UNIT 1

INTRODUCTION TO GEOLOGY

WHAT IS GEOLOGY

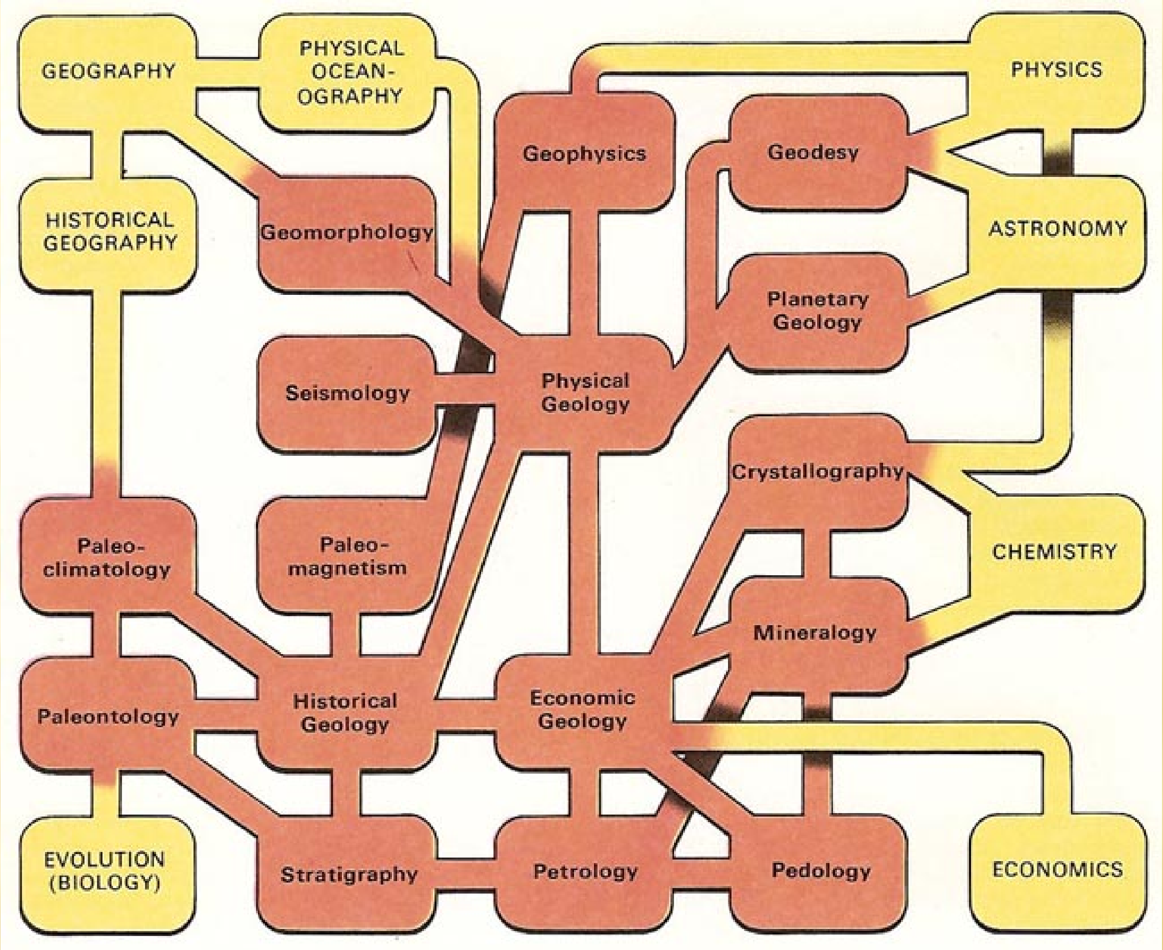
- Geology is the study of Earth, including the materials that it is made of, the physical and chemical changes that take place on its surface and in its interior and the history of the planet and its life form.

- Geology is broadly divided into Physical Geology and Historical Geology.

- Physical geology is concerned with the materials and processes which compose and operate on the surface of, and within the Earth.

- Historical geology is concerned with the origin and evolution of Earth's continents, oceans, atmosphere, and life.

BRANCHES OF GEOLOGY



GEOLOGY IN OUR LIVES

- Geology is relevant to everyone's day-to-day life.
- Metals and energy sources such as coal and petroleum are geologic products that build and power modern society.
- Water, a precious natural resource is used in industry, agriculture and domestic purpose is also a geologic product.
- Natural hazards like tsunamis, landslides, earthquakes and volcanic eruptions are also related to geology,

WHAT DOES A GEOLOGIST DO

- Geologists work to understand the history of our planet. The better they can understand Earth's history the better they can foresee how events and processes of the past might influence the future.

- Geologists study earth processes:

  - Many processes such as landslides, earthquakes, floods and volcanic eruptions can be hazardous to people.
  - Geologists work to understand these processes well enough to avoid building important structures where they might be damaged.
  - If geologists can prepare maps of areas that have flooded in the past they can prepare maps of areas that might be flooded in the future.
  - These maps can be used to guide the development of communities and determine where flood protection or flood insurance is needed.

- Geologists study earth materials:

  - People use earth materials every day. They use oil that is produced from wells, metals that are produced from mines, and water that has been drawn from streams or from underground.
  - Geologists conduct studies that locate rocks that contain important metals, plan the mines that produce them and the methods used to remove the metals from the rocks. They do similar work to locate and produce oil, natural gas and ground water.

- Geologists study earth history:

  - Today we are concerned about climate change. Many geologists are working to learn about the past climates of earth and how they have changed across time.
  - This historical geology news information is valuable to understand how our current climate is changing and what the results might be.

WHERE DO GEOLOGISTS WORK

- Jobs in geology are found in government agencies, private companies, and non-profit and academic institutions.
- Government agencies hire geologists to investigate, plan and evaluate excavations, construction sites, natural disaster preparedness, and natural resources.
- Private companies hire geologists to help locate natural resources (minerals, oil and natural gas), evaluate environmental impact and comply with government regulations, among many other tasks.
- Geologists who prefer an academic career usually work, either as educators, researchers or both, in middle or high schools, colleges, universities and museums.

PROCESSES ACTING ON THE EARTH

- The Earth is a Dynamic system that is it undergoes constant changes with time both internally and on its surface.

Internal Processes

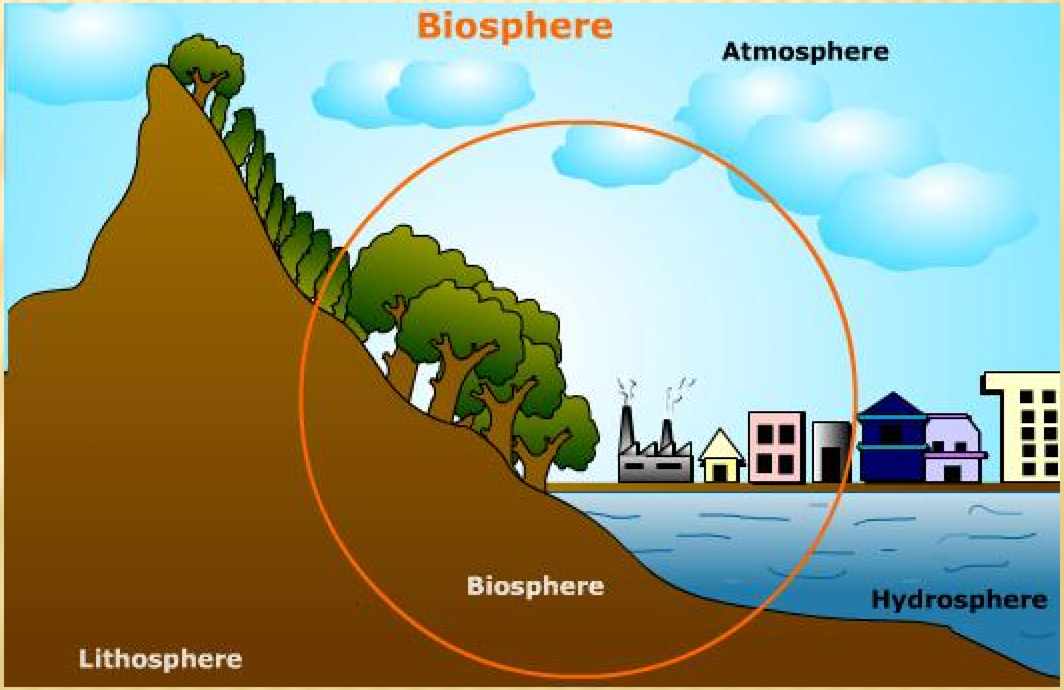
- Processes that originate deep within the Earth are termed as internal processes. These are the driving forces that raise mountains, cause earthquakes and produce volcanic eruptions.

Surface Processes

- Surface processes are all those processes which take place on the earth's surface and result in sculpting the earth's surface. Most of the surface processes are driven by water, though wind, ice and gravity also play an important role.

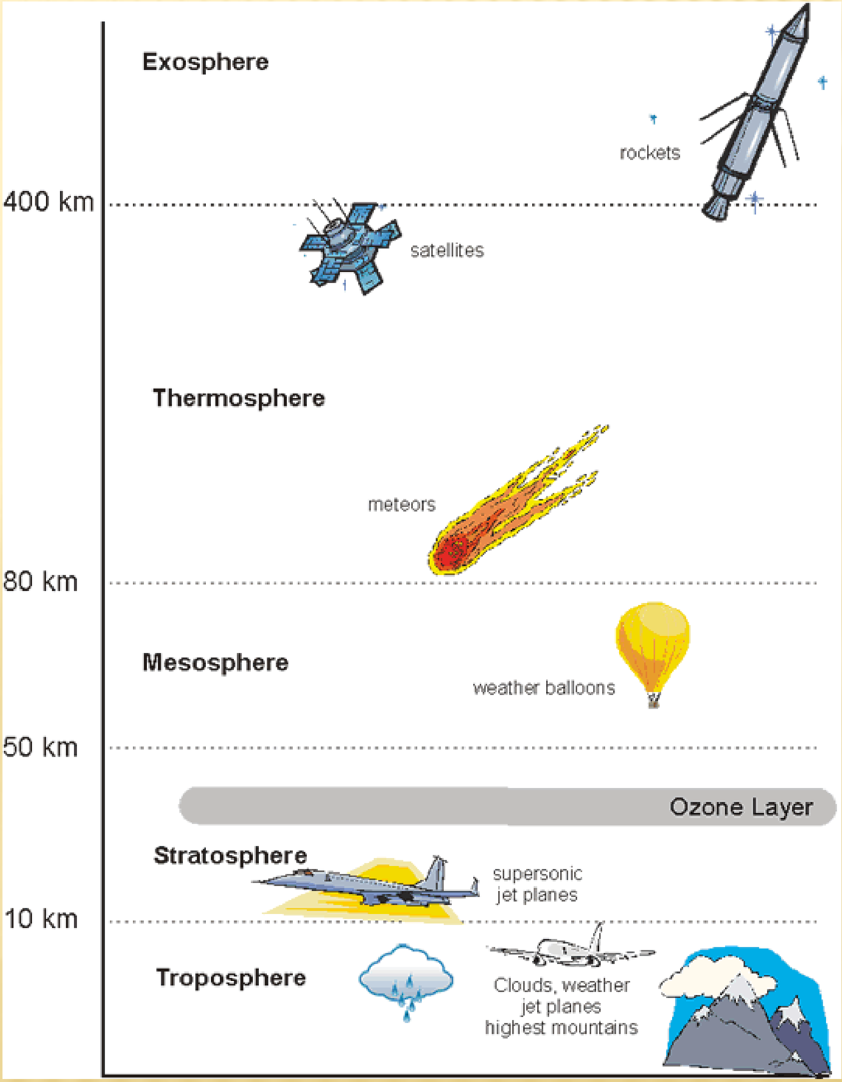
GEO-SPHERES

- The area near the surface of the earth can be divided into four inter-connected "geo-spheres:" the atmosphere, hydrosphere, lithosphere and the biosphere.



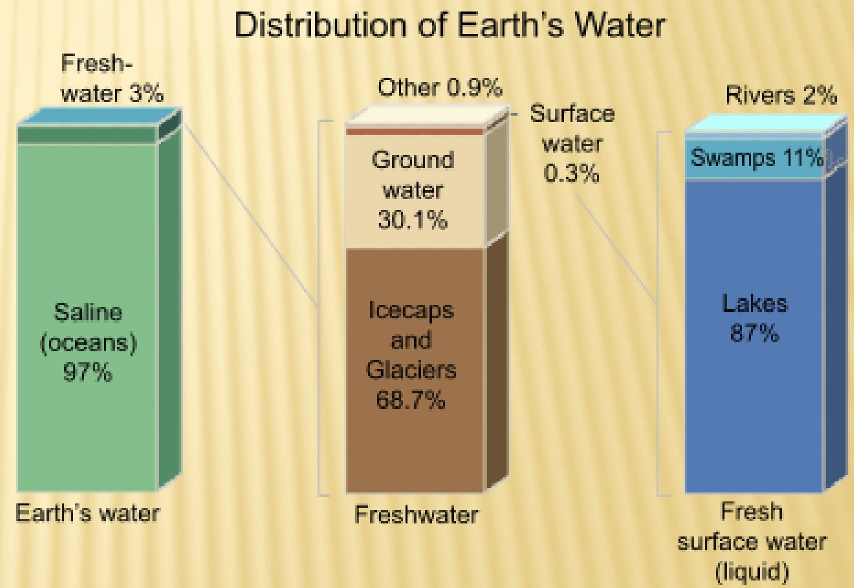
ATMOSPHERE

- The atmosphere is the body of air which surrounds our planet.
- Most of our atmosphere is located close to the earth's surface where it is most dense.
- The atmosphere not only provides the air that we breathe but also acts to protect us from the Sun's intense heat and dangerous ultraviolet radiation.
- The energy exchanges that continually occur between the atmosphere and the surface and between the atmosphere and space produce the effects we call weather and climate.
- The air of our planet is 79% nitrogen and just under 21% oxygen; the small amount remaining is composed of carbon dioxide and other gasses.



