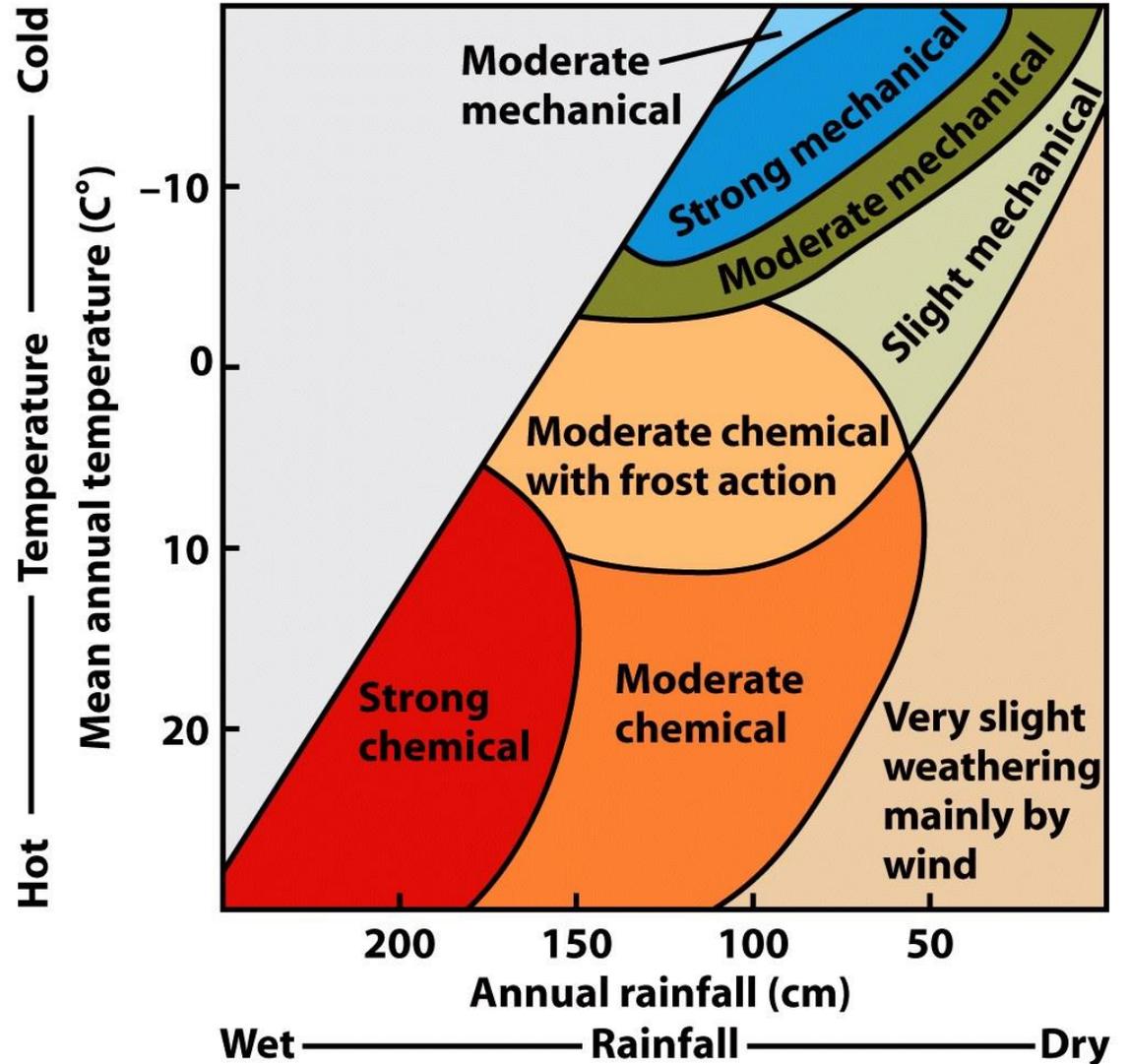
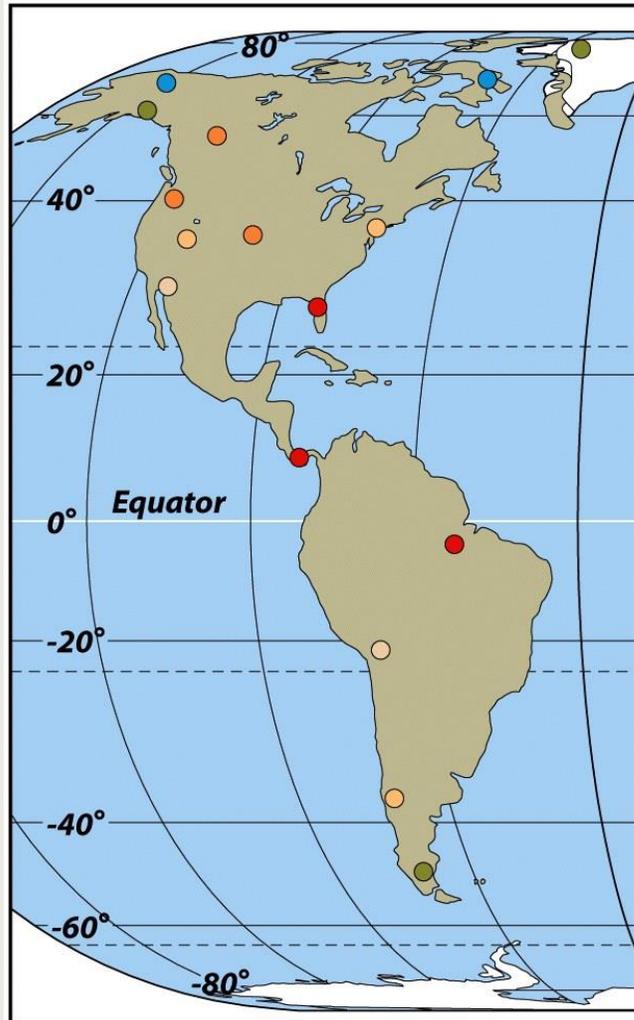
Climate

- Different climates and temperatures produce more favorable forms of weathering.
 - Chemical weathering is more prevalent in warm, wet tropical climates
 - Humid Climates are moist and the rate of weathering is fairly fast.
 - Mechanical weathering less important here
 - Mechanical weathering is more prevalent in cold, relatively dry regions
 - Arid Climates are very dry and the rate of weathering is slow
 - Chemical weathering occurs slowly here
- Usually in the presence of heat weathering rates will also increase.



Factors affecting weathering:

color dots on map match colors on chart



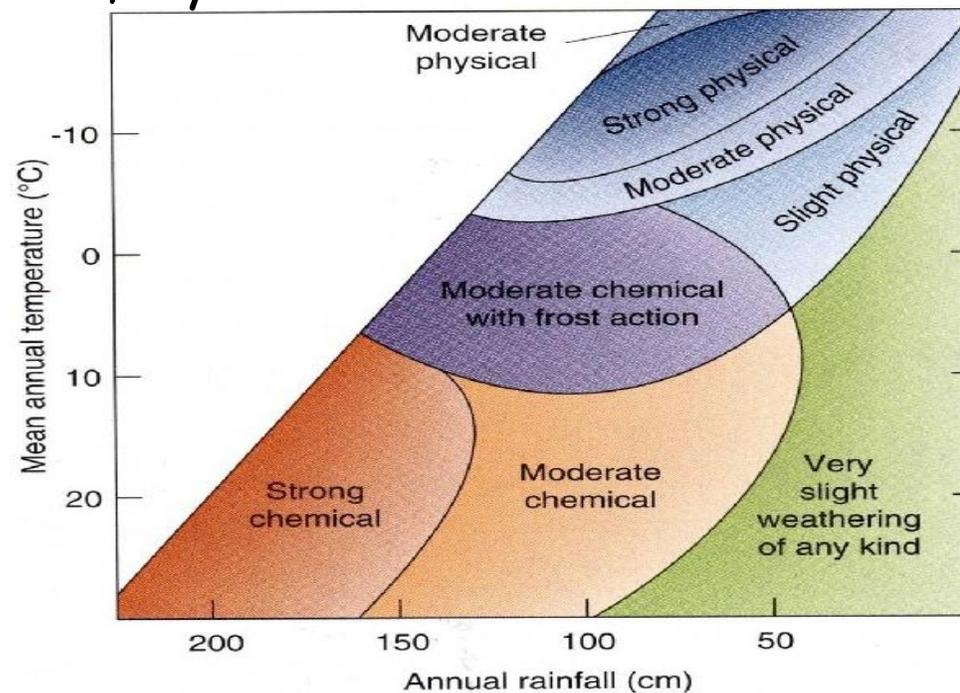
Cold and Humid - Physical weathering is dominant at high altitudes, or in the winter.

latitudes

-Frost Action and Glacial Abrasion

Hot and Humid - Chemical weathering is dominant near the equator and in the summer.

-Oxidation, Hydration



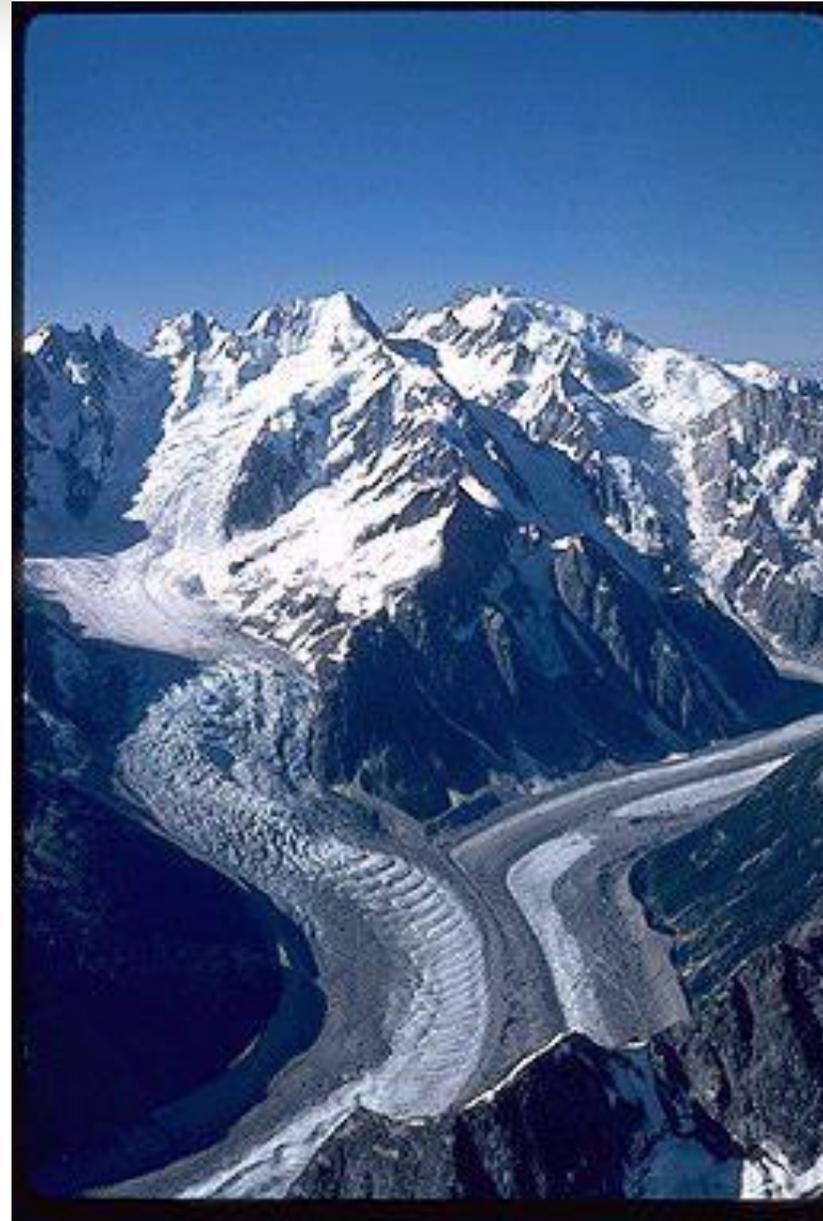


■ Humid climates also favor chemical weathering and increase the rate in which water will dissolve minerals.

■ Hot & humid climates can also increase the rate of physical weathering by biological action.