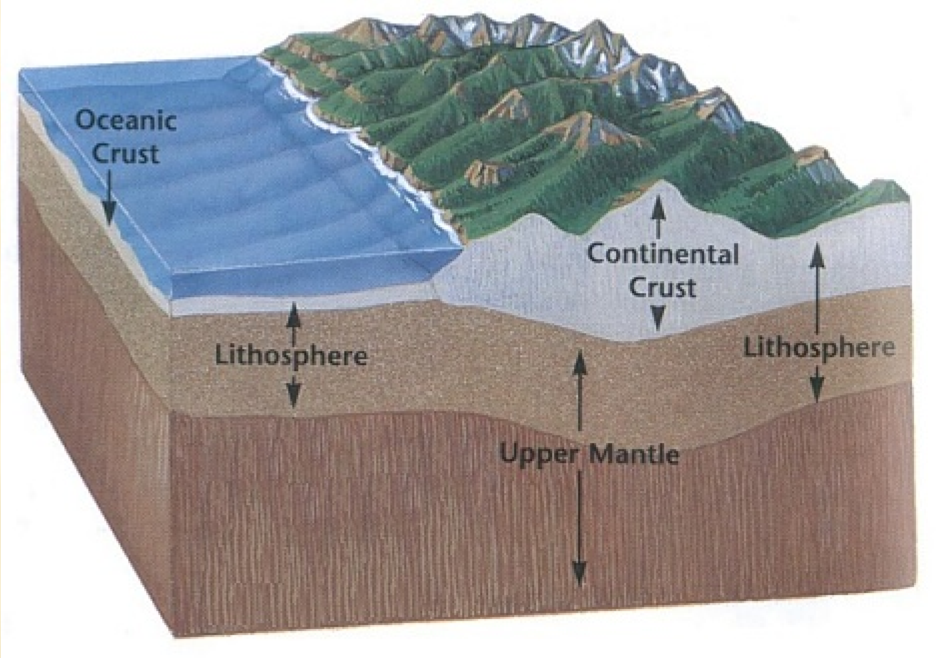
HYDROSPHERE

- The hydrosphere is composed of all of the water on or near the earth.
- This includes the oceans, rivers, lakes, and even the moisture in the air.
- Ninety-seven percent of the earth's water is in the oceans.
- The remaining three percent is fresh water; three-quarters of the fresh water is solid and exists in ice sheets.



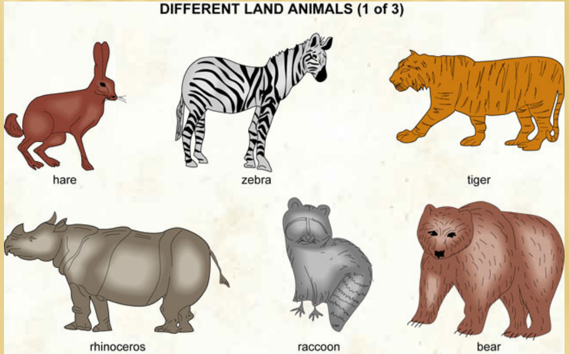
LITHOSPHERE

- Beneath the atmosphere and the oceans is the solid Earth, or lithosphere.
- The lithosphere is the solid, rocky crust covering entire planet.
- This crust is inorganic and is composed of minerals.



BIOSPHERE

- The biosphere is composed of all living organisms.
- Plants, animals, and one-celled organisms are all part of the biosphere.
- Most of the planet's life is found from three meters below the ground to thirty meters above it and in the top 200 meters of the oceans and seas.



UNIFORMITARIANISM AND CATASTROPHISM

- James Hutton a Scotish gentleman in 18th century gave the concept of Uniformitarianism.

- According to the Principle of Uniformitarianism, geological changes take place over a long period of time.

- Hutton summarized that geological processes operating today also operated in the past therefore scientists can explain events that occurred in the past by observing changes that are occurring today.

- Sometimes this whole idea is also known as "The present is the key to the past."

UNIFORMITARIANISM

The formation of river valleys due to the action of running water or the movement of the continents are examples of very slow and gradual changes

UNIFORMITARIANISM AND CATASTROPHISM

- William Whewell, another early geologist, agreed that the Earth is very old, but he argued that geologic change was sometimes rapid.
- He wrote that the geologic past may have “consisted of epochs catastrophic action, interposed between periods of comparative tranquility.”
- This phenomenon where earth was subjected to rapid geological change as a result of certain catastrophe came to be known as Catastrophism

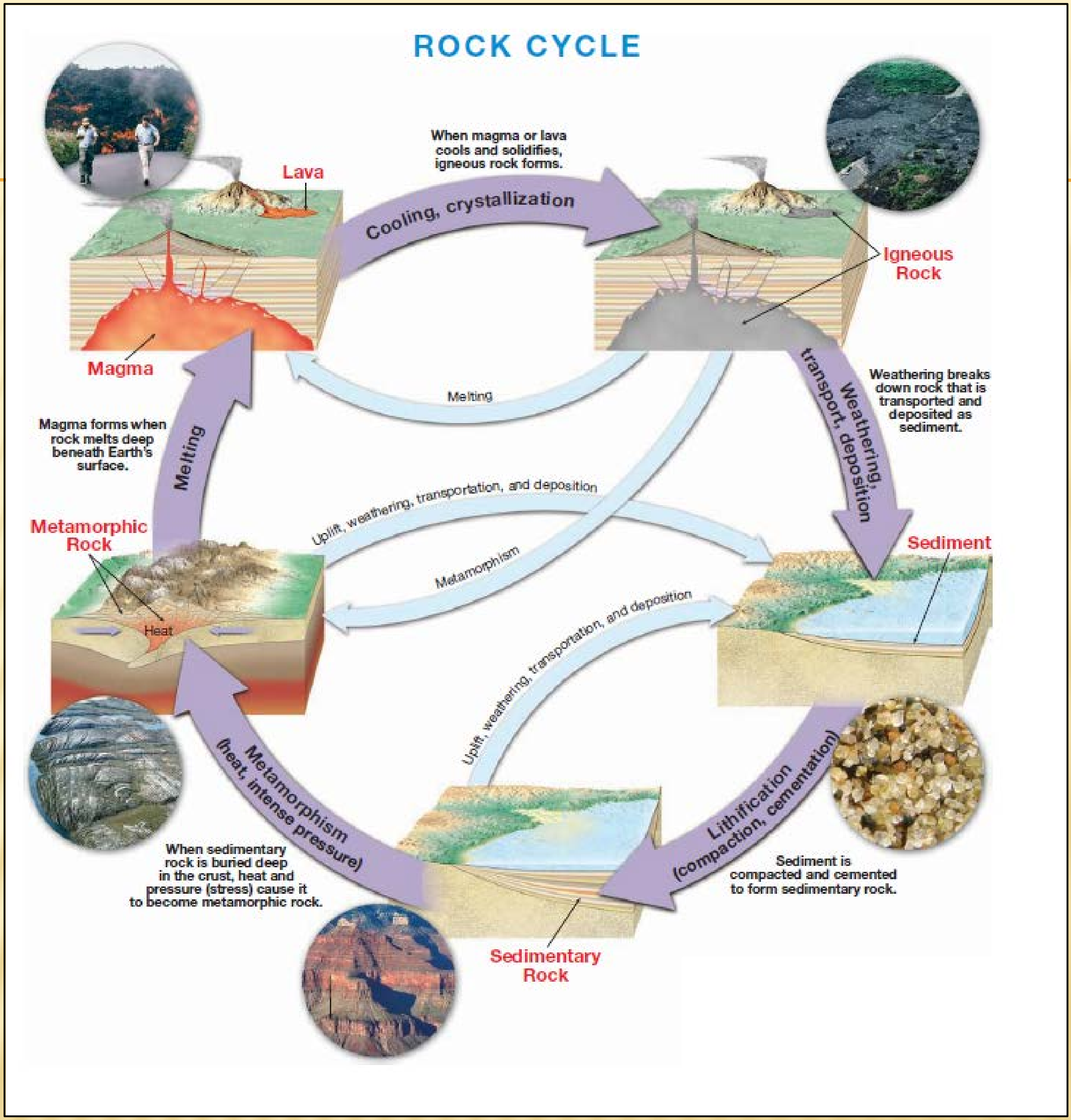
CATASTROPHISM

UNIFORMITARIANISM AND CATASTROPHISM

- Today, geologists know that both Hutton's uniformitarianism and Whewell's catastrophism are correct.
- Thus, over the great expanses of geologic time, slow, uniform processes are significant, but improbable, catastrophic events radically modify the path of slow change.

ROCK CYCLE

- Rock is the most common and abundant material on Earth.
- A rock consists of smaller crystals or grains called minerals. Minerals are chemical compounds (or sometimes single elements), each with its own composition and physical properties. The grains or crystals may be microscopically small or easily seen with the unaided eye.
- The nature and appearance of a rock is strongly influenced by the minerals that compose it.
- A rock's texture—the size, shape, and/or arrangement of its constituent minerals—also has a significant effect on its appearance.
- A rock's mineral composition and texture, in turn, are a reflection of the geologic processes that created it
- Geologists divide rocks into three major groups: igneous, sedimentary, and metamorphic.



- **Rock Cycle** is the fundamental concept of Geology that describes the dynamic transition through geologic time among the three rock types Each type of rock is altered or destroyed when it is forced out of equilibrium condition.

IGNEOUS ROCKS

- Magma is the molten material which is formed when the pressure and temperature conditions are high enough to melt the rocks.
- The Magma is formed in the interior of the earth and then gradually migrates upwards to the earth's crust.
- When it reaches the surface its cools and solidifies by the process of crystallization.
- The rocks formed as a result are known as Igneous Rocks.

SEDIMENTARY ROCKS

- These igneous rocks when exposed to the atmosphere undergo weathering where they disintegrate into smaller particles.
- These particles known as sediments are transported by the agents of erosion such as water, wind and ice.
- Finally these sediments are deposited.
- These sediments are then converted to rocks by the process of lithification.
- The resulting rocks are known as **Sedimentary Rocks.**

METAMORPHIC ROCKS

- If the resulting sedimentary rock is buried deep within Earth and involved in the dynamics of mountain building or intruded by a mass of magma, it will be subjected to great pressures and/or intense heat.

- The sedimentary rock will react to the changing environment and turn into the third rock type, metamorphic rock.

- When metamorphic rock is subjected to additional pressure changes or to still higher temperatures, it will melt, creating magma, which will eventually crystallize into igneous rock, starting the cycle all over again.

FORMATION OF THE SOLAR SYSTEM

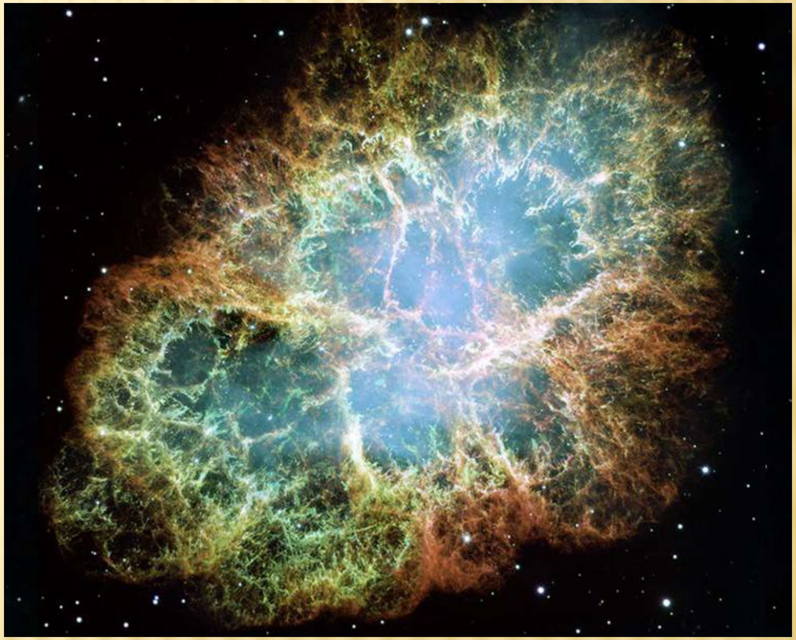
- Earth was not around at the beginning—the universe began without us some 10 billion years earlier than Earth.

- The universe started out with only two elements, hydrogen and helium gas.

- They formed stars that burned these elements in nuclear fusion reactions.