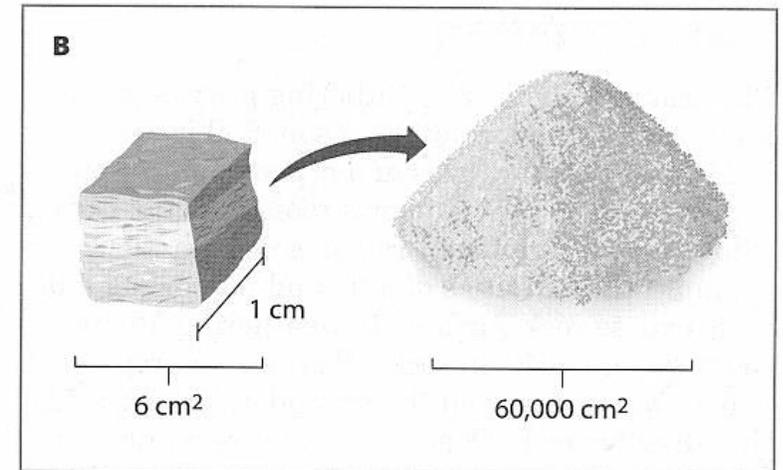
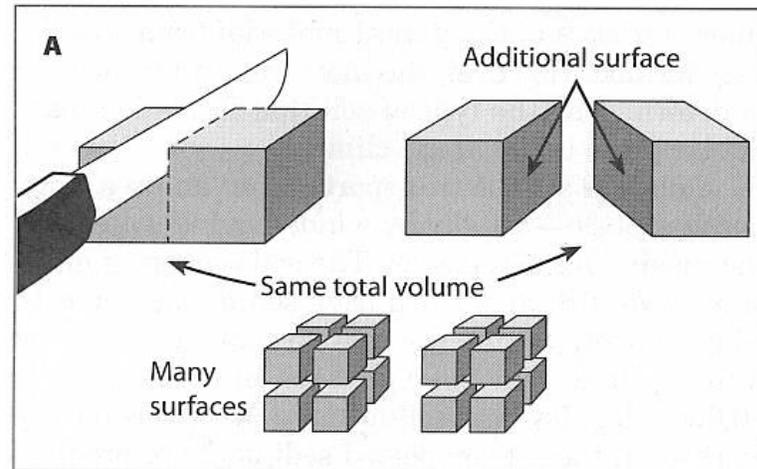
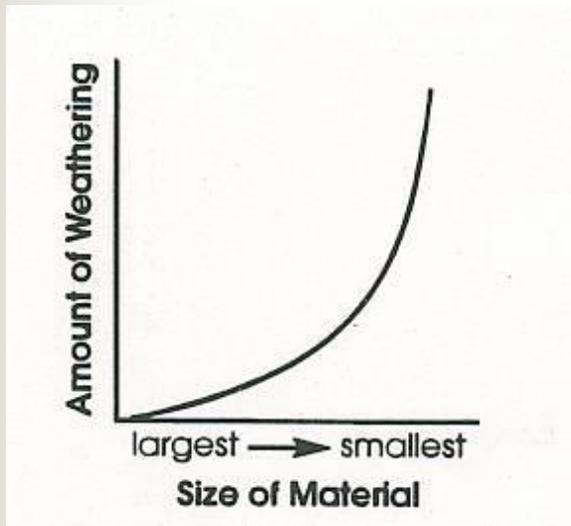


- In the mountains and at the poles physical weathering like frost action and abrasion are more likely.

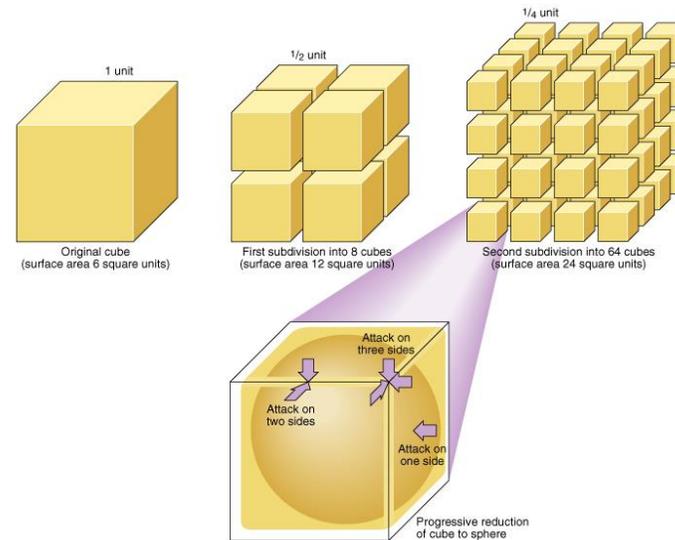


2. Particle Size and Shape as particle size decreases the weathering rate increases

- When the surface area increase, more sides are able to react with the elements



- Angular Sediments have more surface area.
 - weather at a faster rate.
- Round sediments have less surface area
 - weathering rate decreases.



3. Mineral Composition - some rocks are resistant to weathering because of their composition



- More Resistant

- Hard Rocks have Strong Chemical Compositions



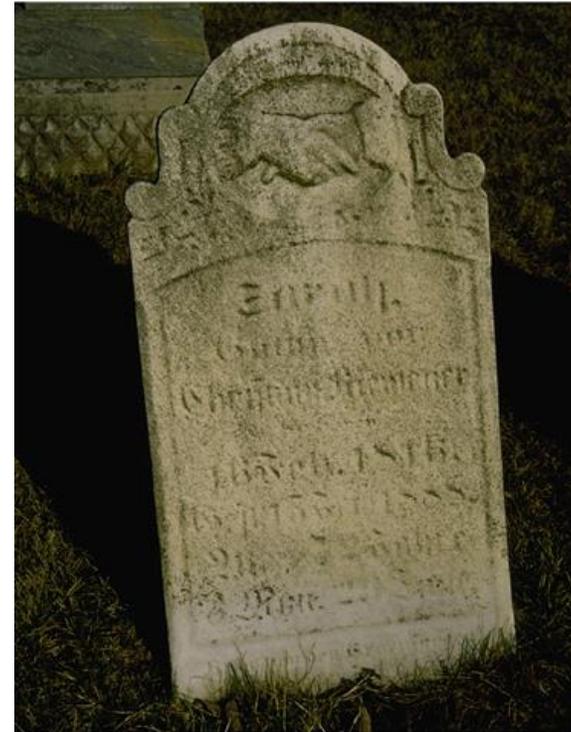
- Less Resistant

- Soft Rocks have Weak chemical compositions

- Rocks will weather at different rates due to their chemical compositions.



■ Granite w/ strong chemical composition (hard rock)



■ Limestone w/ weak chemical composition (soft rock)

■ Rock composition

- Minerals weather at different rates
 - Calcite weathers quickly through dissolution
 - Quartz is very resistant to chemical and mechanical weathering
 - Mafic rocks with ferromagnesian minerals weather more easily



■ Rock structure

- Distribution of joints influence rate of weathering
 - Relatively close joints weather faster



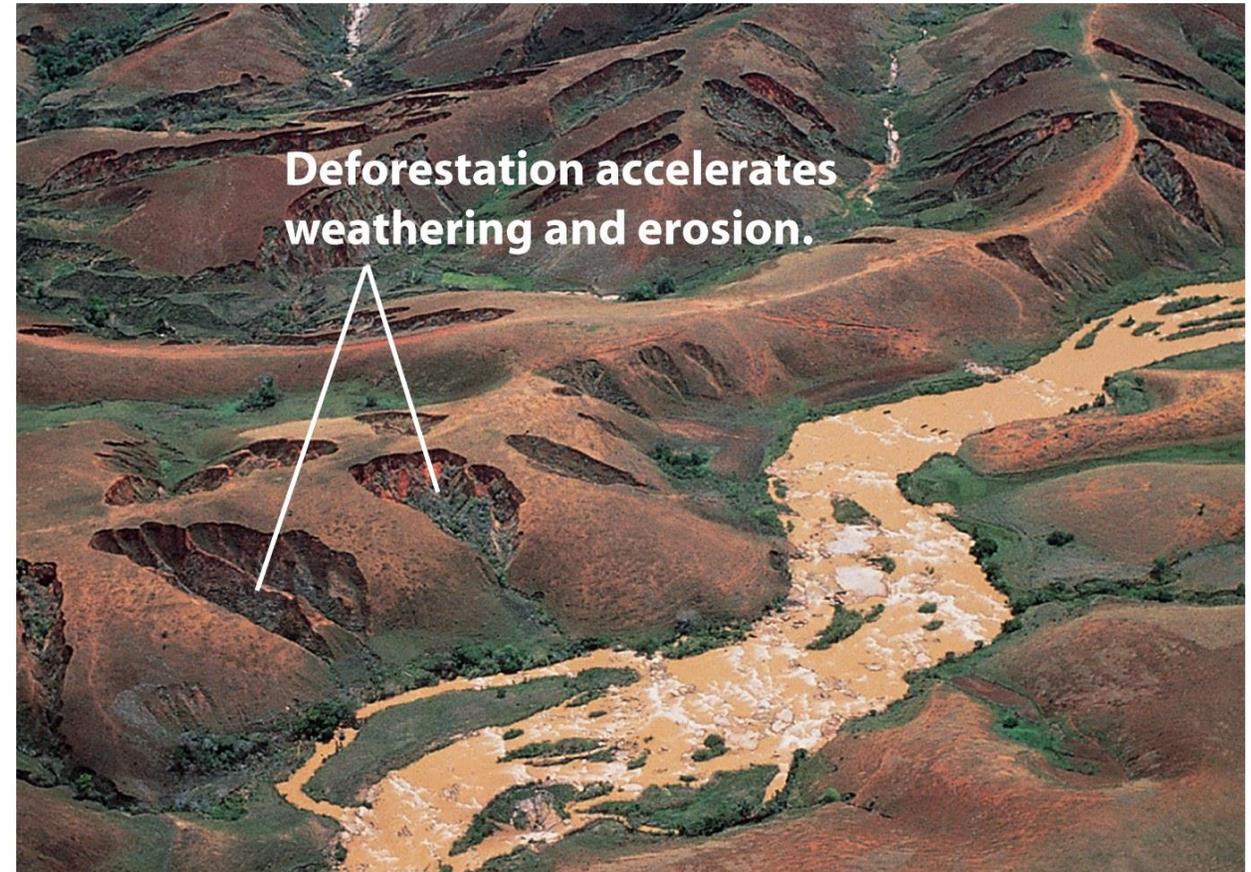
■ Topography

- Weathering occurs faster on steeper slopes
 - Rockslides



■ Vegetation

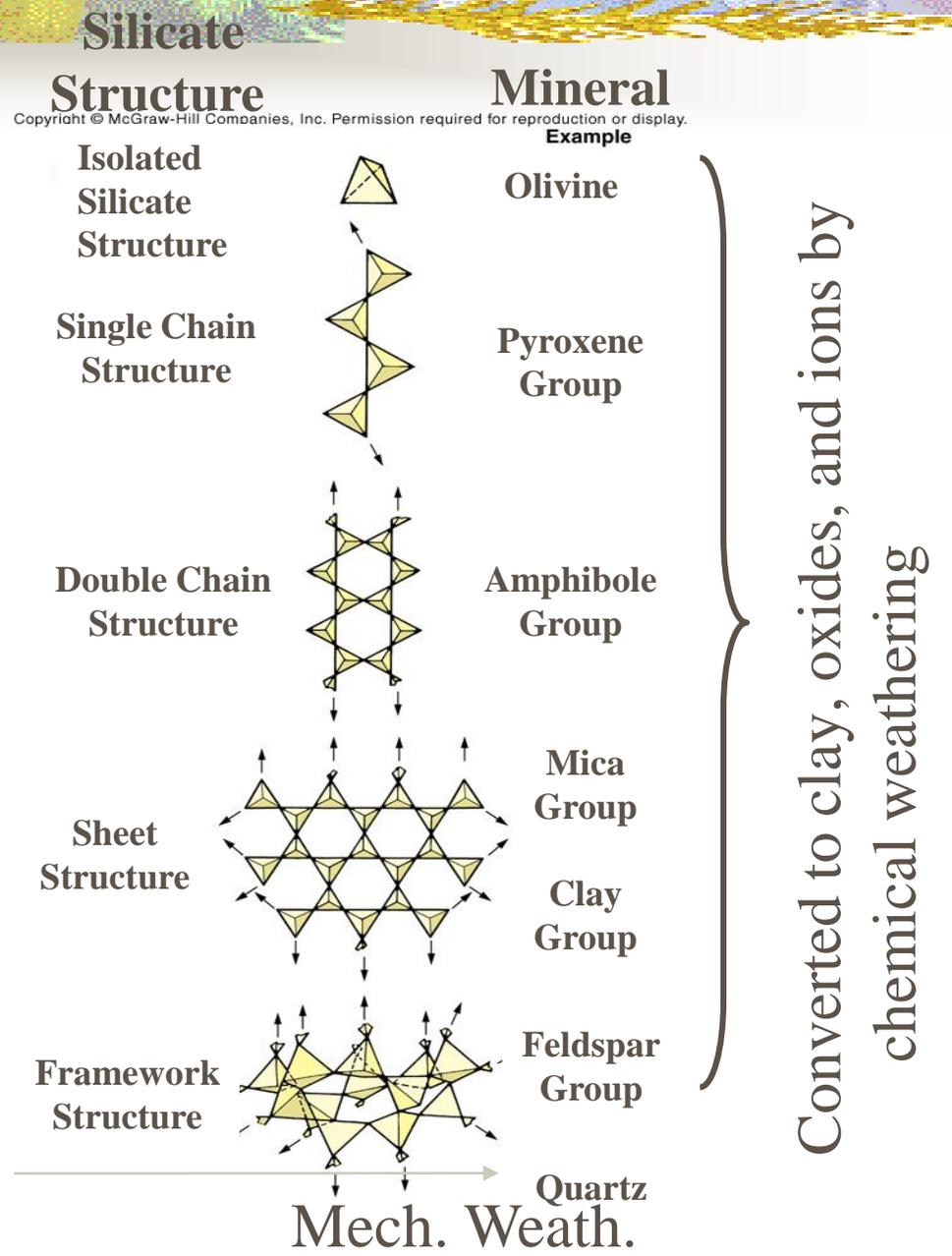
- Contribute to mechanical and chemical weathering
- Promotes weathering due to increased water retention
- Vegetation removal increases soil loss



**Vegetation can both hold water
And increase weathering. If removed
Rocks may also be vulnerable to abrasion**

Rates of Weathering

- Stable at High Temperatures
- Quickly Weathered
- Slowly Weathered
- Stable at Atmos. Temperatures _____



IV. Products of Weathering - sediments and soils

1. Sediment Types

- a. Solids - Are clastic sediments
such as pebbles, sand, silt, or clay
- b. Colloids - Are suspended clay size particles
- c. Ionic Solutions - Are dissolved compounds in water



Products of Weathering

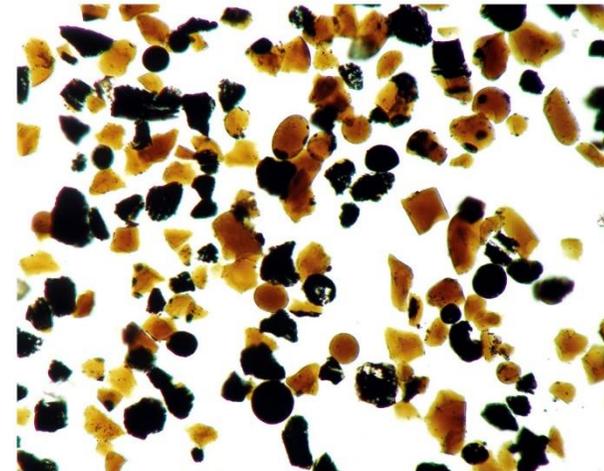
■ Clay

- Tiny mineral particles of any kind that have physical properties like those of the clay minerals
- Clays are hydrous aluminosilicate minerals



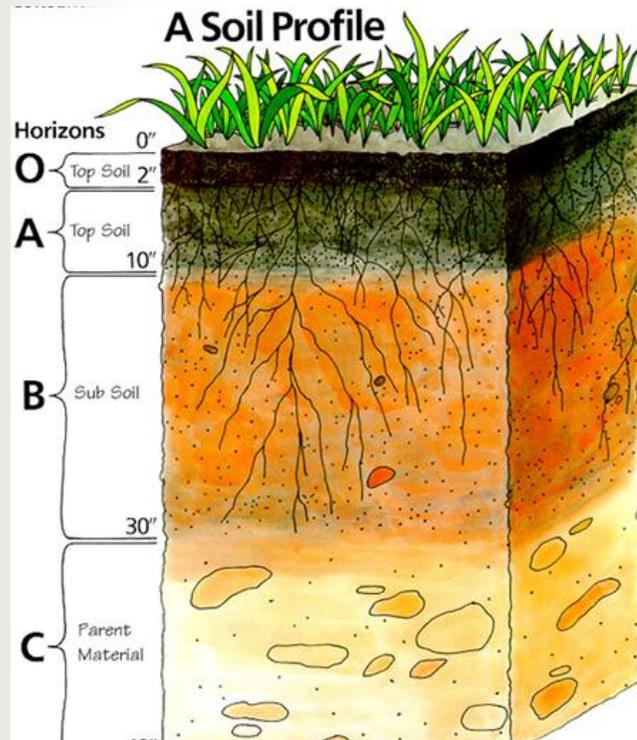
Products of Weathering

- Sand
 - A sediment made of relatively coarse mineral grains
- Soil
 - Mixture of minerals with different grain sizes, along with some materials of biologic origin
 - Humus
 - Partially decayed organic matter in soil



2. Soil Types

- a. Residual - Soils formed from the weathering of the local bedrock and have the same mineral composition.
- b. Transported - Soil that has been moved & the sediments are not of the same composition as the local rock

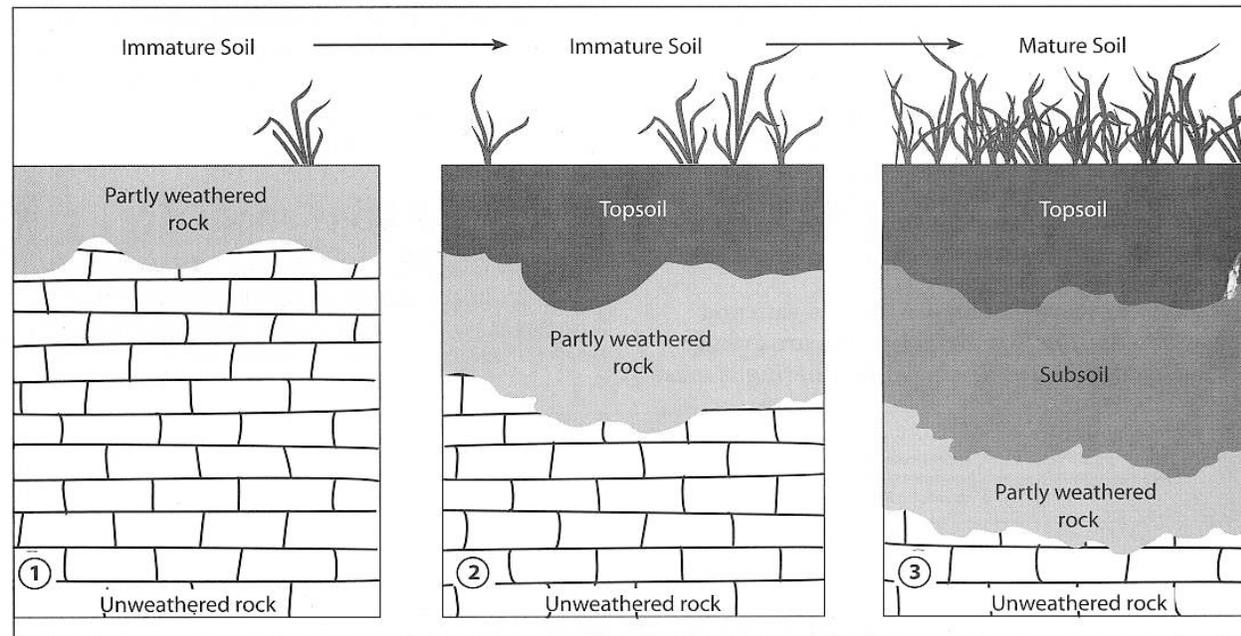


■ Soil Horizons

- A. Top layer rich in organics & minerals from biologic activity.
- B. Sediments with minerals dissolved from above are found here.
- C. Mostly un-weathered bedrock.

Soil development from local bedrock.

- Stage 1 Mostly un-weathered bedrock
- Stage 2 Development of top soil by biologic activity
- Stage 3 Mature thick and well developed soil horizons

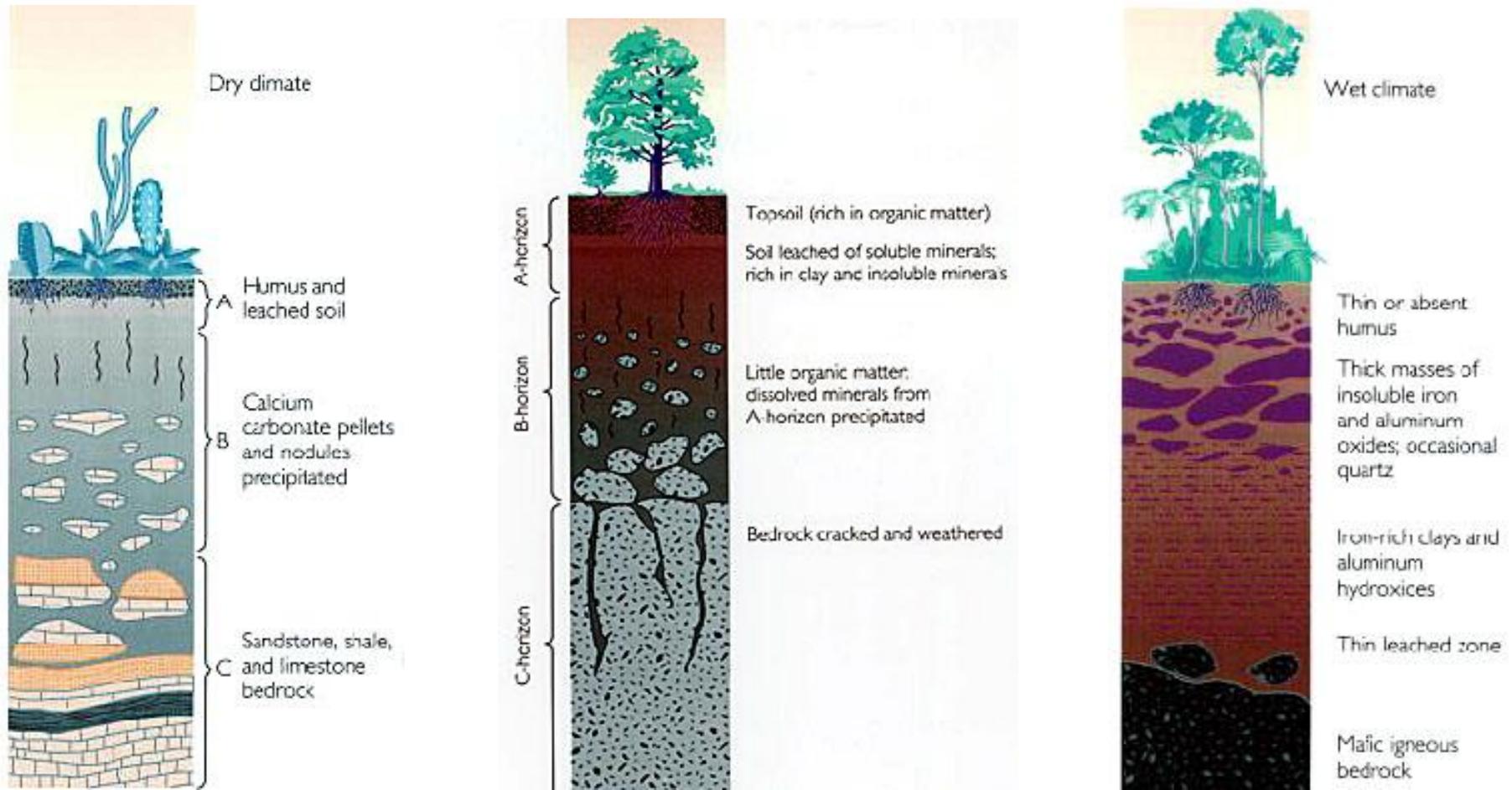


- Soil is non-renewable resource

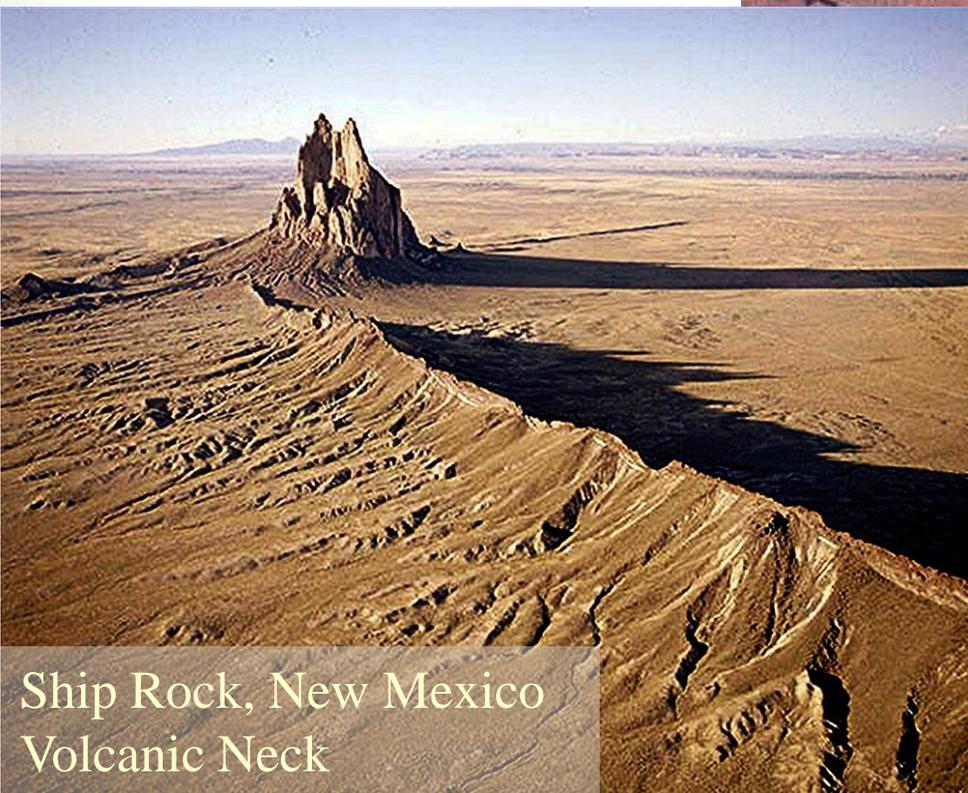
1 inch is made for every 100 years in New York

Different climates produce different soil types

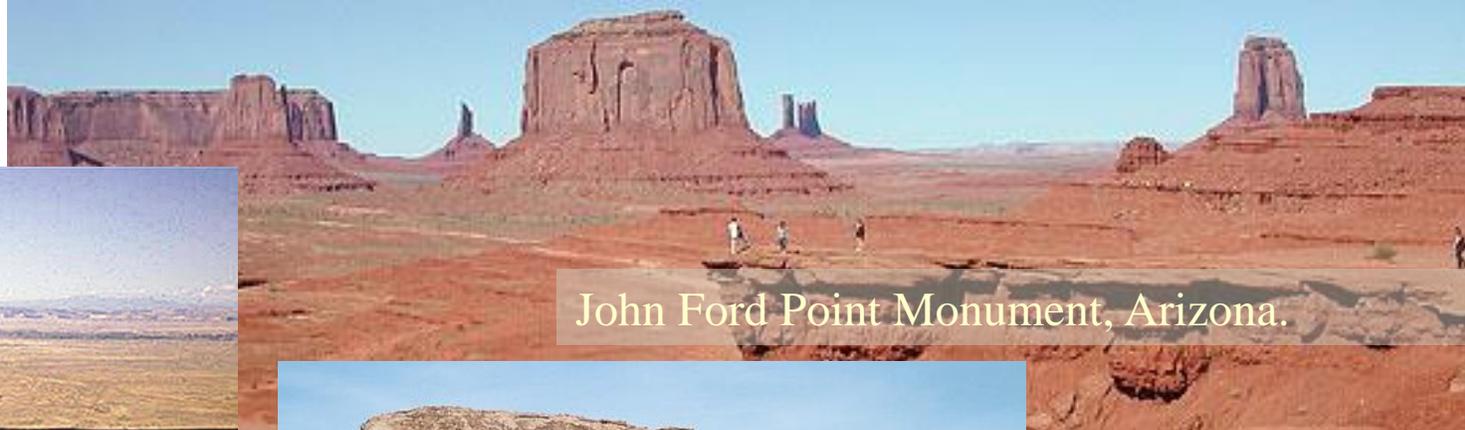
- Form at different rates.