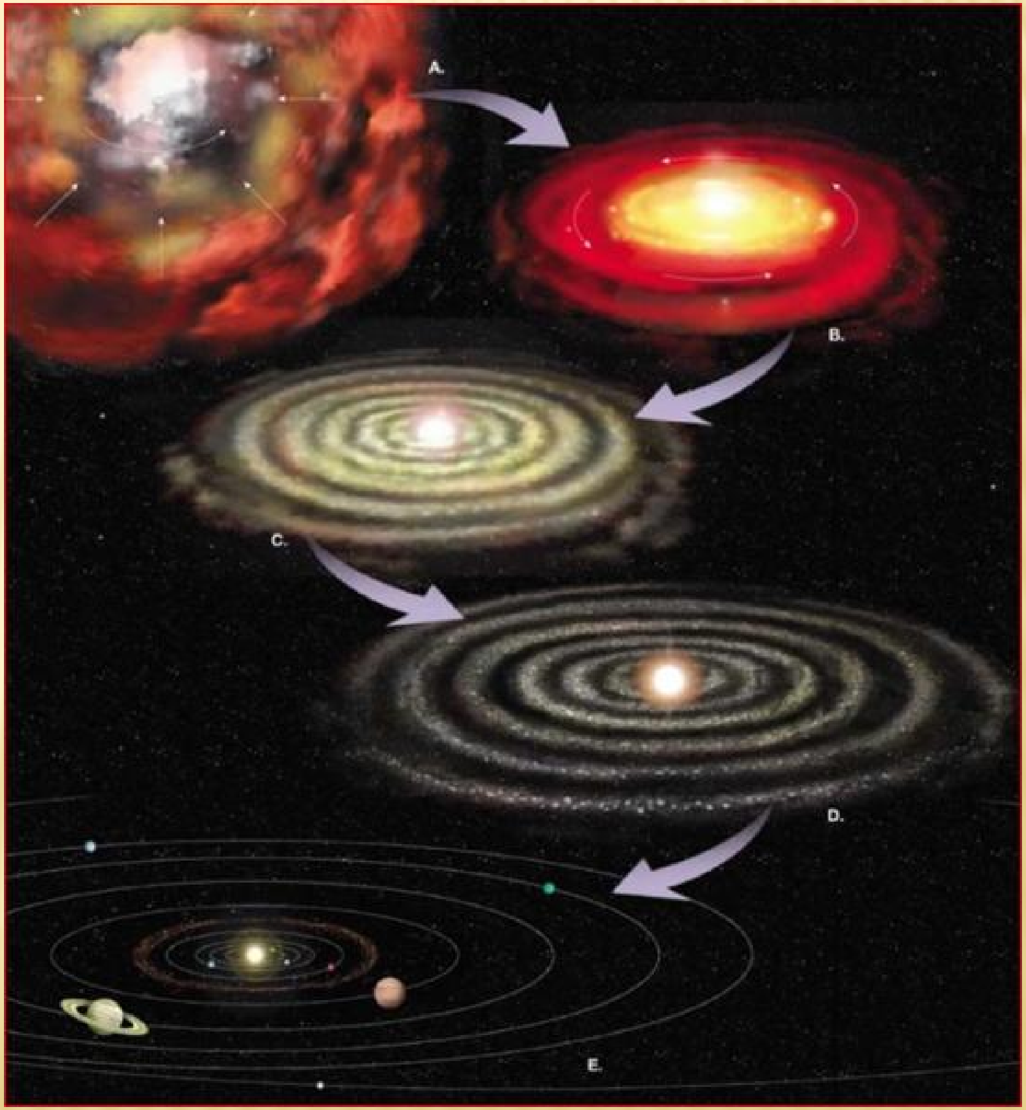
- Generations of stars were born in gas clouds and died in explosive novas.

- Long, long ago (some 5 billion years ago) a supernova exploded, pushing a lot of its heavy-element wreckage into a nearby cloud of hydrogen gas and interstellar dust.

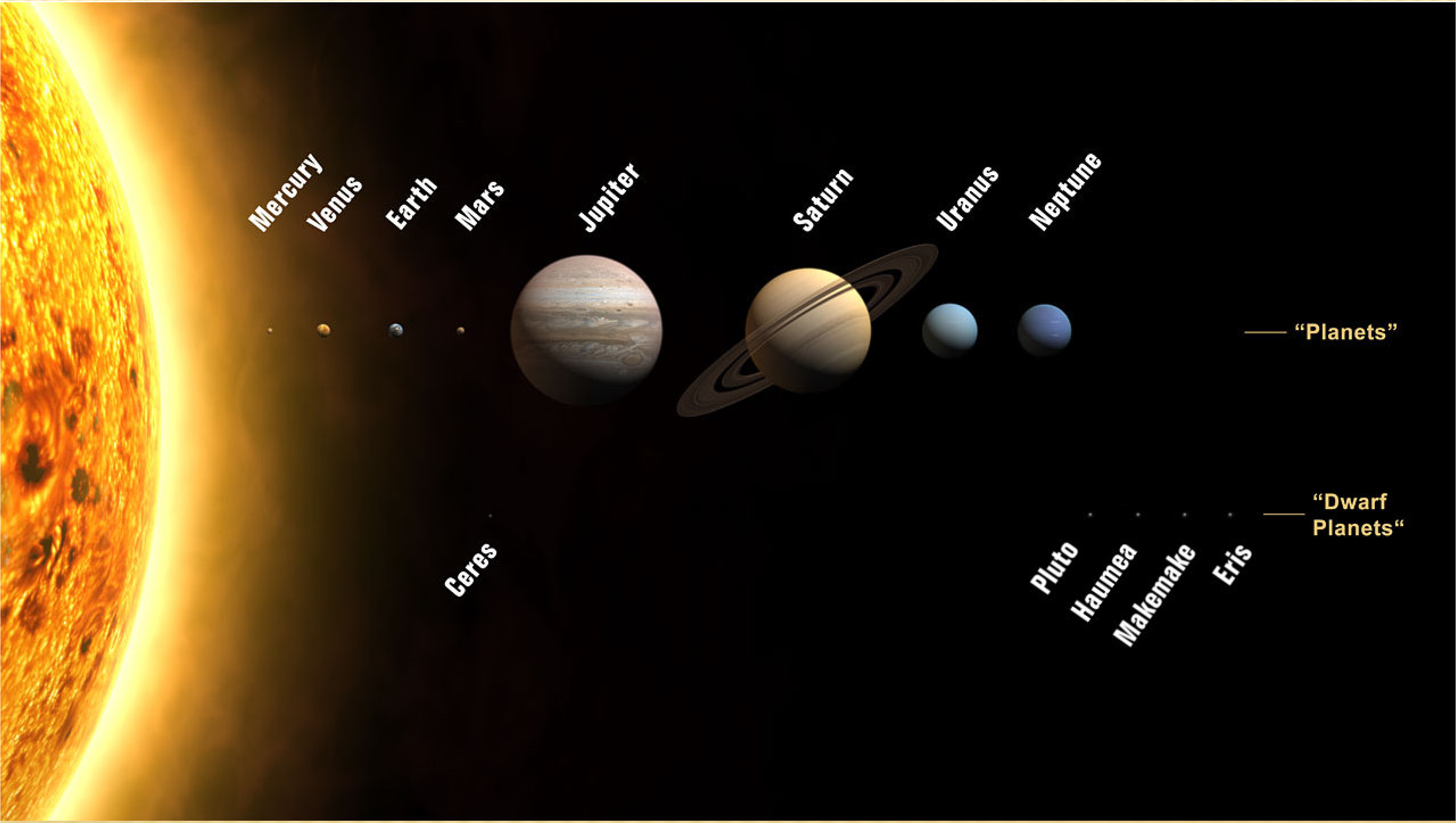


FORMATION OF THE SOLAR SYSTEM

- The mixture grew hot and compressed under its own gravity, and at its center a new star began to form.
- Around it swirled a disk of the same material, which grew white-hot from the great compressive forces.
- That new star became our Sun, and the glowing disk gave rise to Earth and its sister planets.



FORMATION OF THE SOLAR SYSTEM



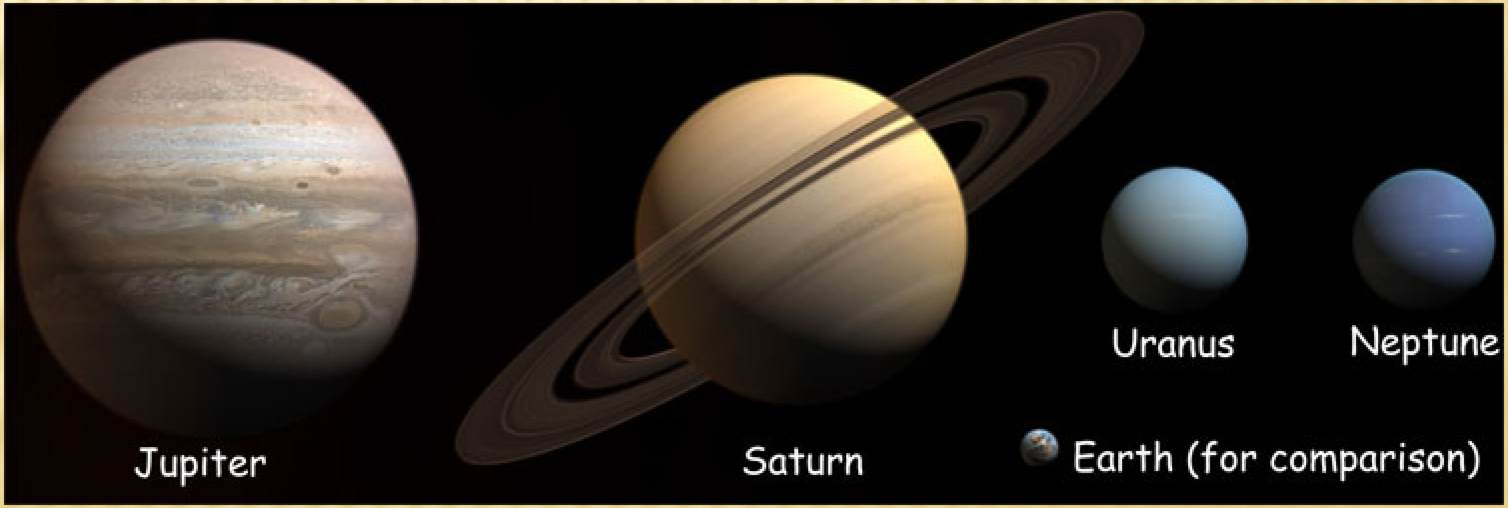
FORMATION OF THE SOLAR SYSTEM

- The planets of the Solar system can be divided into groups depending on their proximity to the sun and their density.

- The terrestrial planets are the four closest to the sun and are all similar to the Earth in density. They include Mercury, Venus, Earth and Mars. All four terrestrial planets are small, rocky and dense (3 g/cm^3 or more).

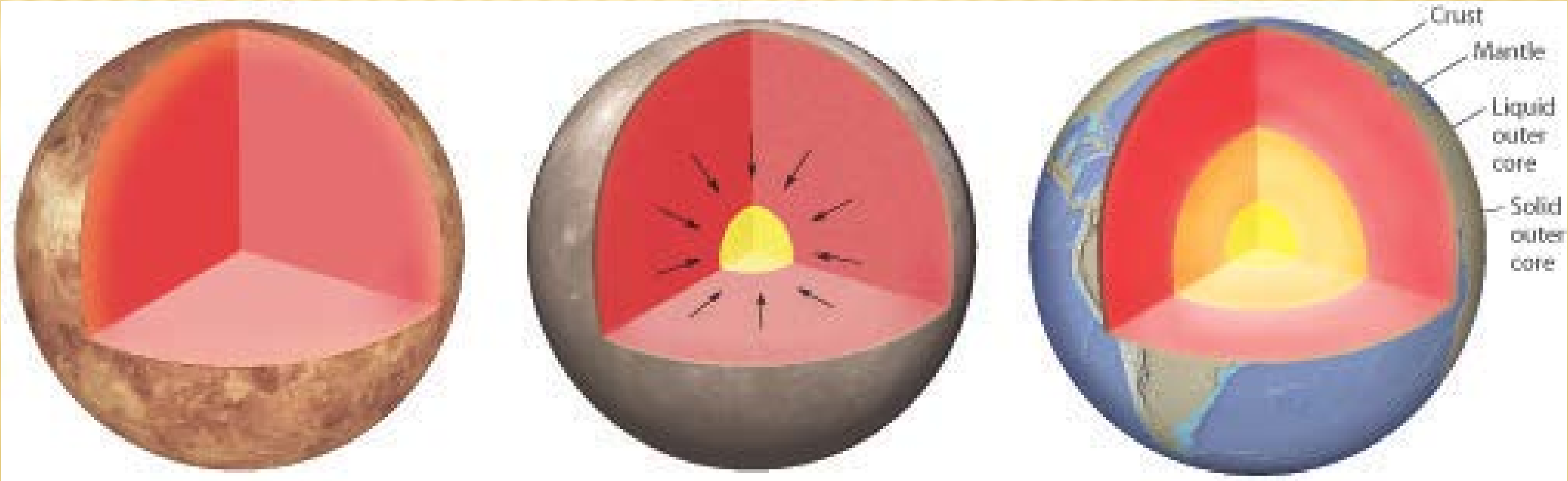
FORMATION OF THE SOLAR SYSTEM

- The Jovian planets are those farther from the sun than Mars
- They include Jupiter, Saturn, Uranus and Neptune. They are much larger than the Earth but their densities are very low.
- They are made up of light elements most Hydrogen and Helium and hence their densities are low,

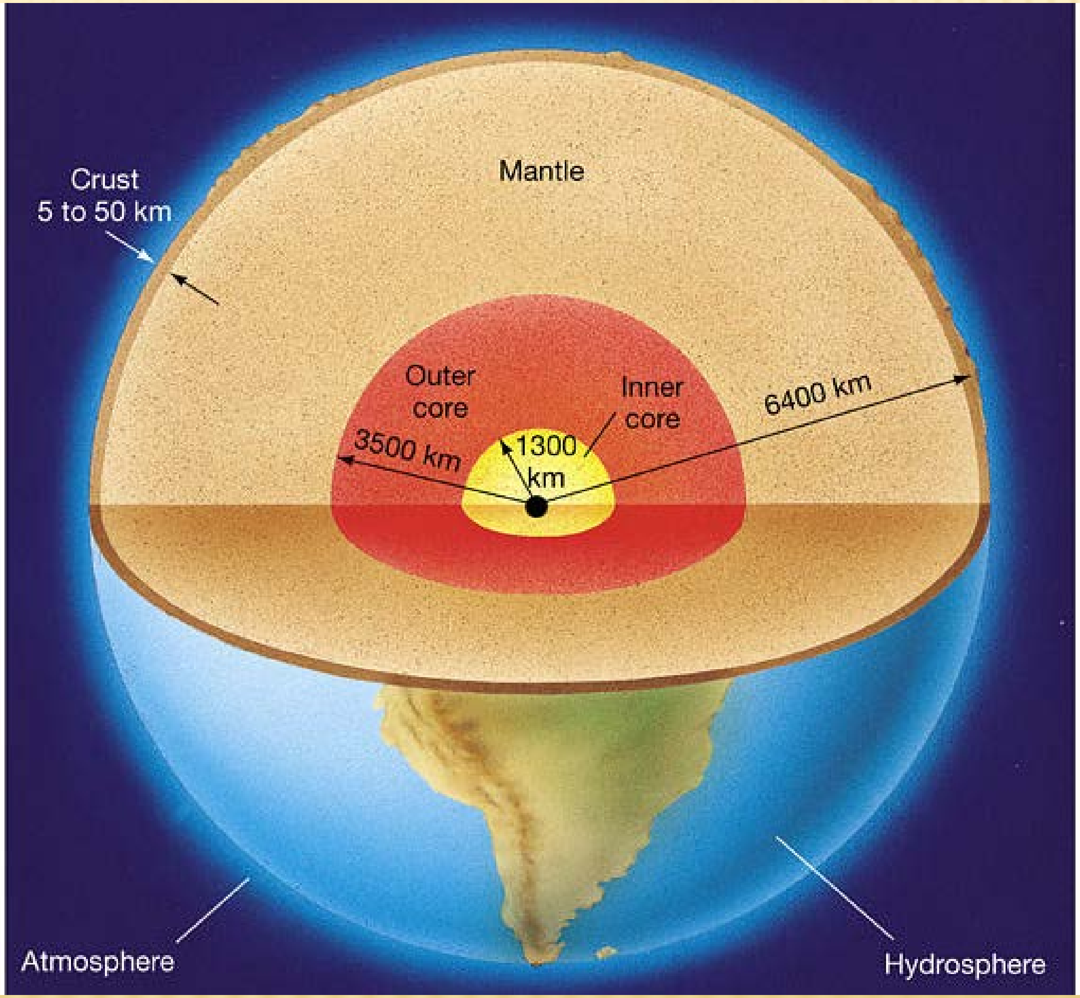


FORMATION OF THE EARTH

- The Earth is approximately 4.6 billion years old and is believed that it was formed by accretion of small particles.
- The Earth has a layered structure. The center is a dense, hot core composed mainly of iron and nickel .
- A thick mantle, composed mainly of solid rock, surrounds the core and contains 80 percent of the Earth's volume.
- The crust is a thin surface also composed of rock.



STRUCTURE OF THE EARTH



GEOLOGIC TIME

- The earth is estimated to be 4.6 Billion Years old.
- Geologic time differs from the human perspective of time.
- Earth goes through cycles of much longer duration than the human perspective of time.
- The geologic time scale is the calendar that geologists use to date past events in Earth's history.
- The Geological time scale is divided into **Eons, Eras, Periods, and Epochs** and is identified primarily by the types of life that existed at the various times.
- The two earliest eons, the Hadean and Archean, cover the first 2.5 billion years of Earth history.
- Life originated during Archean time and with the passage of time the life form evolved.
- Evolution was very gradual until the last 5 million years where many new species evolved which were more complex than their ancestors.

The Geological Time Scale

Eon	Era	Period	Epoch	m.y.
Phanerozoic	Cenozoic	Quaternary	Holocene	
			Pleistocene	1.5
		Neogene	Pliocene	
			Miocene	23
		Paleogene	Oligocene	
			Eocene	
			Paleocene	65
	Mesozoic	Cretaceous		
		Jurassic		
		Triassic		250
	Paleozoic	Permian		
		Carboniferous: Pennsylvanian		
		Carboniferous: Mississippian		
		Devonian		
		Silurian		
		Ordovician		
		Cambrian		540
Precambrian	Proterozoic			2500
	Archean			3800
	Hadean			4600

UNIT 2

MATTER AND MINERALS

ROCKS AND MINERALS

- A rock is any solid mass of mineral, or mineral-like, matter that occurs naturally as part of our planet.
- Most rocks, like the common rock granite, occur as aggregates of several different minerals.
- The term aggregate implies that the minerals are joined in such a way that their individual properties are retained.
- However, some rocks are composed almost entirely of one mineral.
- A common example is the sedimentary rock limestone, which consists of impure masses of the mineral calcite.

WHAT IS A MINERAL

- A mineral is a **naturally occurring, inorganic solid** with a **characteristic chemical composition** and a **crystalline structure**.

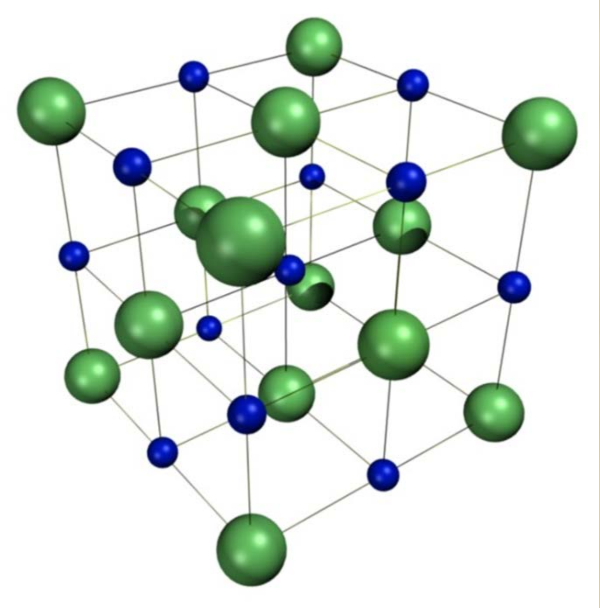
- Chemical composition and crystalline structure are the two most important properties of a mineral: They distinguish any mineral from all others.

WHAT ARE MINERALS

- Naturally occurring
  - Minerals form by natural, geologic processes.
  - Synthetic materials, meaning those produced in a laboratory or by human intervention, are not considered minerals.
- Solid substance
  - Only solid crystalline substances are considered minerals.
  - Ice (frozen water) fits this criterion and is considered a mineral, whereas liquid water and water vapor do not.
  - The exception is mercury, which is found in its liquid form in nature.

WHAT ARE MINERALS

- **Generally inorganic**
  - Minerals do not contain compounds of organic carbon.
  - Organic carbon which is found in all living organisms bonds with hydrogen to form compounds.
  - Inorganic carbon is formed when carbon combines with elements other than hydrogen.
  - Thus coal is not a mineral because it contains organic carbon derived from plant remains.
- **Orderly crystalline structure**
  - Minerals are crystalline substances, which means their atoms are arranged in an orderly, repetitive manner
  - This orderly packing of atoms is reflected in the regularly shaped objects called crystals.
  - To have a crystalline structure, a substance must be solid at at Earth's surface temperature and not in the liquid or gaseous phase.
  - Some naturally occurring solids, such as volcanic glass (obsidian), lack a repetitive atomic structure and are not considered minerals.



NaCl (Sodium Chloride)
HALITE

WHAT ARE MINERALS

- Can be represented by a chemical formula
  - Most minerals are chemical compounds having compositions that can be expressed by a chemical formula.
  - For example, the common mineral quartz has the formula SiO2, which indicates that quartz consists of silicon (Si) and oxygen (O) atoms in a ratio of one-to-two.
  - This proportion of silicon to oxygen is true for any sample of pure quartz, regardless of its origin.
  - However, the compositions of some minerals vary within specific, well-defined limits.
  - This occurs because certain elements can substitute for others of similar size without changing the mineral's internal structure.
  - An example is the mineral olivine in which either the element magnesium (Mg) or the element iron (Fe) may occupy the same site in the crystal structure.
  - Therefore, olivine's formula, (Mg, Fe)2SiO4, expresses variability in the relative amounts of magnesium and iron. However, the ratio of magnesium plus iron to silicon (Si) and oxygen (O) remains fixed at 2:1:4.

ELEMENTS & ATOM

- An element cannot be broken into simpler particles by ordinary chemical processes.

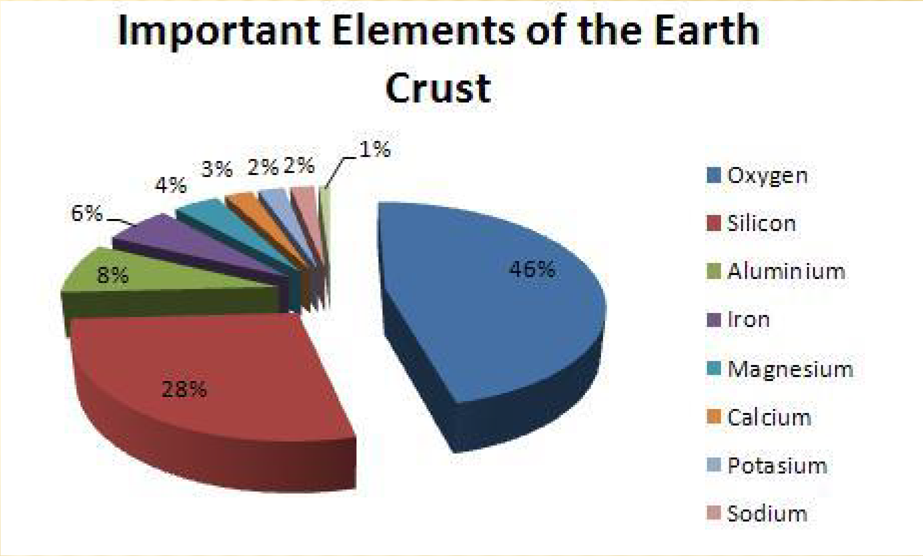
- Most common minerals consist of a small number—usually two to five of different chemical elements

ROCKS – MINERALS – ELEMNTS - ATOMS

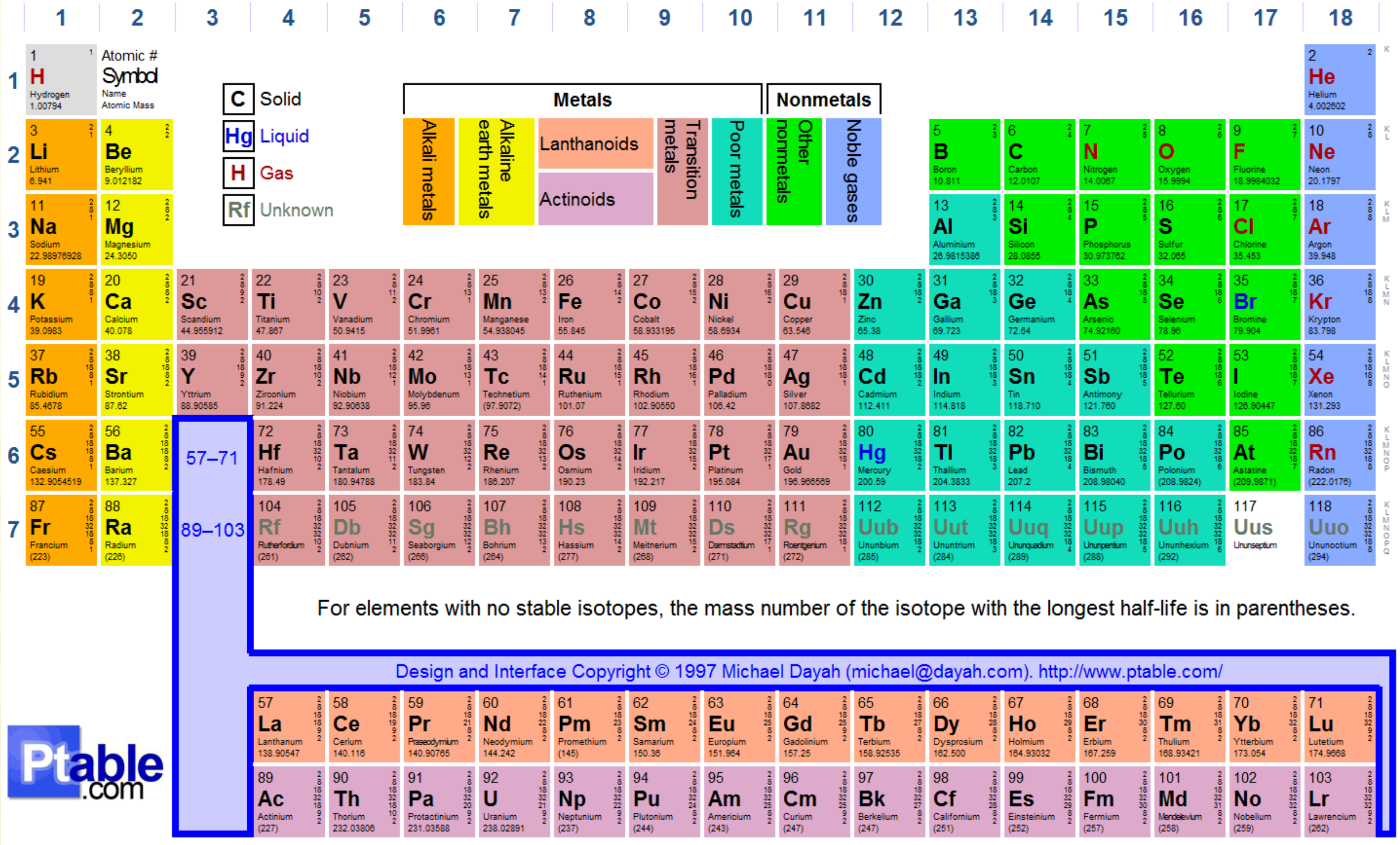
COMMON ELEMENTS

- A total of 91 elements occur naturally in the Earth's crust. However, eight elements make up more than 98 percent of the earth's crust. These elements are

- Oxygen,
- Silicon,
- Aluminum,
- Iron,
- Calcium,
- Magnesium,
- Potassium and
- Sodium



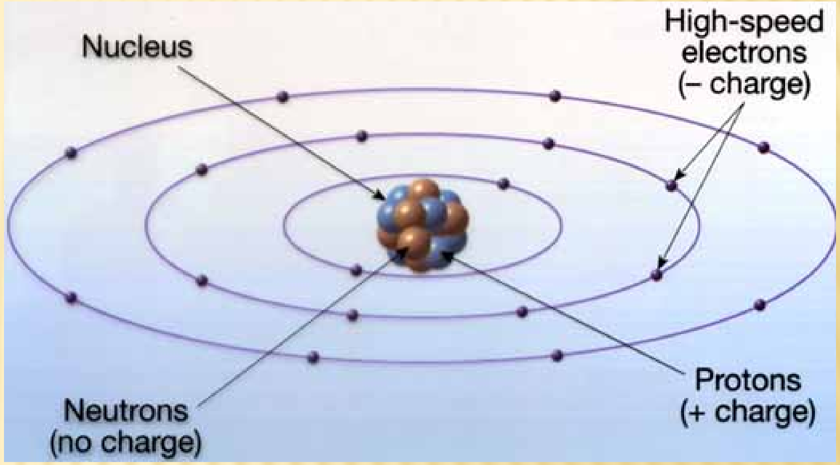
THE PERIODIC TABLE

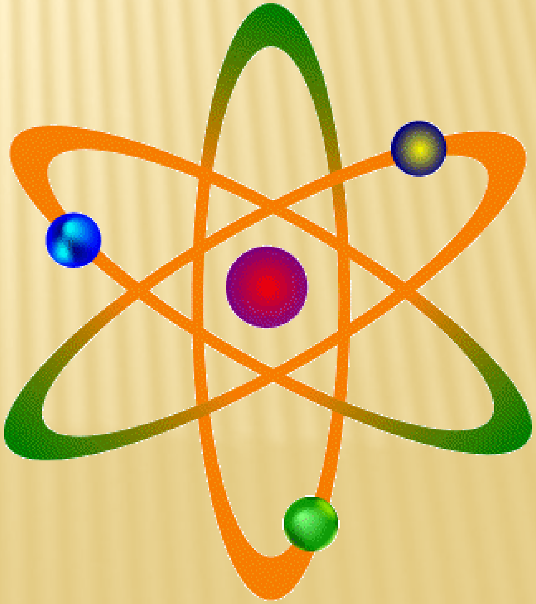


As of June 2011, the periodic table includes 118 chemical elements whose discoveries have been confirmed. Of these, 91 are regularly occurring primordial or recurrently produced elements found naturally on the Earth,

STRUCTURE OF AN ATOM

- An atom is the basic unit of an element.
- An atom is tiny; the diameter of the average atom is about 10^{-10} meters.
- An atom consists of a small, dense, positively charged center called a Nucleus .
- The Nucleus contains dense particles with positive electric charge known as Protons .
- and equally dense particles with neutral electric charges know as Neutrons.
- The nucleus is surrounded by negatively charged Electrons.
- An electron is a fundamental particle; it is not made up of smaller components. An electron orbits the nucleus, but not in a clearly defined path.