Differential Weathering



Ship Rock, New Mexico
Volcanic Neck



John Ford Point Monument, Arizona.





ENGINEERING PROPERTIES OF ROCKS

Engineering properties of rock determines geologic, chemical, mechanical, deformation and technological properties of rocks

1. Geological properties

- a) Generation time of rocks
- b) Generation environment of rocks
- c) Lithological properties of rocks
- d) Structural properties of rocks
- e) Hydrological properties of rocks



ENGINEERING PROPERTIES OF ROCKS

2. Chemical properties; include behavior of melting, weathering and against water with respect the composition of rocks. It directly influences various engineering works and their projects.

3. Physical Properties; Unit volume weight, density, natural water content, porosity and void ratio, degree of saturation, permeability, weight water absorption and volumetric water absorption are physical properties of rocks.

4. Mechanical Properties; Are characteristics that determine the behavior of rocks under various stresses

a) Compression strength (Uniaxial compressive strength, Schmidt Attractor Test, Point load resistance, Disc Shear Index Test)

b) Tensile strength (Direct pull, Indirect pull (Brazilian test))

c) Shear Strength (Triaxial compression test, Direct shear test)

d) Buckling Strength

e) Bending Strength

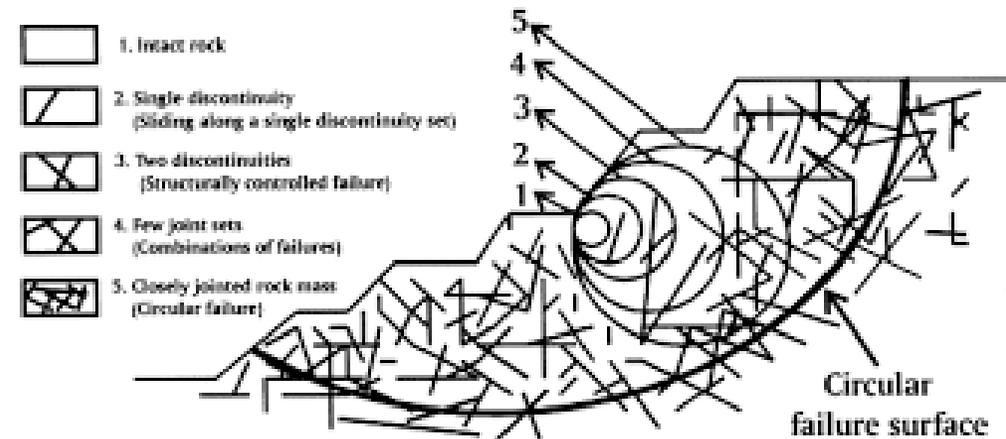
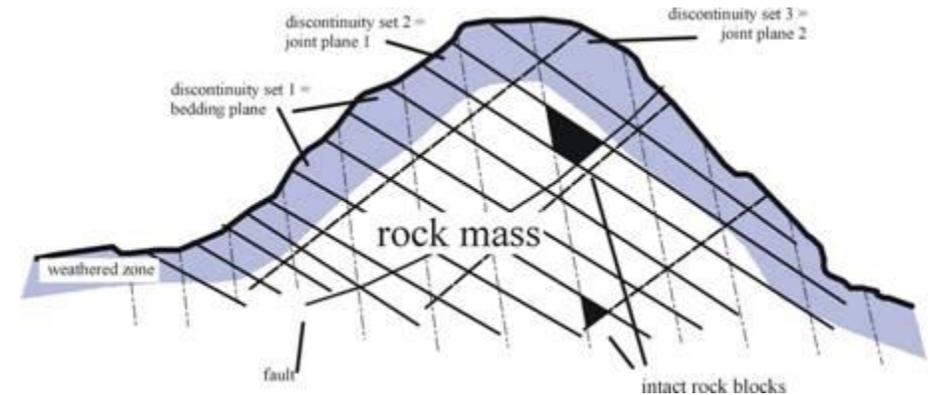
5. Deformation Properties; Elastic modulus and Poisson ratio, Rigidity module etc.

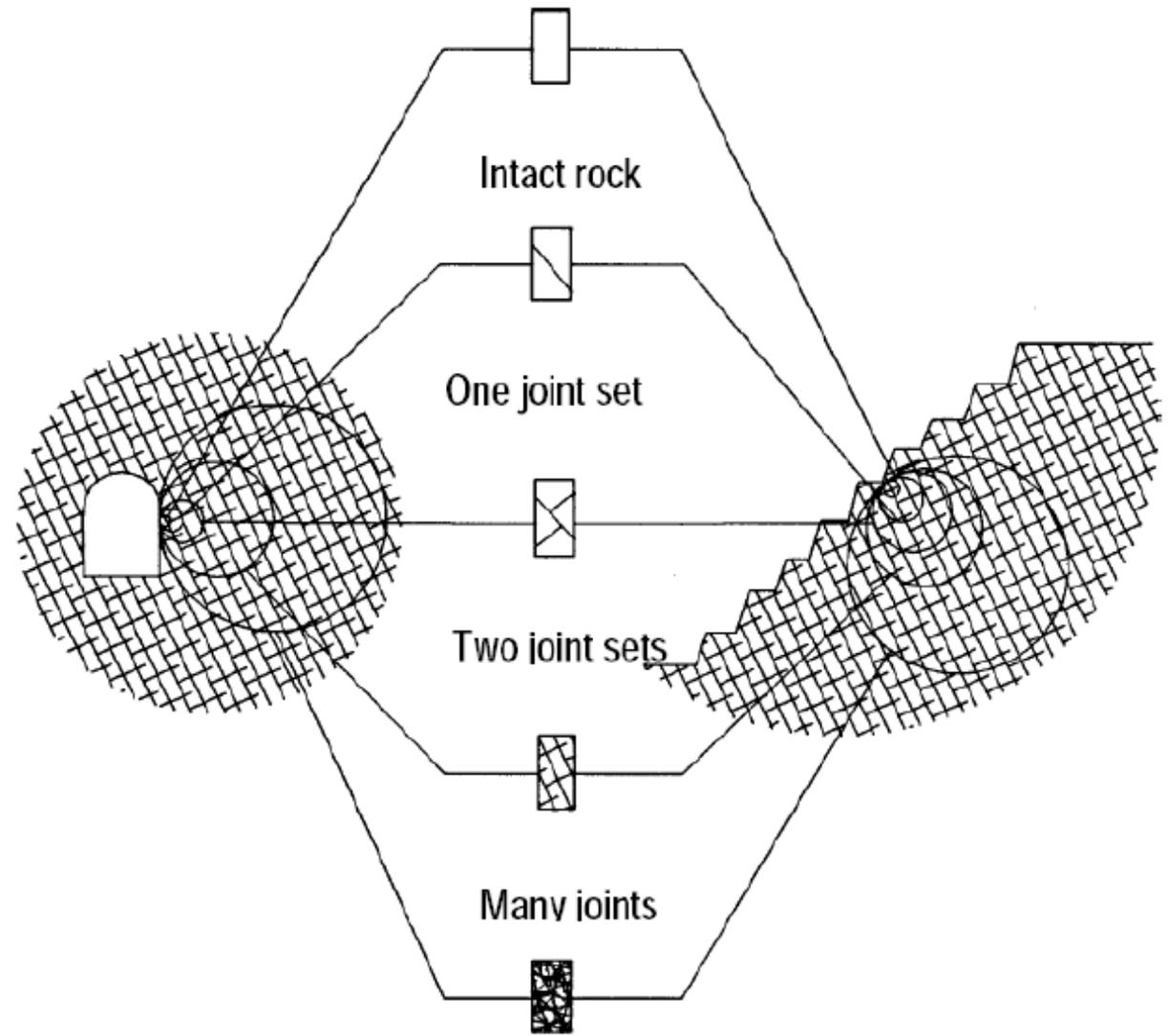
6. Technological Properties; Pierceable, breakable, excavable, interceptable, polishable, machinable, usable, tunnelable ...

Rock Material, Discontinuity, Rock Mass

Intact rock material: Rock mass is a matrix consisting of rock material and rock discontinuities. As discussed early, rock discontinuity that distributed extensively in a rock mass is predominantly joints. Faults, bedding planes and dyke intrusions are localised features and therefore are dealt individually. Properties of rock mass therefore are governed by the parameters of rock joints and rock material, as well as boundary conditions

Discontinuity: A discontinuity is a plane or surface that marks a change in physical or chemical characteristics in a soil or rock mass. A discontinuity can be in the form of a bedding plane, schistosity, foliation, joint, cleavage, fracture, fissure, crack, or fault plane. This discontinuity controls the type of failure which may occur in a rock slope. The properties of discontinuities such as orientation, persistence, roughness and infilling are play important role in the stability of jointed rock slope. Discontinuities may occur multiple times with broadly the same mechanical characteristics in a discontinuity set, or may be a single discontinuity. It makes a soil or rock mass anisotropic.



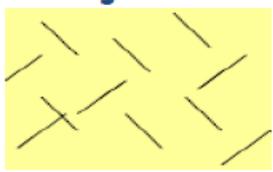


6.5.2a

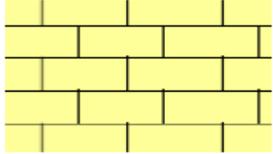
Rock Material, Discontinuity, Rock Mass

In various engineering works and excavations; projects such as dams, tunnels, underground power plants, bridges, etc., calculation of the stability of foundation and materials which are used for them, the discontinuity properties that affect the engineering properties of the rocks in advance with the determined deformations in front of various forces must be well known.





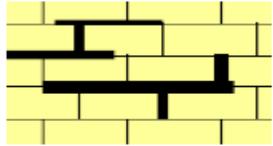
Massive rock types: This rock types are found below the degradation zones and rock masses which do not include foliation such as massive sandstone and granites are in this group. Such masses are considered as continuous, homogeneous, isotropic rocks.



Partially jointed rock mass: rocks which have fewer than three and continuous discontinuity can be obtained as individual blocks when excavated.



Partially Blocked Rock Mass : It is a rock mass which includes fewer than three discontinuities and whose discontinuities are filled by secondary material and which contain closed secondary discontinuity. If one of the closed joint sets is opened due to deformation, blockage in the rock mass develops.



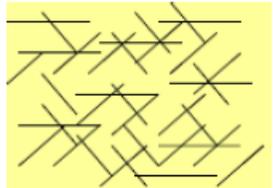
Blocked Rock Mass: It is rock masses that contain well-developed, open or soft fillings, high continuity, and a set of discontinuities in excess of 3. It is easy to obtain blocks from such rock masses during excavation.



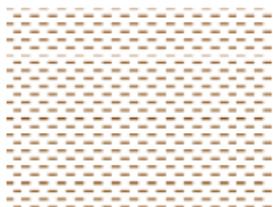
Hollow Rock Mass: The soluble limestones in this group are composed of dolomite, gypsum, rock salt and a soluble cement



Very porous rock mass: In such rock masses, significant amounts of pores influence the mechanical behavior of the rock.



Advanced fissured rock mass: Fissured rock substantially brittleness and anisotropy also contain small discontinuities frequent cause a deviation with respect to all mechanical properties.

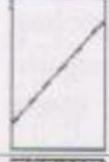


Jammed and swollen rock mass: Such rock masses, when they come into contact with water, suddenly and intermittently crack and change volume and contain active clay minerals. The basic principles of ground mechanics can be applied to such rocks.