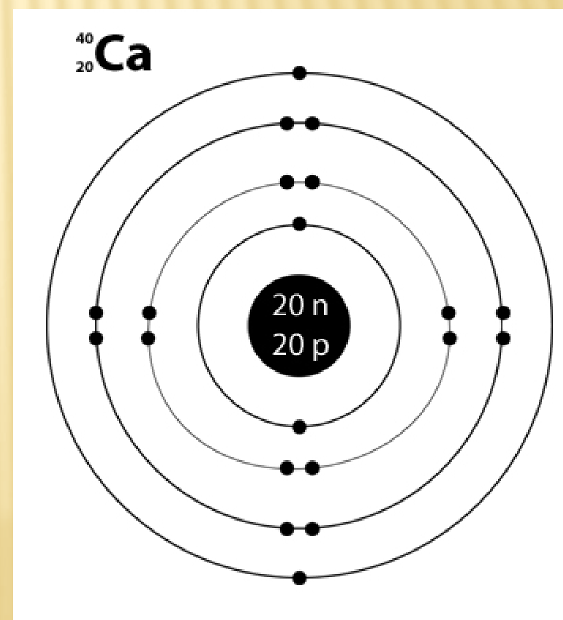


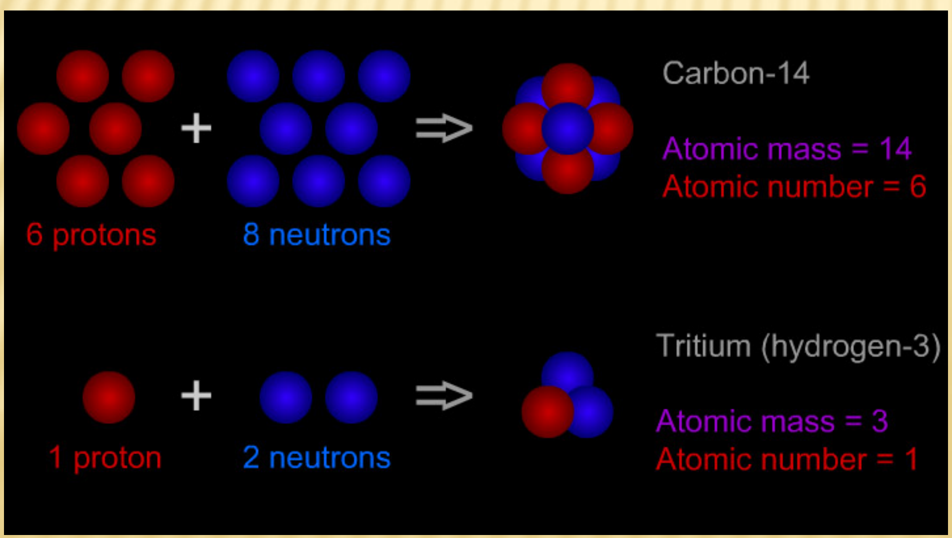
ATOMIC MASS AND NUMBER

- In its normal state an atom is electrically neutral as the number of protons(+ charge) is always equal to the number of electrons (- charge)

- Atomic weight/mass of an atom is equal to the total number of Neutrons + Protons

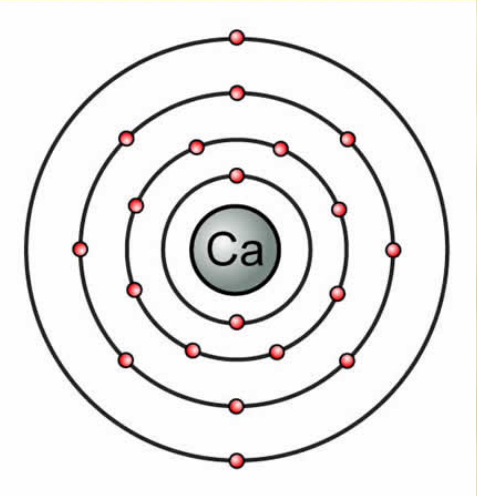
- Atomic Number of an atom is equal to its number of Proton or Electron.

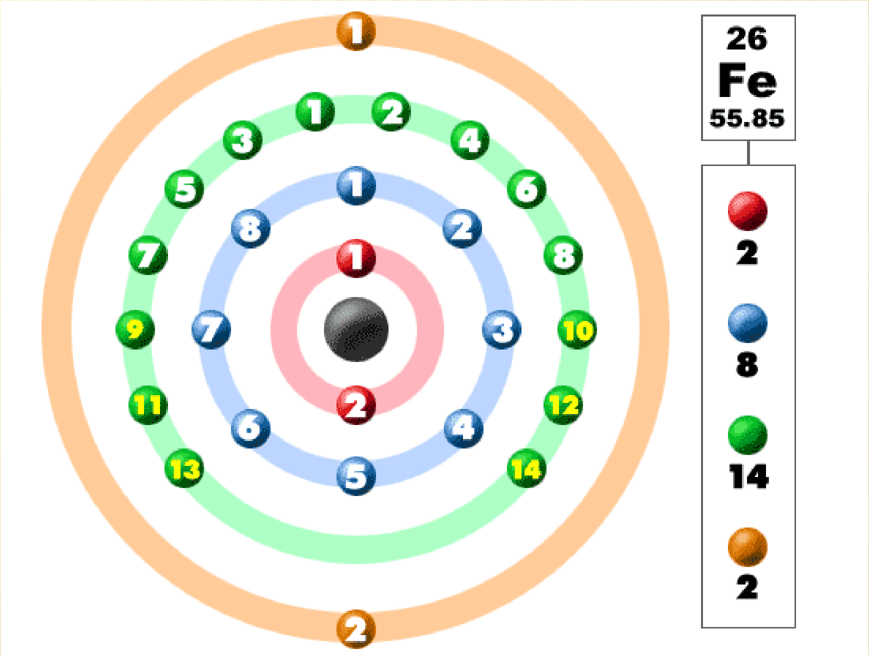




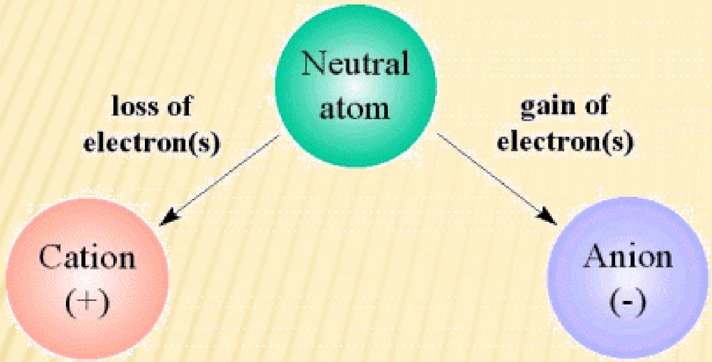
IONS

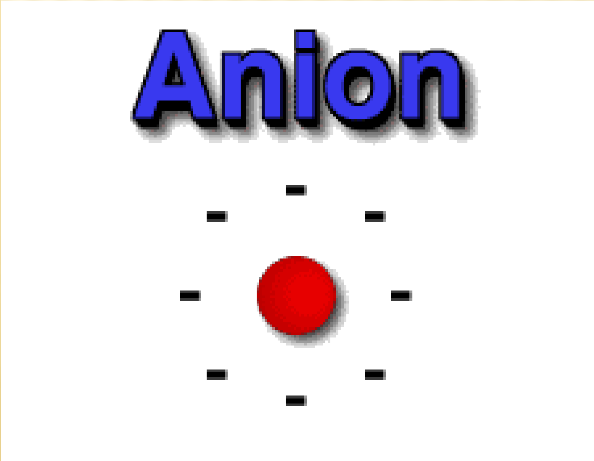
- Electrons concentrate in spherical layers or **shells** around the nucleus.
- Each shell can hold a certain number of electrons.
- An atom is completely stable when its outermost shell is completely fill with electrons.
- However in their neutral states most atoms do not have a filled outer shell.
- The atoms can loose or gain an electron to make its outer shell complete.
- When an atom loses one or more electrons, its protons outnumber its electrons and it develops a positive charge.
- If an atom gains one or more extra electrons, it becomes negatively charged.
- A charged atom is called an **Ion**.





IONS





- A positively charged ion is a Cation. (Na^+).
- Atom with a negative charge is called Anion, (Cl^-).
- Atoms and ions rarely exist independently. Instead, they unite to form Compounds. (NaCl).
- The forces that hold atoms and ions together to form compounds are called chemical bonds.

ELECTRON PATTERN FOR THE FIRST 20 ELEMENTS

Element	Symbol	Atomic Number	Number of Electrons in Each shell			
			First (2 is stable)	Second (8 is stable)	Third (8 is stable)	Fourth (8 is stable)
Hydrogen	H	1	1			
Helium	He	2	2			
Lithium	Li	3	2	1		
Beryllium	Be	4	2	2		
Boron	B	5	2	3		
Carbon	C	6	2	4		
Nitrogen	N	7	2	5		
Oxygen	O	8	2	6		
Fluorine	F	9	2	7		
Neon	Ne	10	2	8		
Sodium	Na	11	2	8	1	
Magnesium	Mg	12	2	8	2	
Aluminum	Al	13	2	8	3	
Silicon	Si	14	2	8	4	
Phosphorus	P	15	2	8	5	
Sulfur	S	16	2	8	6	
Chlorine	Cl	17	2	8	7	
Argon	Ar	18	2	8	8	
Potassium	K	19	2	8	8	1
Calcium	Ca	20	2	8	8	2

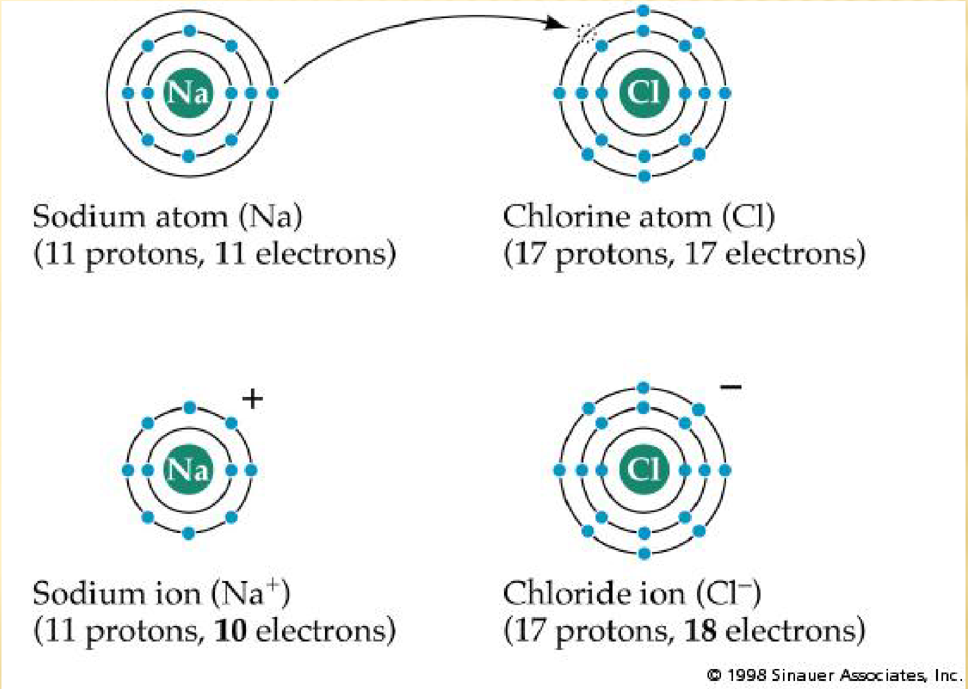
CHEMICAL BONDS

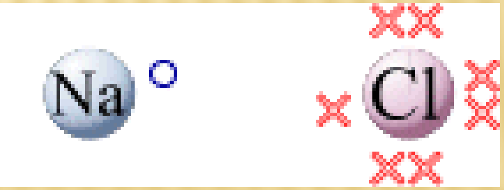
- Four types of chemical bonds are found in minerals:

1. Ionic,
2. Covalent
3. Metallic
4. Van der Waals forces

IONIC BONDS

- Cations and anions are attracted by their opposite electronic charges and thus bond together.
- This union is called an **ionic bond.**
- An ionic compound (made up of two or more ions) is neutral because the positive and negative charges balance each other.
- For example, when sodium and chlorine form an ionic bond, the sodium atom loses one electron to become a cation and chlorine gains one to become an anion.
- When they combine, the +1 charge balances the -1 charge





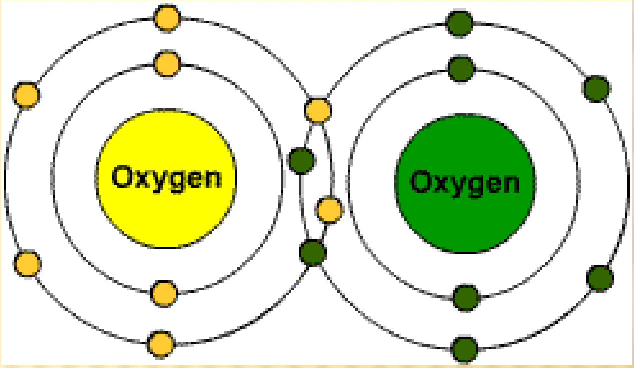
COVALENT BONDS

- Not all atoms combine by transferring electrons to form ions.