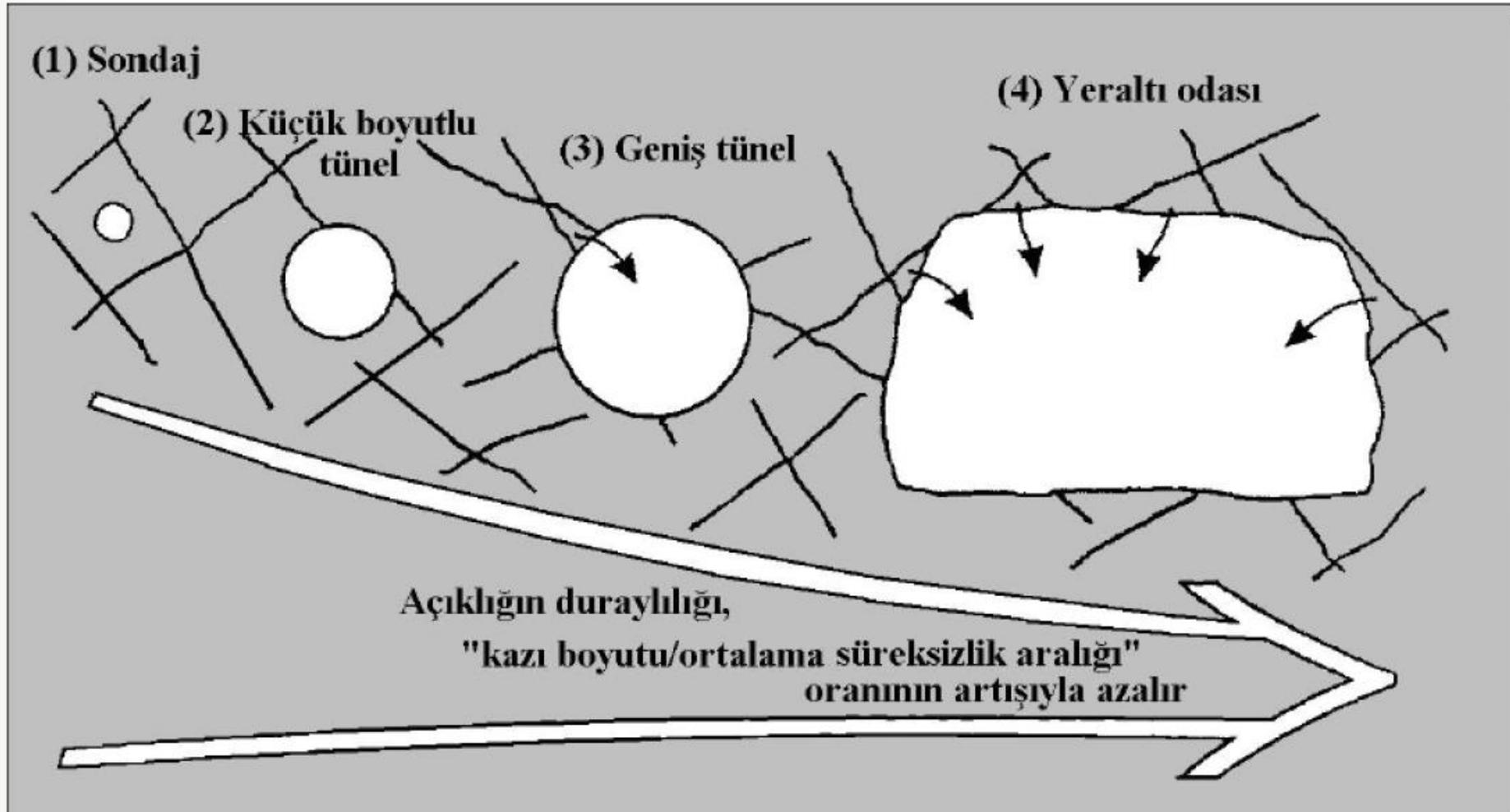
Rock Mass Properties And Test Methods

Table 6.4.1a Geological Strength Index (GSI)

GEOLOGICAL STRENGTH INDEX (GSI)		JOINT SURFACE CONDITION					
According to rock mass structure and discontinuity surface conditions observed on the rock mass at site, select the appropriate box in this chart. Estimate the average value of the GSI from the contours.		VERY GOOD – very rough, fresh, unweathered joint surfaces	GOOD – rough, slightly weathered, stained joint surfaces	FAIR – Smooth, moderately weathered, and altered surfaces	POOR – Slickensided, highly weathered surfaces with compact coating or fillings or angular fragments.	VERY POOR – Slickensided, highly weathered, surfaces with soft clay coating or filling	
ROCK MASS STRUCTURE		⇒ Decreasing of Surface Quality ⇒					
	BLOCKY – very well interlocked undisturbed rock mass consisting of cubical blocks formed by three orthogonal joint sets	80					
	VERY BLOCKY – interlocked, partially disturbed rock mass with multi-faced angular blocks formed by four or more joint sets.	70					
	BLOCKY/FOLDED – folded and faulted with many intersecting discontinuities forming angular blocks.	60					
	CRUSHED – poorly interlocked, heavily broken rock mass with a mixture of angular and rounded blocks.	50					
		40					
		30					
		20					
		10					

	Tanımlama	Dayanım özellikleri	Dayanım deneyi	Teorik hususlar
	Kaya malzemesi (A)	Kırılgan- elastik ve genellikle izotrop davranış	Karot örneklerinde yapılan üç eksenli deneyler basit ve ucuz olup, genellikle güvenilir sonuçlar verir.	Elastik-izotrop davranış, pek çok uygulama için yeterli derecede anlaşılmiştir.
	Eğimli tek süreksizlik içeren kaya malzemesi (B)	Süreksizliğin eğimine ve makaslama dayanımına bağlı olarak yönserliğe sahip	Üç eksenli deney güç ve pahalı olduğundan, doğrudan makaslama deneyi tercih edilir. Sonuçlar çok dikkatli yorumlanmalıdır.	Süreksizliklerin davranışı pek çok uygulama için yeterli derecede anlaşılmıştır.
	Birkaç süreksizlik seti içeren masif kaya (C)	Süreksizliklerin sayısı, yönelimi ve makaslama dayanımına bağlı olarak yönserliğe sahip	Örnek örselenmesi ve boyut sınırlamalarından dolayı laboratuvar deneyleri çok güçtür.	Seyrek eklemlili kaya kütlelerindeki bloklar arasındaki karmaşık etkileşim çok az anlaşılmıştır.
	İleri derecede eklemlili kaya kütleleri (D)	Oldukça izotrop. Düşük gerilim seviyelerinde fazla miktarda genişleyen, yüksek gerilim seviyelerinde ise kırılabilen	Örnek örselenmesinden dolayı, temsil edici örneklerde üç eksenli deneyler oldukça güçtür.	Kenetlenen köşeli parçaların davranışı çok az anlaşılmıştır.
	Sıkıştırılmış kaya dolgusu veya zayıf çimentolu konglomera (E)	Oldukça izotrop. Dokunun tahrip olmasından dolayı yerindeki (arazideki) orijinal durumundakinden daha az kabaran ve daha düşük dayanımlı.	Üç eksenli deneyler basittir, ancak örneklerin yerleştirilmesi için geniş hücreye gerek duyulduğundan pahalıdır.	Tüneli malzemeler üzerinde yapılan zemin mekaniği çalışmaları sayesinde davranışı nisbeten daha iyi anlaşılmıştır.
	Gevşek kaya parçaları veya çakıllar (F)	Zayıf sıkıştırma ve derecelenme, devingenliğe ve düşük dayanıma neden olan tane hareketlerine yol açar	Üç eksenli deneyler ve doğrudan makaslama deneyleri basittir, ancak büyük boyutlu ekipman gereksinimi nedeniyle pahalıdır.	Az sıkıştırılmış kaya parçalarının ve çakılların davranışı pek çok uygulama için yeterli düzeyde anlaşılmıştır.

Rock Mass Behavior (Scale Effect) due to Increase in Excavation Dimensions



Definition of Rock Masses



Discontinuity properties are defined for;

- Determination of geological structure,
- Engineering classification of rock mass
- Determination of rock stability

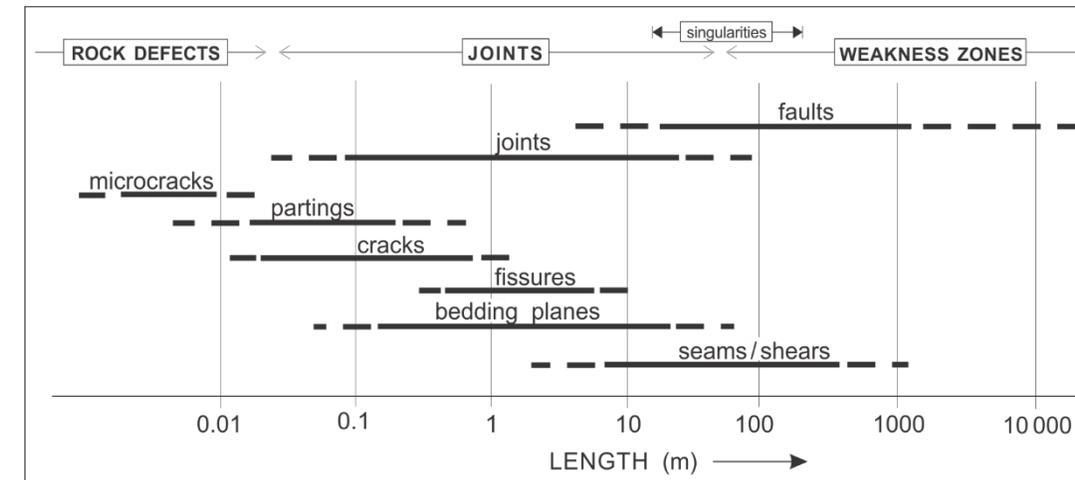
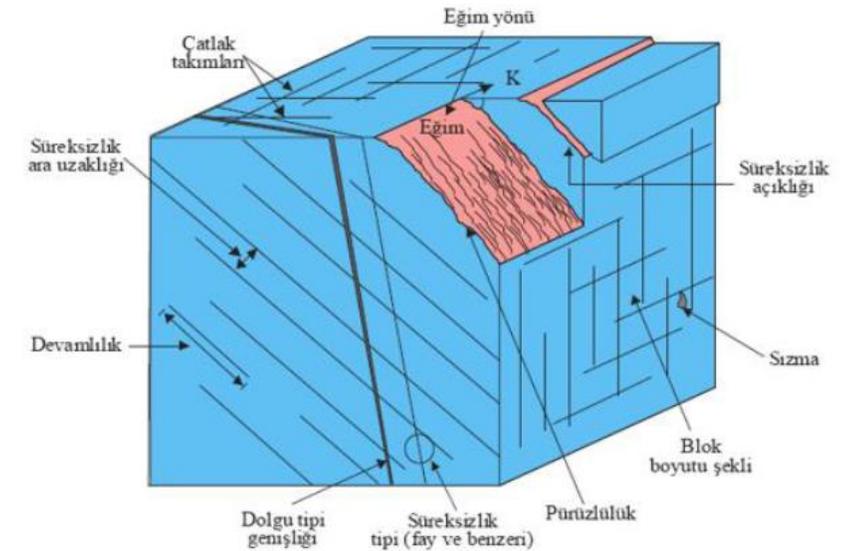


The rock masses are not continuous, homogeneous and isotropic materials, but are cut by various discontinuities. For this reason, the behavior of rock masses, which can be exposed to external loads, can not be analyzed as close to reality without taking into account the characteristics of the discontinuities they contain.

Discontinuity properties of rock mass

The properties of discontinuities are determined and / or identified on the surface or in drilling cores by using different measurement techniques. Physical parameters of discontinu

- Type of discontinuity
- Discontinuity interval and frequency
- Continuity of discontinuity
- Roughness and fluctuation of discontinuity surface
- Properties of filling material
- The strength of discontinuity surface and the degree of degradation
- Water condition on discontinuity surface
- The number of discontinuity set and discontinuity orientation
- Block size



Discontinuity Properties / Discontinuity Types

Group 1: discontinuities as set or appears to be a system, which can be subjected to statistical analysis and surface along the layer in which the occurrence of any displacement, such as joint, cleavage (cleavage) Schistosity, foliation lamination.

Group 2: Located alone, not subjected to statistical analysis and a displacement is observed along its surface such as fault and shear zone.



1. Contact: It is boundary between two different lithological boundaries, it is either conformal or disconformal
2. Structure: It is developed depending on the grain size and orientation, the mineralogical composition, the color and hardness of the surface during the occurrence of sedimentary rocks.

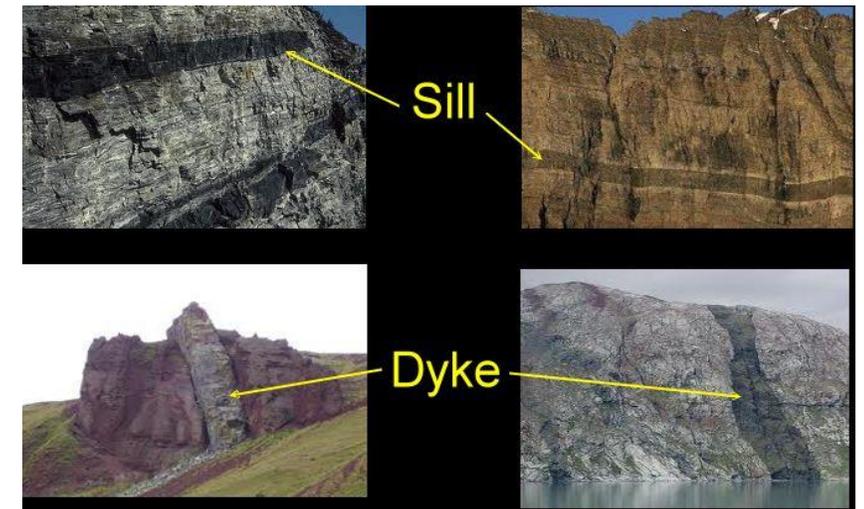


Figure 4.11 Sedimentary rock layers exposed in the walls of the Grand Canyon, Arizona. Both of resistant sandstone and limestone produce bold cliffs. By contrast, weaker, poorly cemented shale, or siltstone and produce a gentler slope of weathered strata as they more readily erode. (Photo by Tom, 201)

Discontinuity Properties / Discontinuity Types



3. Fault surfaces exposed to shear failure where a relative displacement from a few centimeters to a kilometer long occurs.
4. Joint surfaces Fractures where it is not possible to change anywhere along the Joint Surface.
5. Foliation is the metamorphic origin weakness planes which are formed by preferential orientation of minerals under high pressure and / or temperature.
6. The veins are fractures filled by a different material from the perimeter of the rock. Since the surfaces are not discrete, they are not weak discontinuities.

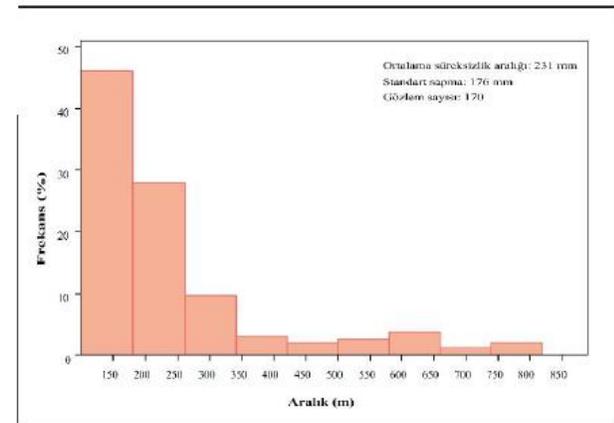
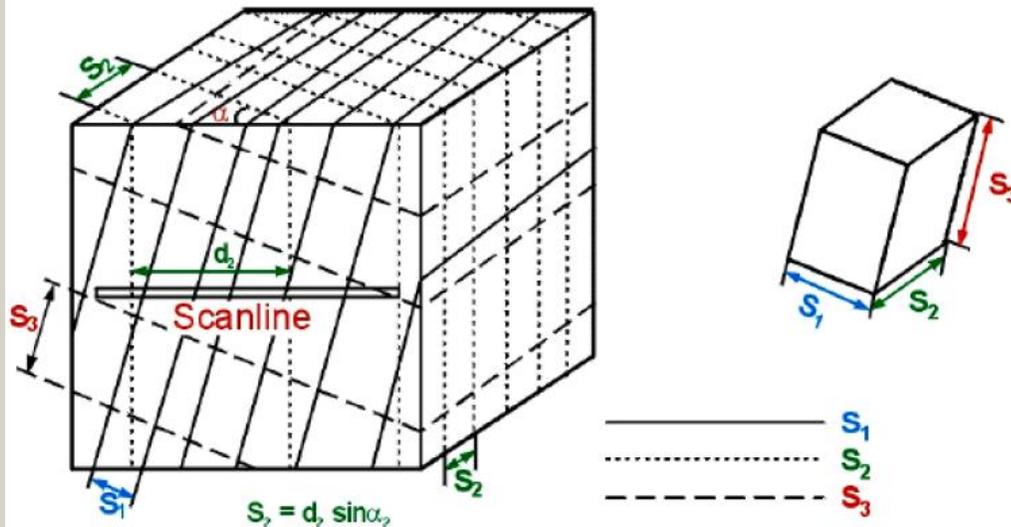


Discontinuities Properties / discontinuity and Frequency Range

The discontinuity interval (or intermediate distance) is the distance between two discontinuities in a discontinuity set consisting of 2 adjacent discontinuities or parallel discontinuities in the rock masses. This value can be measured from the discontinuities intersecting the strip meter along the strip meter laid on a certain area on the outcrop surface as well as from the drilling cores.

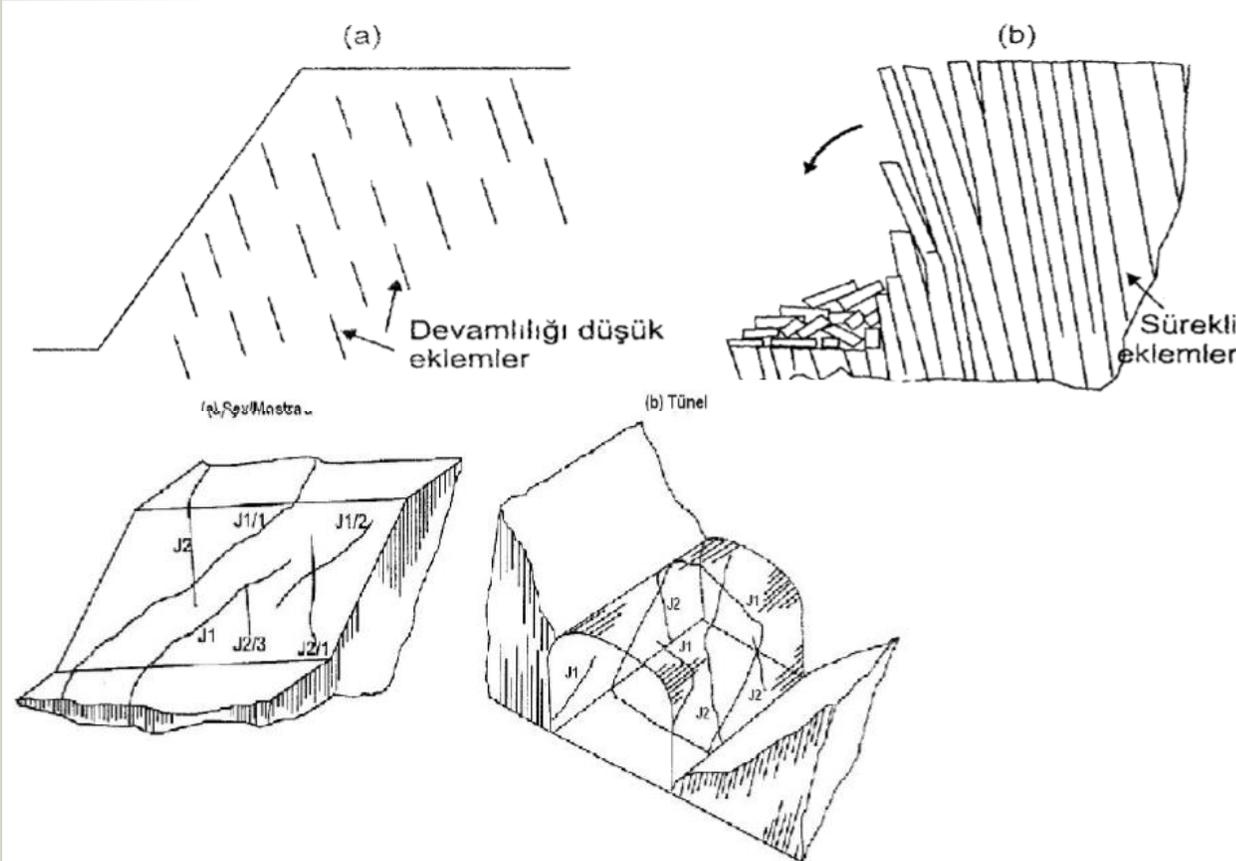
Süreksizlik aralığı tanımlama ölçütleri (ISRM, 1981)

Aralık (mm)	Tanımlama
< 20	Çok dar aralıklı
20-60	Dar aralıklı
60-200	Yakın aralıklı
200-600	Orta derecede aralıklı
600-2000	Geniş aralıklı
> 2000	Çok geniş aralıklı
>>> 6000	İleri derecede geniş aralıklı



Discontinuities Properties / Discontinuity Continuity

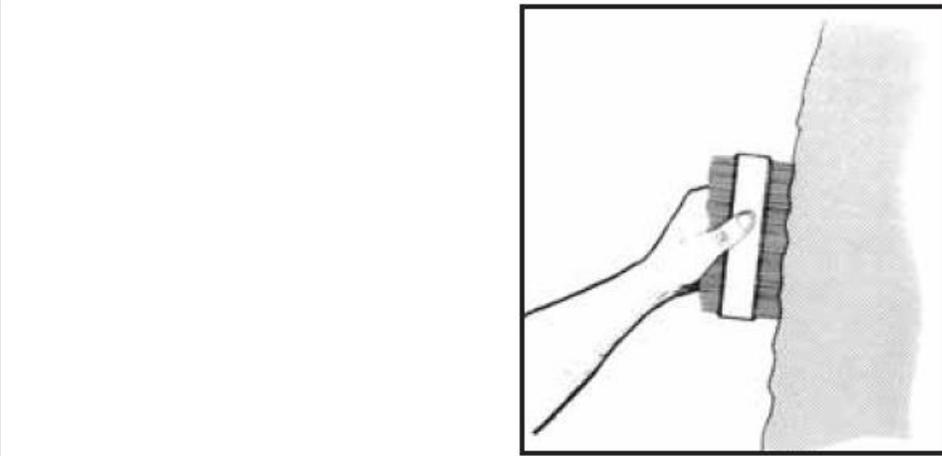
The continuity of discontinuities is an important parameter affecting the stability of discontinuities. As the continuity increases, the slope durability increases. Continuous and uninterrupted joints out of the slope in figures are observed. Continuity is measured directly by the tape measure in the rock outcrop and is recorded as a three-dimensional concept.



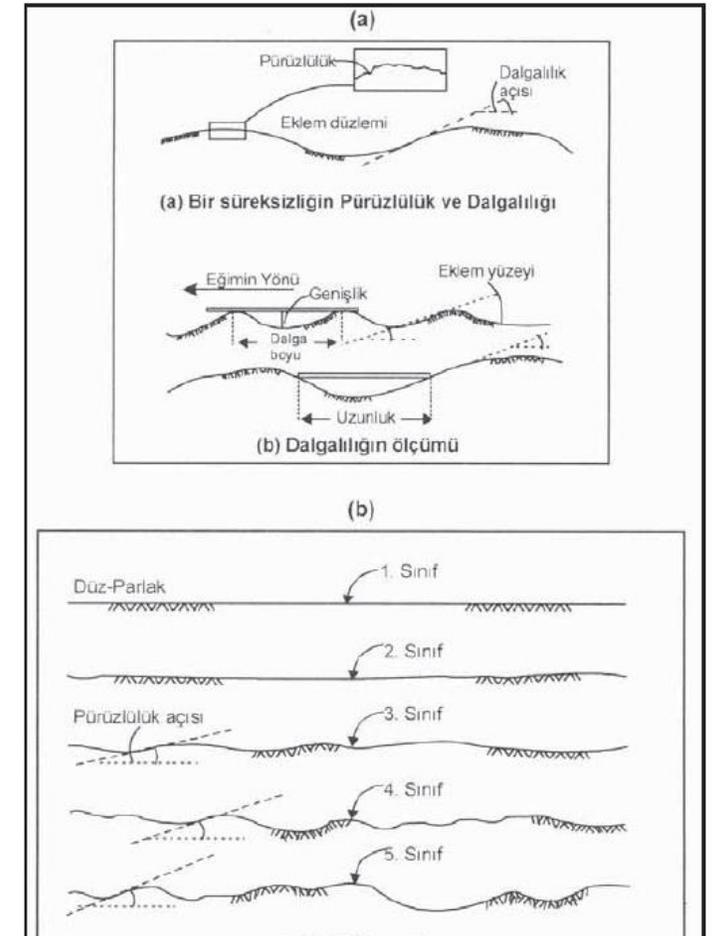
Tanımlama	Süreksizlik izinin uzunluğu
Çok düşük devamlılık	< 1 m
Düşük derecede devamlılık	1-3 m
Orta derecede devamlılık	3-10 m
Yüksek devamlılık	10-20 m
Çok yüksek devamlılık	>20 m

Discontinuities Properties / Roughness and ripples

Roughness and waviness are a measure of the deviation of a discontinuity surface from small and large scale planarity, respectively. Ripple characterizes a deviation in a large measure from planarity, while deviations in a small measure are defined as roughness.

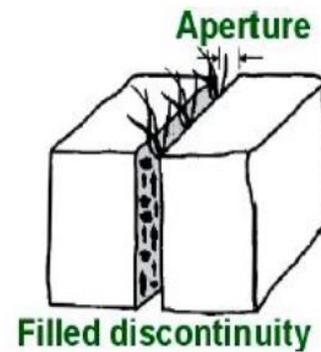
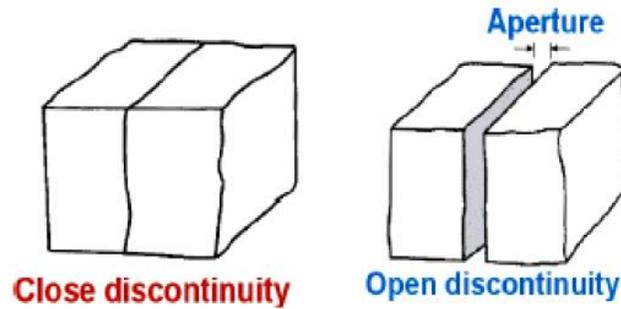
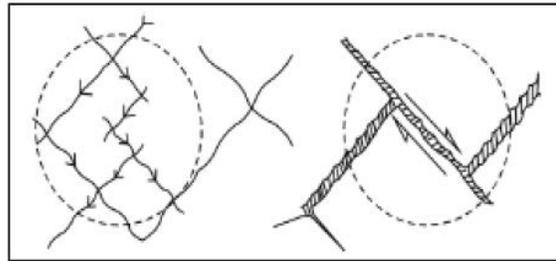


Şekil 10.8.B) Metal telli profilometre ile bir kaya mostrasında süreksizlik yüzeyi üzerindeki pürüzlülüğün pratik olarak ölçümü (Milne et al., 1992).