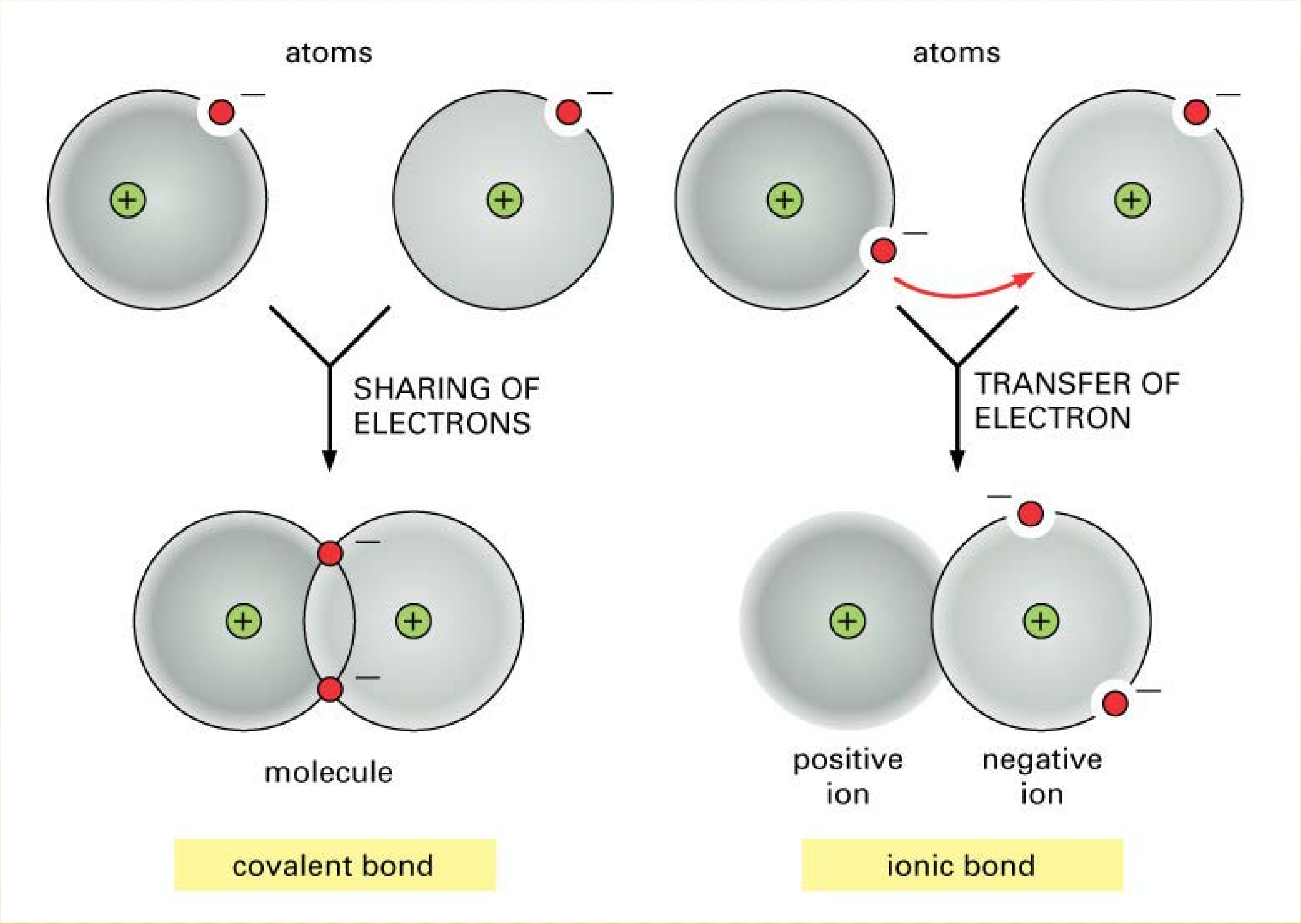
- Other atoms share electrons.

- A covalent bond develops when two or more atoms share their electrons to produce the effect of filled outer electron shells.

- For example the gaseous elements Oxygen,O_2; Hydrogen,H_2 and Chlorine, Cl_2 exist as stable molecules consisting of two atoms bonded together by sharing their valence electrons

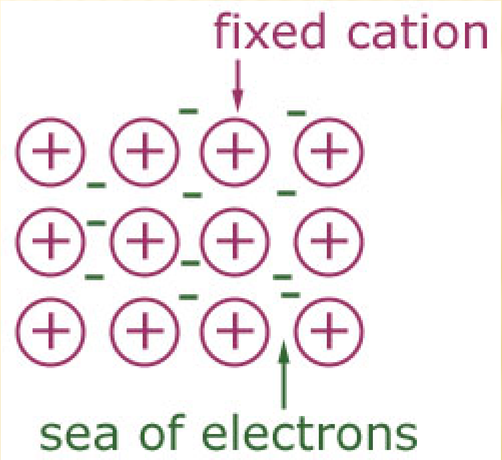


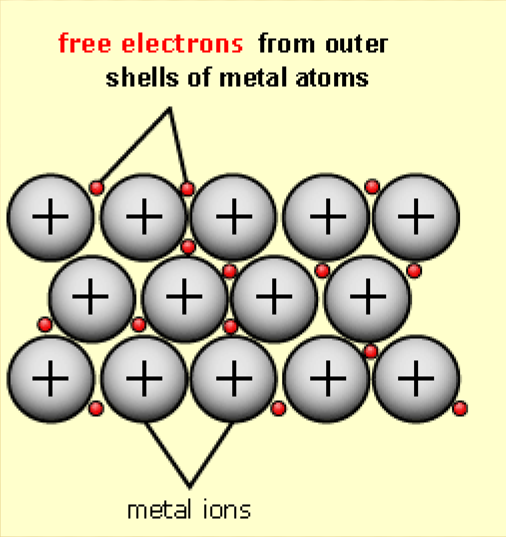
IONIC AND COVALENT BONDS



METALLIC BONDS

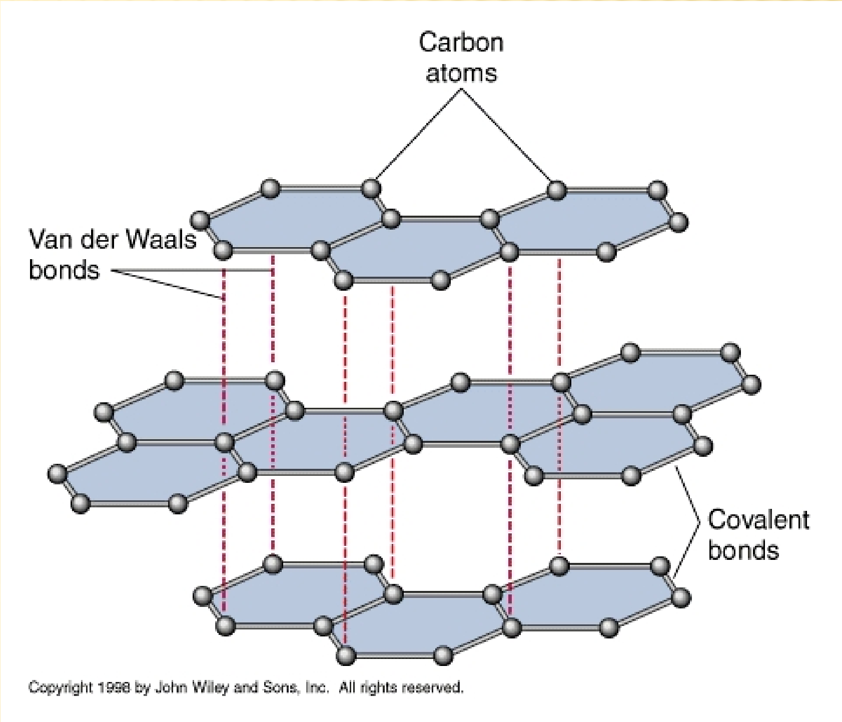
- In a metallic bond, the outer electrons are loose; that is, they are not associated with particular atoms.
- This arrangement allows the nuclei to pack together as closely as possible, resulting in the characteristic high density of metals and metallic minerals, such as pyrite.
- Because the electrons are free to move through the entire crystal, metallic minerals are excellent conductors of electricity and heat.





VAN DER WAALS FORCES

- Weak electrical forces called van der Waals forces also bond molecules together.
- These weak bonds result from an uneven distribution of electrons around individual molecules, so that one portion of a molecule may have a greater density of negative charge while another portion has a partial positive charge.
- Because van der Waals forces are weak, minerals in which these bonds are important, such as talc and graphite, tend to be soft and cleave easily along planes of van der Waals bonds.



GRAPHITE

MATTER AND MINERALS

- Most minerals are **compounds.**
- When ions bond together to form a mineral, they do so in proportions so that the total number of negative charges exactly balances the total number of positive charges.
- Thus, minerals are always electrically **neutral.**

MATTER AND MINERALS

- The composition of a mineral can be expressed as a chemical formula, which is written by combining the symbols of the individual elements.

Quartz (SiO_2)

Calcite (CaCO3)

MATTER AND MINERALS

- A few minerals, such as gold and silver, consist of only a single element. Their chemical formulas, respectively, are Au (the symbol for gold) and Ag (the symbol for silver).
- Most minerals, however, are made up of two to five essential elements.
- For example, the formula of quartz is SiO_2: It consists of one atom of silicon (Si) for every two of oxygen (O). The chemical composition of Quartz is uniform throughout the universe and this is one of the main criteria for a substance to be called as a mineral.

MATTER AND MINERALS

- The 91 elements that occur naturally in the Earth's crust can combine in many ways to form many different minerals.
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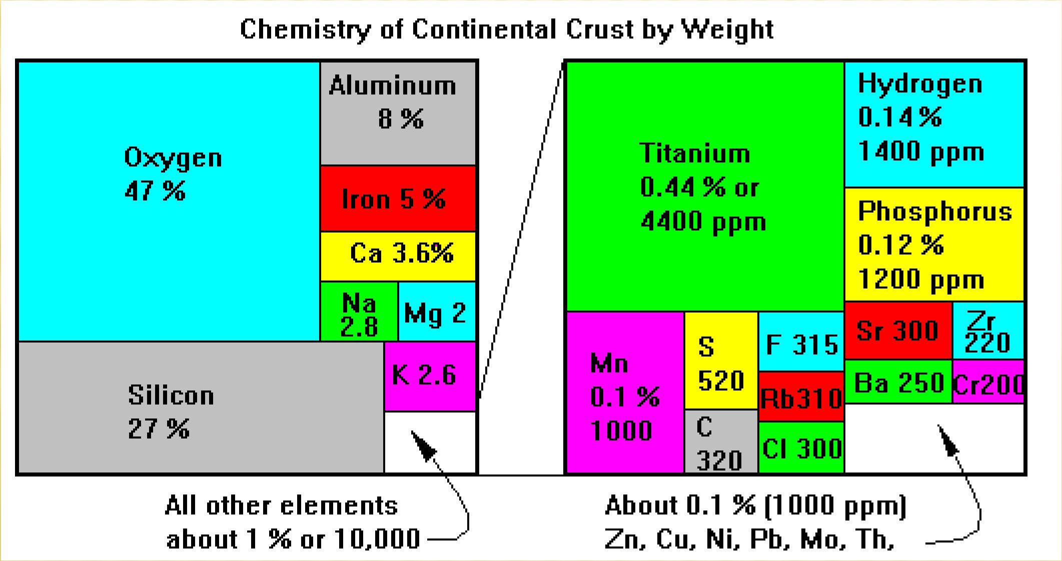
- However, the eight abundant elements commonly combine in only a few ways.
- As a result, only nine rock forming minerals (or mineral "groups") make up most rocks of the Earth's crust.



- They are

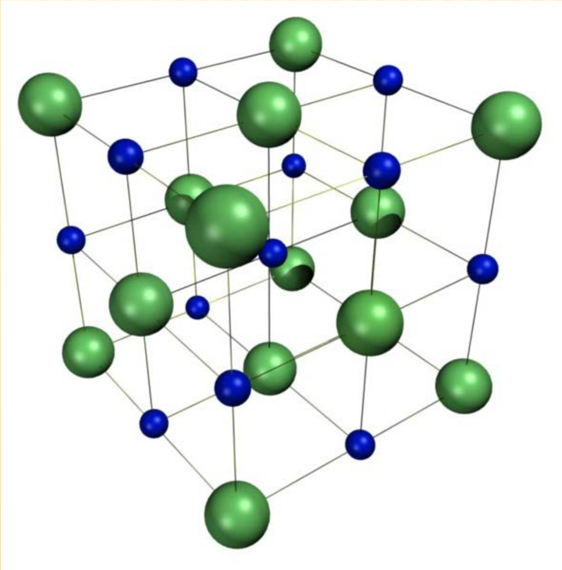
1. Olivine,
2. Pyroxene,
3. Amphibole,
4. Mica,
5. Clays,
6. Quartz,
7. Feldspar,
8. Calcite, and
9. Dolomite.