Discontinuities Properties / Discontinuities Interval

The clearance is the perpendicular distance between two opposing surfaces of a discontinuity, which may be empty or filled with water or any filler material.



Açıklık	Tanımlama	
< 0.1 mm	Çok sıkı	
0.1-0.25 mm	Sıkı	KAPALI yapılar
0.25-0.5 mm	Kısmen açık	
0.5-2.5 mm	Açık	
2.5-10 mm	Orta derecede geniş	BOŞLUKLU yapılar
> 10 mm	Geniş	
10-100 mm	Çok geniş	
100-1000 mm	Aşırı geniş	AÇIK yapılar
>1000 mm	Boşluklu	

Filling in discontinuities

Filler material is a material that fills between two opposing surfaces of discontinuity and is generally weaker than the parent rock material. The filler material reduces the roughness effect and reduces the shear strength of the discontinuities.

Discontinuities Properties / Degradation and Strength of Discontinuity Surfaces

The rock mass is often degraded in areas close to the surface, the deeper can be altered depending on the hydrothermal process. The impairment on the discontinuity surfaces is one of the factors affecting the strength of the discontinuities and should be defined by taking into consideration both the rock material and the impairment classifications recommended for the rock mass.

Table 4. Allocation of soils to aggressiveness classes (Jarvis and Hedges, 1994).

TABLE IV. ALLOCATION OF SOILS TO AGGRESSIVENESS CLASSES		
Aggressiveness class	Soil	Description
Non-aggressive chalky soils	Andover	Shallow well-drained calcareous silty soils over chalk
	Coombe	Well-drained calcareous silty soils over chalky drift or chalk
	Charity	Well-drained fine silty flinty soils over flinty silty drift
Non-aggressive other soils	Curstons	Well-drained fine silty over clayey soils over Plateau Drift and Clay-with-Flints
	Efford	Well-drained fine loamy soils over river and marine terrace gravel
	Hamble	Deep well-drained stoneless fine silty soils in brickearth
	Sonning	Well-drained flinty coarse loamy soils over river terrace gravel and drift
Moderately aggressive	Bursledon	Deep fine loamy soils with slowly permeable subsoils and slight seasonal waterlogging
	Holidays Hill	Acid sandy over clayey soils with slowly permeable subsoils and slight seasonal waterlogging
	Park Gate Shabington	Deep stoneless silty soils in brickearth affected by groundwater Deep fine loamy soils in river terrace gravel affected by groundwater
Highly aggressive	Wickham	Slowly permeable seasonally waterlogged fine loamy over clayey soils
Very highly aggressive	Windsor	Slowly permeable seasonally waterlogged clayey soils
	Fladbury	Stoneless clayey soils in alluvium affected by groundwater
	Wallasea	Deep stoneless clayey soils affected by groundwater in marine alluvium; saline groundwater
	Unripened gley soils	Soils of variable texture which may be flooded by high tides; saline groundwater

Kaya malzemesinin bozunma derecesiyle ilgili sınıflama (ISRM, 1981).

Tanım	Tanımlama ölçütü
Taze (bozunmamış)	Kaya malzemesinin bozunduğuna ilişkin belirgin bir gösterge yoktur.
Rengi değişmiş	Orijinal kaya malzemesinin rengi değişmiş olup, renkteki değişimin derecesi belirgindir. Renk değişimi sadece bazı mineral taneleriyle sınırlı ise, bu durum kayıtlarda belirtilmelidir.
Bozunmuş	Kaya malzemesi orijinal dokusunu korumakla birlikte, toprak zemine dönüştürmüştür. Ancak minerallerin bir kısmı veya tamamı bozunmuştur.
Bozunmuş-dağılmış	Kayanın orijinal dokusu korunmakla birlikte, kaya malzemesi tamamen bozunarak toprak zemine dönüştürmüş olup, kırılmıştır.

Discontinuities Properties / Degradation and Strength of Discontinuity Surfaces

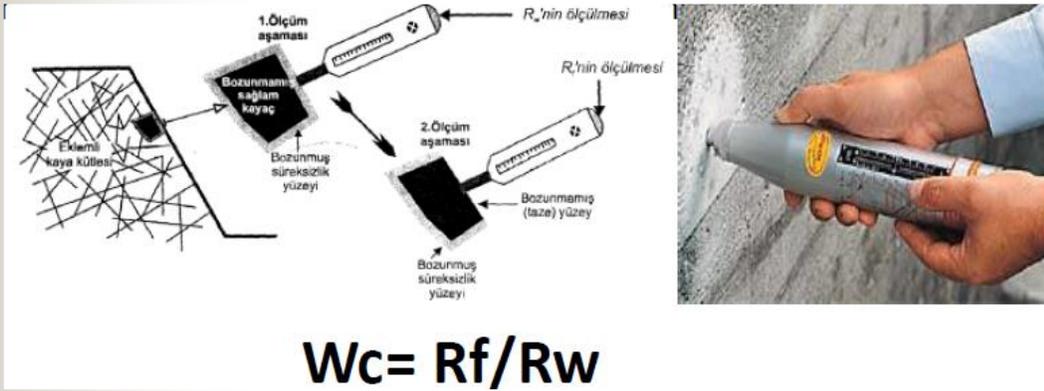
The strength of the discontinuity surfaces is closely related to the degree of impairment of these surfaces and the rock material in the immediate vicinity. For this purpose, ISRM (1981) proposed a classification criterion of dislocation which can be used during field study. These categorizations lead to subjective evaluations in some cases since they are purely observational.

Kaya kütlelerinin bozunma derecesiyle ilgili sınıflama (ISRM, 1981).

Tanım	Tanımlama ölçütü	Bozunmanın derecesi
Bozunmamış (Taze)	Kayanın bozunduğuna ilişkin gözle ayırdedilebilir bir belirti olmamakla birlikte, ana süreksizlik yüzeylerinde önemsiz bir renk değişimi gözlenebilir.	W 1
Az bozunmuş	Kaya malzemesinde ve süreksizlik yüzeylerinde renk değişimi gözlenir. Bozunma nedeniyle tüm kayacın rengi değişmiş ve kaya taze halinden daha zayıf olabilir.	W 2
Orta derecede bozunmuş	Kayanın yarısından az bir kısmı toprak zemine dönüşerek ayrılmış ve/veya parçalanmıştır. Kaya; taze, ya da renk değişimine uğramış olup, sürekli bir kütle veya çekirdek taşı halindedir.	W 3
Tamamen bozunmuş	Kayanın tümü toprak zemine dönüşerek ayrılmış ve/veya parçalanmıştır. Ancak orijinal kaya kütlelerinin yapısı halen korunmaktadır.	W 4
Artık zemin	Kayanın tümü toprak zemine dönüşmüştür. Kaya kütlelerinin yapısı ve dokusu kaybolmuştur. Hacim olarak büyük bir değişiklik olmakla birlikte, zemin taşınmamıştır.	W 5

Discontinuities Properties / Degradation and Strength of Discontinuity Surfaces

In order to estimate the compressive strength of the discontinuity surfaces, the application is usually determined indirectly by Schmidt attractive experiment, while utilizing the simple classification of the land with definitions (ISRM, 1981).

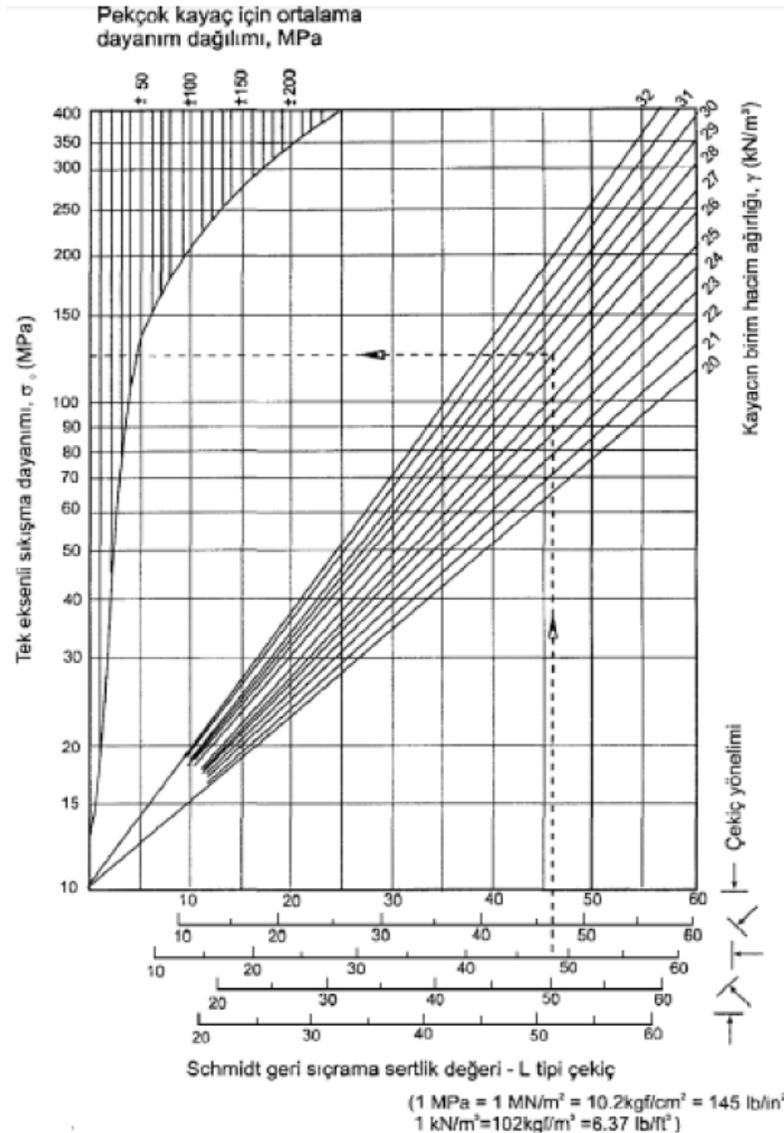


(Rf); Taze kaya Schmidt geri sıçrama sertlik değerleri
 (Rw); Bozunmaya uğramış süreksizlik yüzeyinin Schmidt geri sıçrama sertlik değerleri
 (Wc); bozunma katsayısı

Wc	Sınıf	Tanım (ISRM, 1981)
<1.1	1	Bozunmamış(Taze)
1.1- 1.5	2	Az bozunmuş
1.5-2.0	3	Orta derecede bozunmuş
>2.0	4	Tamamen bozunmuş

Simge	Tanım	Saha tanımlaması	Tek eksenli sıkışma dayanımı, σ_b (MPa)
R0	Aşırı derecede zayıf kayaç	Kayacın yüzeyinde tırnak ile çentik oluşturulabilir.	0.25-1.0
R1	Çok zayıf kayaç	Jeolog çekiciyle sert bir darbeye ufalanan kayaç, çakı ile doğranabilir.	1.0-5.0
R2	Zayıf kayaç	Kayaç, çakı ile güçlkle doğranır. Jeolog çekici ile yapılacak sert bir darbe kayacın yüzeyinde iz bırakır.	5.0-25
R3	Orta derecede sağlam kayaç	Kayaç, çakı ile doğranamaz. Kayaç örneği, jeolog çekici ile yapılacak tek ve sert bir darbeye kırılabilir.	25-50
R4	Sağlam kayaç	Kayaç örneğinin kırılabilmesi için, jeolog çekici ile birden fazla darbenin uygulanması gerekir.	50-100
R5	Çok sağlam kayaç	Kayaç örneğinin kırılabilmesi için jeolog çekici ile çok sayıda darbe gerekir.	100-250
R6	Aşırı derecede sağlam kavac	Kayaç örneği, jeolog çekici ile sadece yontulabilir.	>250

Discontinuities Properties / Degradation and Strength of Discontinuity Surfaces

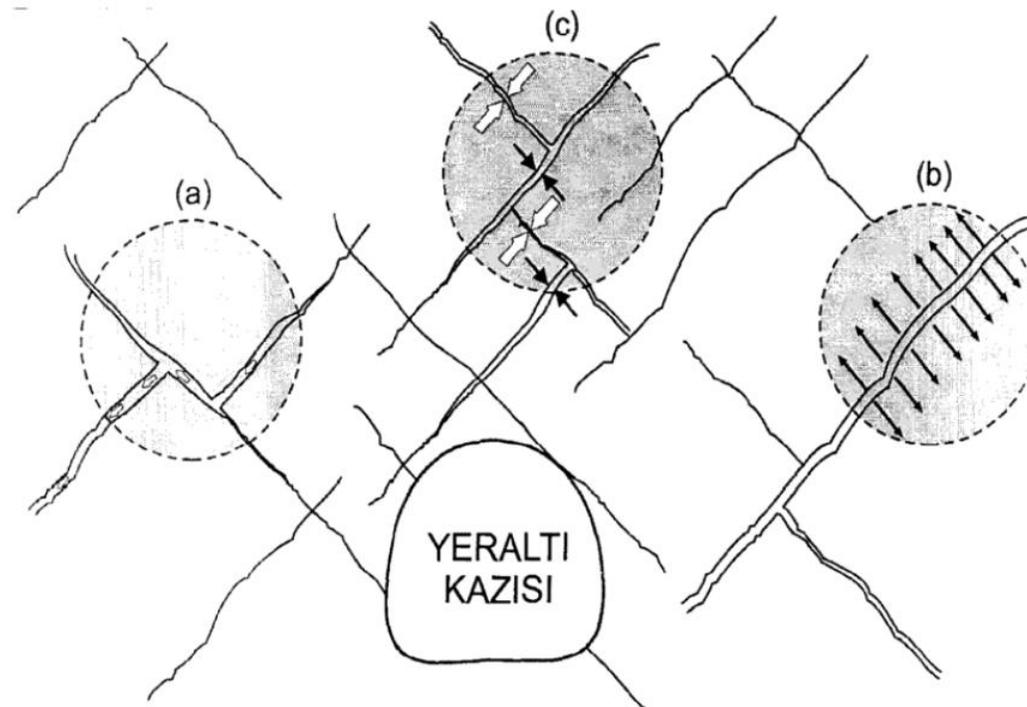


Örnek çözüm:

Düsey bir süreksizlik yüzeyine uygulanan Schmidt deneyinde belirlenen geri sıçrama sayısı 48 ve birim hacim ağırlık 27 kN/m³ ise, yüzeyin sıkışma dayanımı yaklaşık 120 MPa'dır.