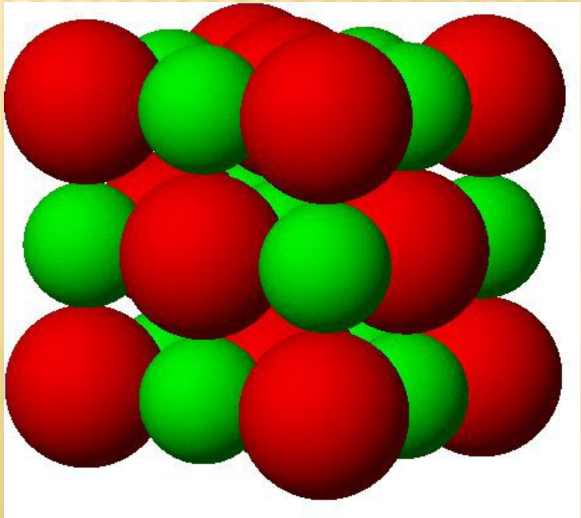
CRYSTALS

- A crystal is any substance whose atoms are arranged in a regular, periodically repeated pattern.

- All minerals are crystalline.

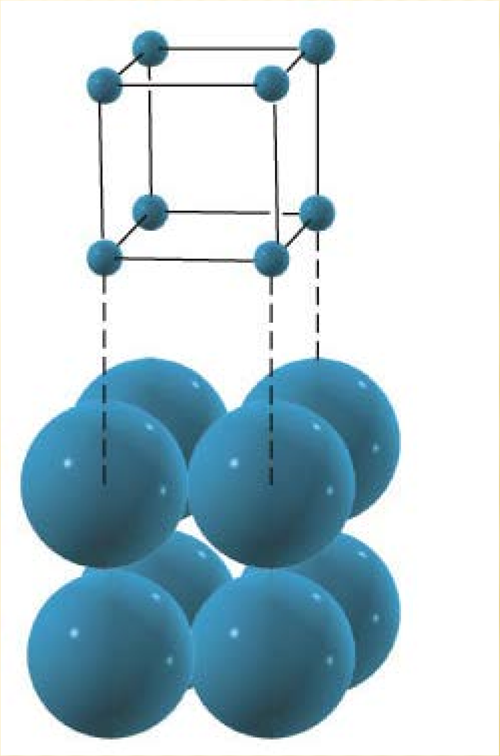
- The mineral halite (common table salt) has the composition NaCl: one sodium ion (Na+) for every chlorine ion (Cl-).

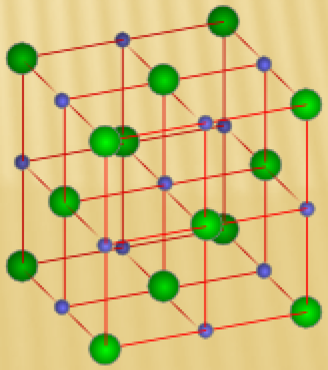




UNIT CELL

- The sodium and chlorine ions alternate in orderly rows and columns intersecting at right angles.
- This arrangement is the crystalline structure of halite.
- In every crystal, a small group of atoms, like a single brick in a wall, repeats itself over and over. This small group of atoms is called a unit cell.





CRYSTAL FACE

- A crystal face is a planar surface that develops if a crystal grows freely in an uncrowded environment.
- In nature, the growth of crystals is often impeded by adjacent minerals that are growing simultaneously or that have formed previously.
- For this reason, minerals rarely show perfect development of crystal faces.

PHYSICAL PROPERTIES OF MINERALS

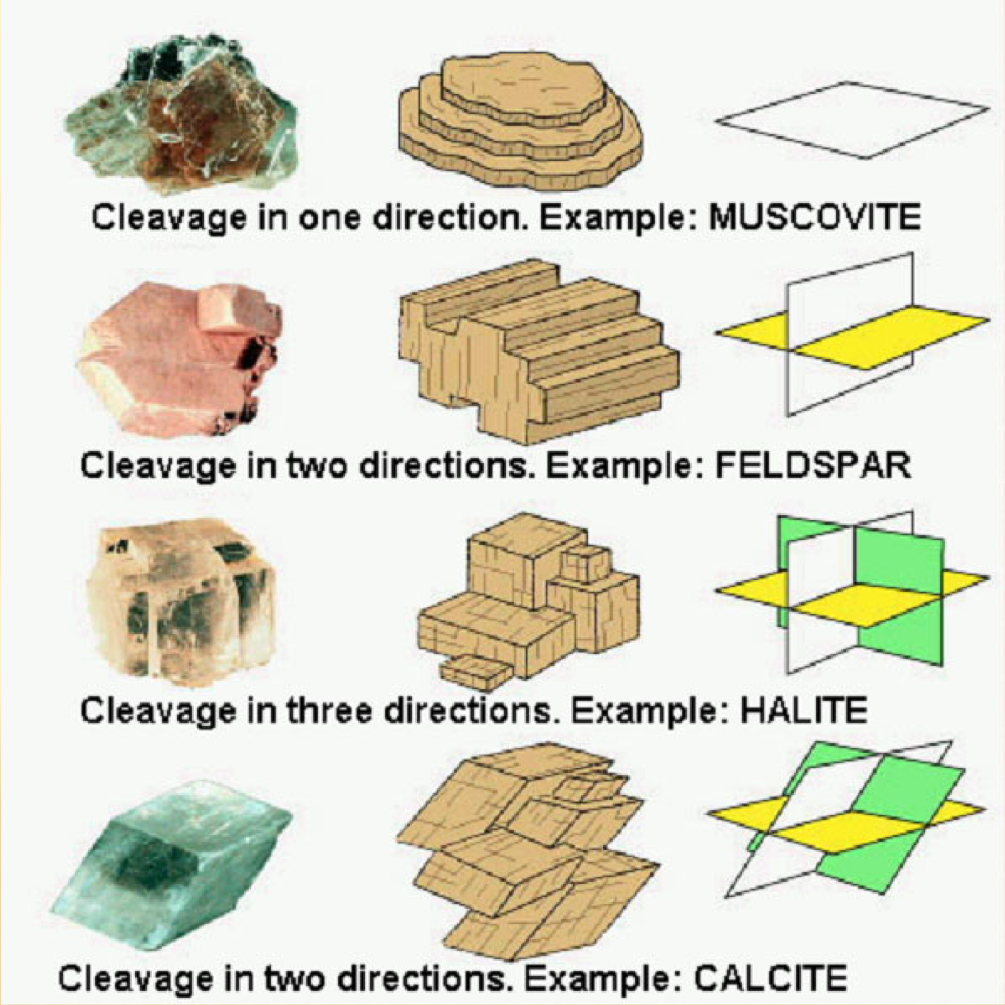
1. Crystal habit
2. Cleavage
3. Fracture
4. Hardness
5. Specific gravity
6. Color
7. Streak
8. Luster

CRYSTAL HABIT

- Crystal habit is the characteristic shape of a mineral and the manner in which aggregates of crystals grow.
- If a crystal grows freely, it develops a characteristic shape controlled by the arrangement of its atoms, as in the cubes of halite. Some minerals such as Quartz occur in more than 1 different crystal habits.
- When crystal growth is obstructed by other crystals, a mineral cannot develop its characteristic habit. They form interlocking texture because some crystals grew around others as the magma solidified.

CLEAVAGE

- Cleavage is the tendency of some minerals to break along flat surfaces.
- The surfaces are planes of weak bonds in the crystal. Some minerals, such as mica and graphite, have one set of parallel cleavage planes. Others have two, three, or even four different sets.
- Many minerals have no cleavage at all because they have no planes of weak bonds.
- A flat surface created by a cleavage and a crystal face can appear identical as both are smooth and flat, however a cleavage plane is duplicated when the sample is broken whereas the crystal face is not.

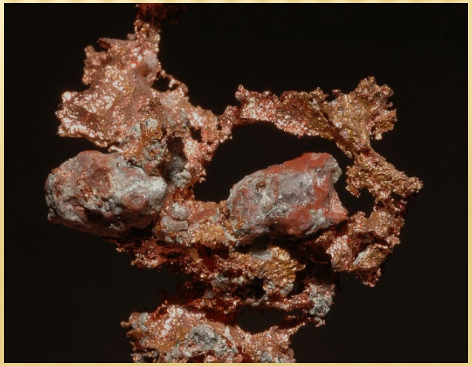


FRACTURE

- Fracture is the pattern in which a mineral breaks other than along planes of cleavage.
- Many minerals fracture into characteristic shapes.
- Conchoidal fracture creates smooth, curved surfaces. It is characteristic of quartz and olivine.
- Some minerals break into splintery or fibrous fragments.
- Most fracture into irregular shapes.

Conchoidal Fracture

Splintery Fracture


Jagged Fracture

SPECIFIC GRAVITY

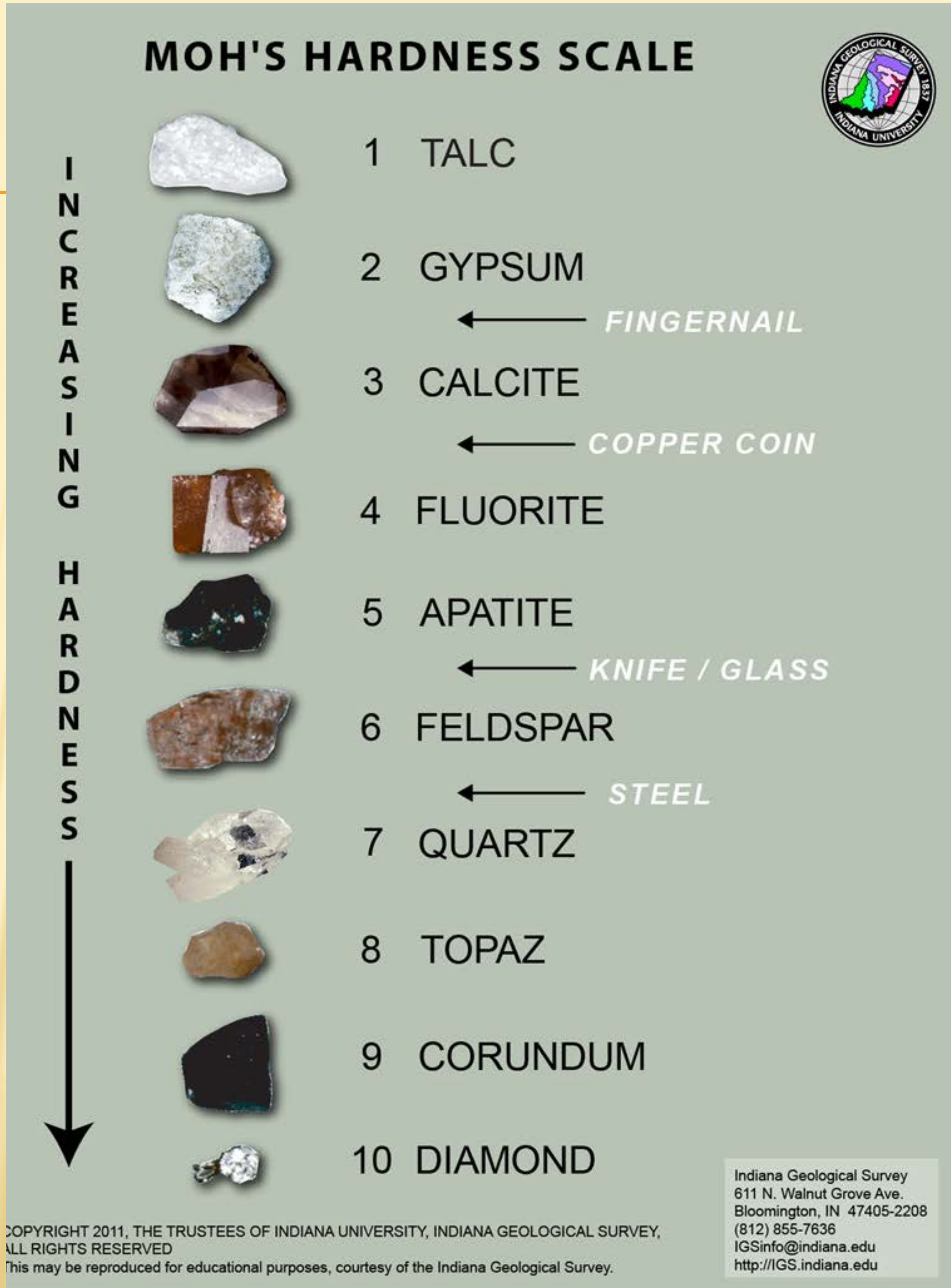
- Specific gravity is the weight of a substance in air divided by the weight of an equal volume of water.
- If a mineral weighs 2.5 times as much as an equal volume of water, its specific gravity is 2.5.
- Most common minerals have specific gravities of about 2.7.
- Metals have much greater specific gravities; for example, gold has the highest specific gravity of all minerals, 19.3. Lead is 11.3, silver is 10.5, and copper is 8.9.

HARDNESS

- Hardness is the resistance of a mineral to scratching.
- It is easily measured and is a fundamental property of each mineral because it is controlled by bond strength between the atoms in the mineral.
- Geologists commonly use a knife or other object of known hardness.
- If the blade scratches the mineral, the mineral is softer than the knife. If the knife cannot scratch the mineral, the mineral is harder.

HARDNESS

- To measure hardness more accurately, geologists use a scale based on ten minerals, numbered 1 through 10.
- Each mineral is harder than those with lower numbers on the scale, so 10 (diamond) is the hardest and 1 (talc) is the softest.
- The scale is known as the Mohs hardness scale after F. Mohs, the Austrian mineralogist who developed it in the early nineteenth century.