Discontinuity Properties / Water Conditions at Discontinuities

The infiltration of water in rock masses occurs through the flow of water through the discontinuities associated with each other (secondary permeability). The mechanical properties of the rock mass change, especially in the presence of a continuous stream of water along discontinuities. The water stress between the surfaces of discontinuity reduces normal shear stress.



Engineering Classification of Rocks

Classification by discontinuities

The rocks in the earth are divided into the following classes according to their discontinuities.

Massive

Thick layered

Stratified

Laminated

Cracked and microcracked

Articulated

Fault

Schistosity and Foliated

Curved

Classification by Mechanical Properties

Kaya dayanımı	Tek eksenli basınç dayanımı (MPa)	Nokta yük dayanımı (MPa)
Çok az dayanımlı	< 25	1
Az dayanımlı	25-50	1-2
Orta dayanımlı	50-100	2-4
Çok dayanımlı	100-200	4-8
Çok fazla dayanımlı	> 200	> 8

Drilling parameters determined from drilling logs

Toplam Karot Verimi:

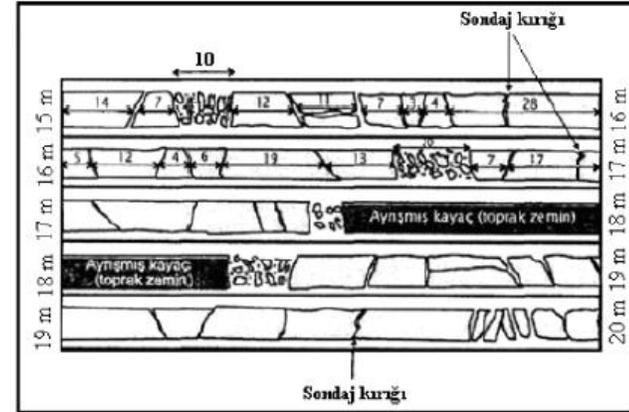
$$TKV = \frac{\Sigma \text{ İlerlemede alınmış tüm karot ve kırıntı parçalarının uzunluğu}}{\text{İlerleme aralığının uzunluğu}}$$

Sağlam Karot Verimi:

$$SKV = \frac{\Sigma \text{ İlerlemede silindirik şeklini koruyan karot parçalarının uzunluğu}}{\text{İlerleme aralığının uzunluğu}}$$

Eklem Sıklığı (Ff):

$$\lambda = \frac{\text{Bir ilerlemedeki doğal süreksizliklerin sayısı}}{\text{İlerleme uzunluğu (m)}} \quad (\text{m}^{-1})$$



Sınıflama	Ortalama süreksizlik aralığı, \bar{x} (m)	Ortalama süreksizlik sıklığı, λ (m^{-1})
Masif	$\bar{x} > 1$	< 1
Az çatlaklı-kırıklı	$0.3 < \bar{x} < 1$	1-3
Kırıklı-çatlaklı	$0.1 < \bar{x} < 0.3$	3-10
Çok çatlaklı-kırıklı	$0.02 < \bar{x} < 0.1$	10-50
Parçalanmış	$\bar{x} < 0.02$	> 50

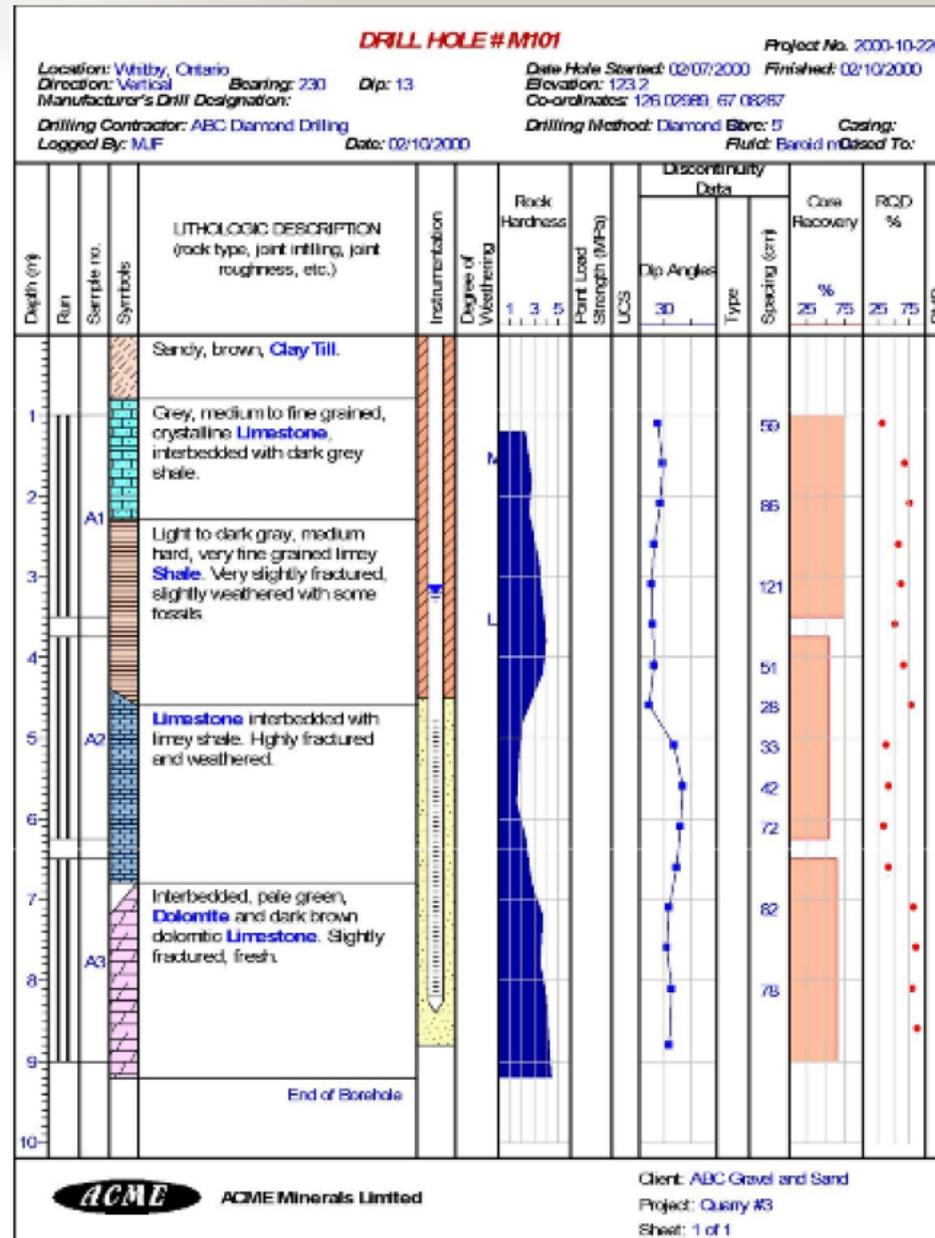
$$TKV = \frac{14+7+10+12+11+7+3+4+28}{100} \times 100 = \%96$$

$$SKV = \frac{14+7+12+11+7+3+4+28}{100} \times 100 = \%86$$

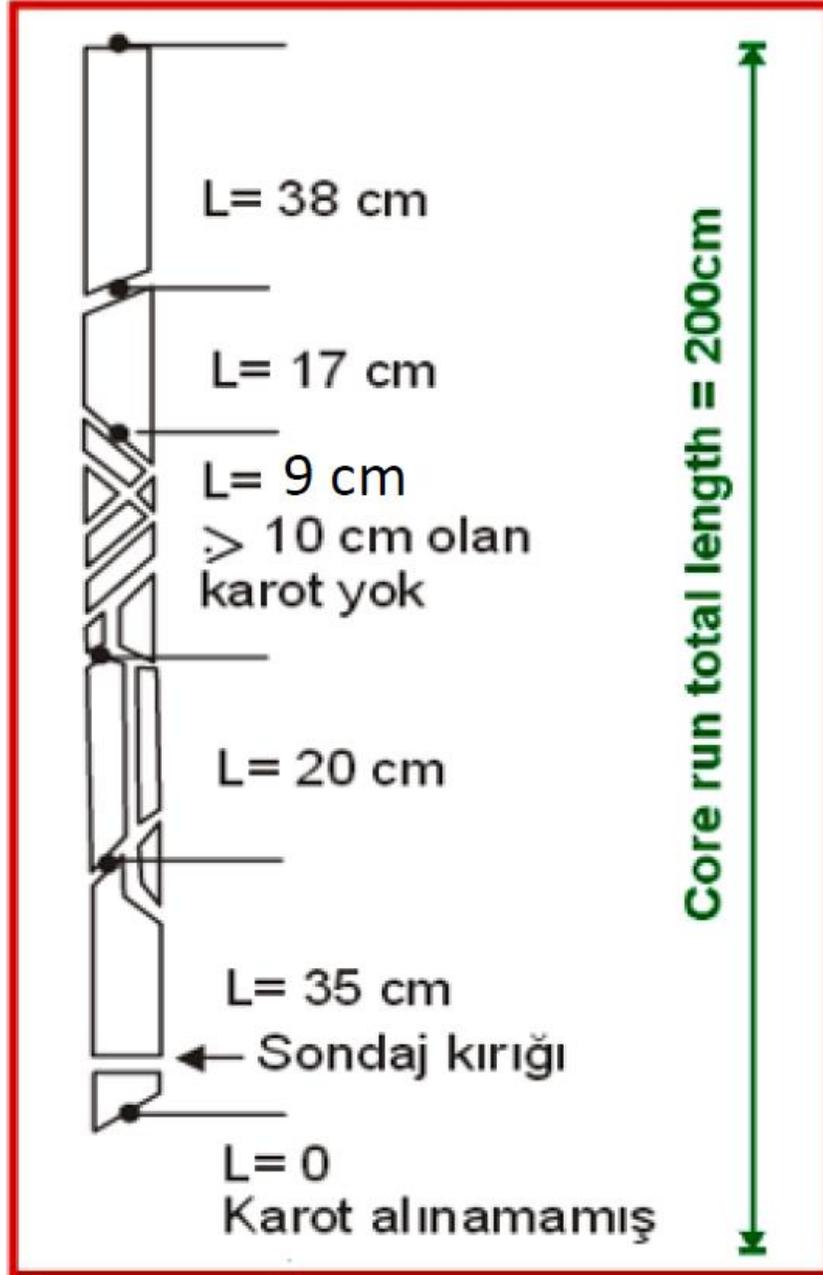
$$RQD = \frac{14+12+11+28}{100} \times 100 = \%65$$

$$FF = \frac{0}{1 \text{ m}} = 0 \text{ m}^{-1}$$

Drilling parameters determined from drilling logs



Bir Örnek; RQD, TCR, SCR, FF



Kaya Kalite Göstergesi (RQD)

$$RQD (\%) = \frac{\sum \text{Karot parçalarının uzunluğu} > 10 \text{ cm}}{\text{İlerleme aralığının uzunluğu}} * 100$$

$$RQD (\%) = \frac{38+17+20+35}{200} * 100 = 55\%$$

Toplam Karot Verimi (TCR)

$$TCR (\%) = \frac{\text{Toplam karot uzunluğu}}{\text{İlerleme aralığının uzunluğu}} * 100$$

$$TCR (\%) = \frac{38+17+9+20+35}{200} * 100 = 60\%$$

Sağlam Karot Verimi (SCR)

$$SCR (\%) = \frac{\text{Silindirik şeklini koruyan toplam karot uzunluğu}}{\text{İlerleme aralığının uzunluğu}} * 100$$

$$SCR (\%) = \frac{38+17+20+35}{200} * 100 = 55\%$$

Süreksizlik Sıklığı (FF)

$$FF (m^{-1}) = \frac{\sum \text{Ayrık ve doğal süreksizliklerin sayısı}}{\text{İlerleme aralığının uzunluğu}} * 100$$

$$FF = \frac{8}{2} = 4 m^{-1}$$