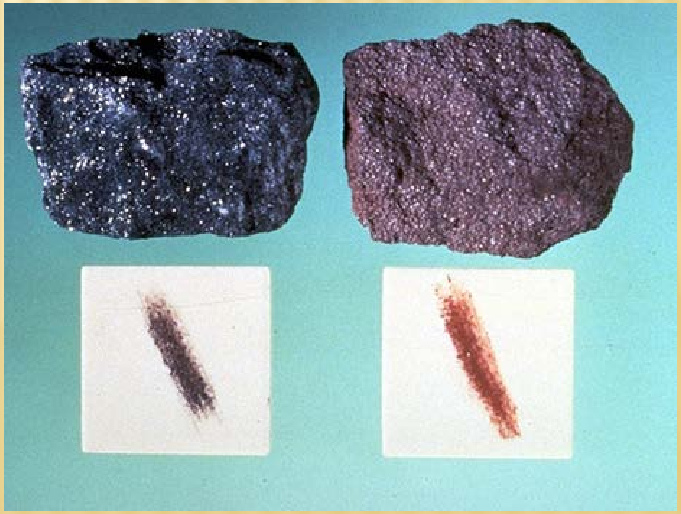


COLOR

- Color is the most obvious property of a mineral, but it is commonly unreliable for identification.
- Color would be a reliable identification tool if all minerals were pure and had perfect crystal structures.
- However, both small amounts of chemical impurities and imperfections in crystal structure can dramatically alter color.

STREAK

- Streak is the color of a fine powder of a mineral.
- It is observed by rubbing the mineral across a piece of unglazed porcelain known as a streak plate.
- Many minerals leave a streak of powder with a diagnostic color on the plate.
- Streak is commonly more reliable than the color of the mineral itself for identification.



LUSTER

- Luster is the manner in which a mineral reflects light.
- A mineral with a metallic look, irrespective of color, has a metallic luster.
- The luster of nonmetallic minerals is usually described by self-explanatory words such as glassy, pearly, earthy, and resinous.

TYPES OF MINERALS

- Although about 3500 minerals are known to exist in the Earth's crust, only a small number – between 50 and 100 are important because they are common or valuable. These minerals can be grouped into 5 categories. They include
- Rock Forming Minerals
- Accessory minerals
- Gem
- Ore minerals
- Industrial Minerals

ROCK FORMING MINERALS

- **Rock Forming Minerals** make up the bulk of most rocks in the Earth's crust.

- They are important to geologists simply because they are the most common minerals. They include

1. olivine,
2. pyroxene,
3. amphibole,
4. mica,
5. the clay minerals,
6. feldspar,
7. quartz,
8. Calcite and
9. dolomite

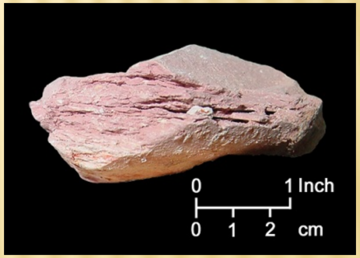

Olivine


Pyroxene


Mica


Amphibole


Quartz



Clay minerals


Dolomite


Feldspar


Calcite

ACCESSORY MINERALS

- **Accessory minerals** are minerals that are common but usually are found only in small amounts.

- Chlorite, garnet, hematite, limonite, magnetite, and pyrite are common accessory minerals.

Garnet

Chlorite

GEMS

- A gem is a mineral that is prized primarily for its beauty, although some gems, like diamonds, are also used industrially.
- Depending on its value, a gem can be either precious or semiprecious.
- Precious gems include diamond, emerald, ruby, and sapphire. Several varieties of quartz, including amethyst, agate, jasper, and tiger's eye, are semiprecious gems.

Diamond

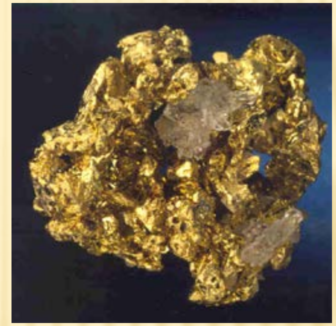
Ruby

Sapphire

Emerald

ORE MINERALS

- Ore minerals are minerals from which metals or other elements can be profitably recovered. A few, such as native gold and native silver, are composed of a single element.
- However, most metals are chemically bonded to anions.
- Copper, lead, and zinc are commonly bonded to sulfur to form the important ore minerals chalcopyrite, galena.


Gold


Silver


Galena


Pyrite


Chalcopyrite

ORE MINERALS

- Argentite: Ag_2S for production of silver
- Barite: $BaSO_4$
- Bauxite Al_2O_3 for production of aluminium
- Beryl: $Be_3Al_2(SiO_3)_6$
- Bornite: Cu_5FeS_4
- Cassiterite: SnO_2
- Chalcocite: Cu_2S for production of copper
- Chalcopyrite: $CuFeS_2$
- Chromite: $(Fe, Mg)Cr_2O_4$ for production of chromium
- Cinnabar: HgS for production of mercury
- Cobaltite: (Co, Fe)AsS
- Columbite-Tantalite or Coltan: $(Fe, Mn)(Nb, Ta)_2O_6$
- Galena: PbS
- Gold: Au, typically associated with quartz or as placer deposits
- Hematite: Fe_2O_3
- Ilmenite: $FeTiO_3$
- Magnetite: Fe_3O_4
- Molybdenite: MoS_2
- Pentlandite:$(Fe, Ni)_9S_8$
- Pyrolusite:MnO_2
- Scheelite: $CaWO_4$
- Sphalerite: ZnS
- Uraninite (pitchblende): UO_2 for production of metallic uranium
- Wolframite: $(Fe, Mn)WO_4$

INDUSTRIAL MINERALS

- **Industrial Minerals** are industrially important, although they are not considered ore because they are mined for purposes other than the extraction of metals.
- Halite is mined for table salt, and gypsum is mined as the raw material for plaster and sheetrock.
- Apatite and other phosphorus minerals are sources of the phosphate fertilizers crucial to modern agriculture.
- Many limestones are made up of nearly pure calcite and are mined as the raw material of cement.

Apatite

Halite

Limestone

MINERAL CLASSIFICATION

- Minerals are classified according to their anions i.e. the negatively charged ions.

- Anions can be either simple or complex. A simple anion is a single negatively charged ion, such as O^{2-}.

- Alternatively, two or more atoms can bond firmly together and acquire a negative charge to form a complex anion. Two common examples are the silicate, $(SiO4)^{4}$-, and carbonate, $(CO3)^{2}$-.

- Each mineral group (except the native elements) is named for its anion. For example, the oxides all contain O^{2-}, the silicates contain $(SiO4)^{4}$-, and the carbonates contain $(CO3)^{2}$-.

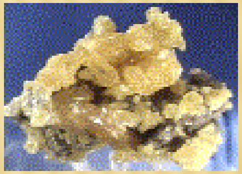
MAJOR MINERAL GROUPS

Mineral Classes	Chemical Makeup
Silicates	Contain silicon (Si) and oxygen (O) at least
Carbonates	CO_3 plus metal(s)
Sulfates	SO_4 plus metal(s)
Sulfides	S plus metal(s)
Oxides	O plus metal(s) without other nonmetals or metalloids (no Si, C, P, S, V, or W)
Hydroxides	OH plus metal(s) without other nonmetals or metalloids
Phosphates	PO_4 plus metal(s)
Halides	F, Cl, Br, or I plus metal(s) without other nonmetals or metalloids
Native elements	Occur in elemental form (one element only)

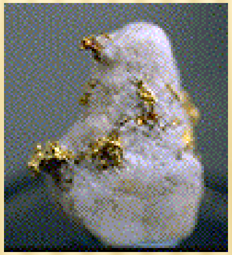
NATIVE ELEMENTS

- About 20 elements occur naturally in their native states as minerals.
- Fewer than ten, however, are common enough to be of economic importance.
- Gold, silver, platinum, and copper are all mined in their pure forms.
- Pure carbon occurs as both graphite and diamond.
- The minerals have identical compositions but different crystalline structures and are called polymorphs.
- Graphite is one of the softest minerals and is opaque and an electrical conductor.
- Diamond, the hardest mineral known, is transparent and an electrical insulator.

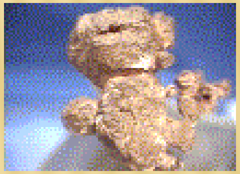
Diamond



Sulfur



Gold

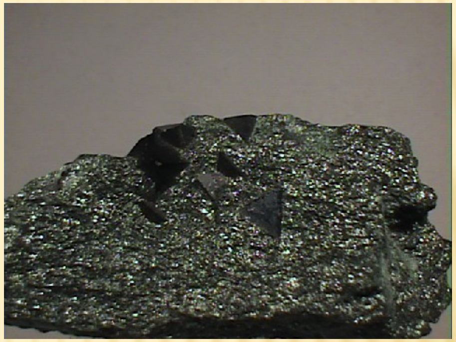


Copper

Platinum

OXIDES

- The oxides are a large group of minerals in which oxygen is combined with one or more metals.
- Oxide minerals are the most important ores of iron, manganese, tin, chromium, uranium, titanium, and several other industrial metals.
- Hematite (iron oxide, Fe_2O_3) occurs widely in many types of rocks and is the most abundant ore of iron.
- Magnetite (Fe_3O_4), a naturally magnetic iron oxide, is another ore of iron.



Magnetite

Haematite

Rutile

SULFIDES

- Sulfide minerals consist of sulfur combined with one or more metals.
- Many sulfides are extremely important ore minerals.
- They are the world's major sources of copper, lead, zinc, molybdenum, silver, cobalt, mercury, nickel, and several other metals.
- The most common sulfides are pyrite (FeS_2), chalcopyrite ($CuFeS_2$), galena (PbS), and sphalerite (ZnS).

Pyrite

Chalcopyrite

Galena

Sphalerite

SULFATES

- The sulfate minerals contain the sulfate complex anion $(SO_4)^{2-}$.
- Gypsum ($CaSO4.\ 2H_2O$) and anhydrite ($CaSO_4$) are two important industrial sulfates used to manufacture plaster and sheetrock.
- Both form by evaporation of seawater or salty lake water.

Gypsum

Anhydrite

PHOSPHATES

- Phosphate minerals contain the complex anion $(PO_4)^{3-}$.
- Apatite, $Ca_5(F,Cl,OH)(PO_4)^{3-}$, is the substance that makes up both teeth and bones. Phosphate is an essential fertilizer in modern agriculture.

Apatite

CARBONATES

- The complex carbonate anion $(CO_3)^{2-}$ is the basis of two common rock-forming minerals, calcite ($CaCO_3$) and dolomite [$CaMg(CO_3)_2$].
- Limestone is mined as a raw ingredient of cement.
- Aragonite is a polymorph of calcite that makes up the shells of many marine animals.

Limestone

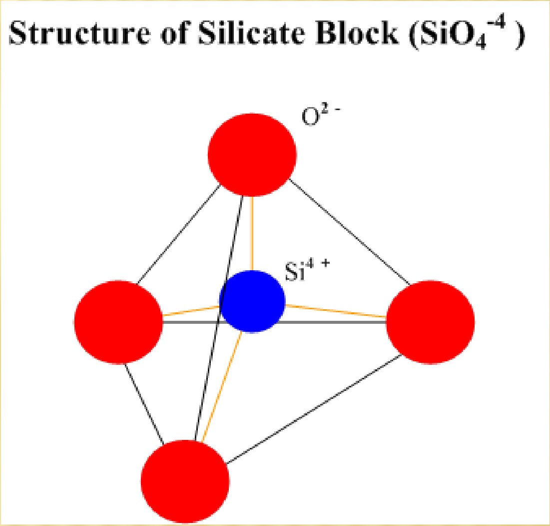
Dolomite

Aragonite

SILICATES

- The silicate minerals contain the $(SiO_4)^{4-}$ complex anion. Silicates make up about 95 percent of the Earth's crust.

- They are abundant for two reasons.
  - First, silicon and oxygen are the two most abundant elements in the crust.
  - Second, silicon and oxygen combine readily.



SILICATE MINERALS

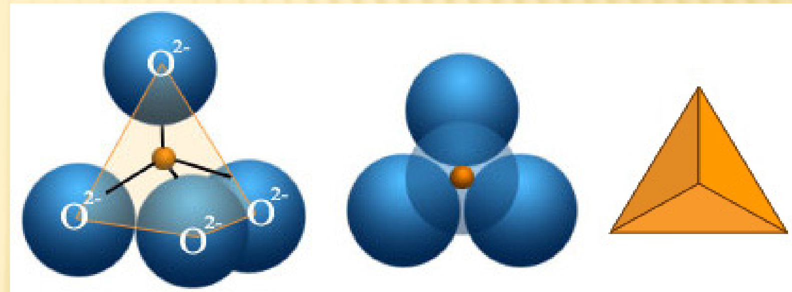
- Every silicon atom surrounds itself with four oxygens. The bonds between each silicon and its four oxygens are very strong.

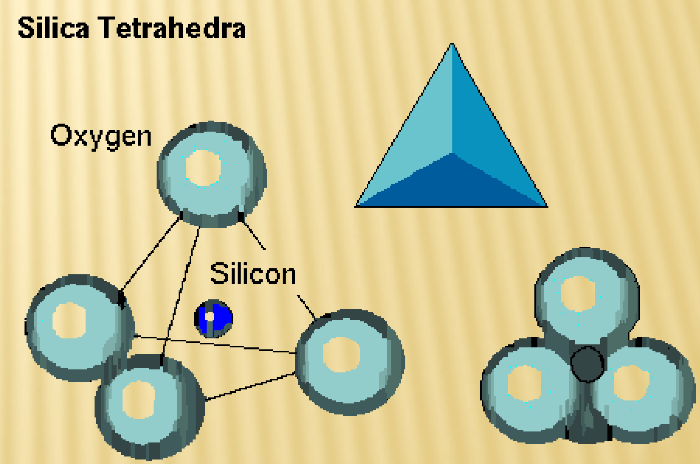
- The silicon atom and its four oxygens form a pyramid-shaped structure called the silicate tetrahedron with silicon in the center and oxygens at the four corners.

- The silicate tetrahedron has a 4- charge and forms the $(SiO_4)^{4-}$ complex anion. The silicate tetrahedron is the fundamental building block of all silicate minerals.

- To make silicate minerals electrically neutral, other cations must combine with the silicate tetrahedra to balance their negative charges.

- Silicate tetrahedra commonly link together by sharing oxygens. Thus, two tetrahedra may share a single oxygen, bonding the tetrahedra together.

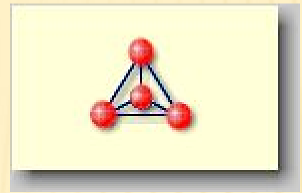


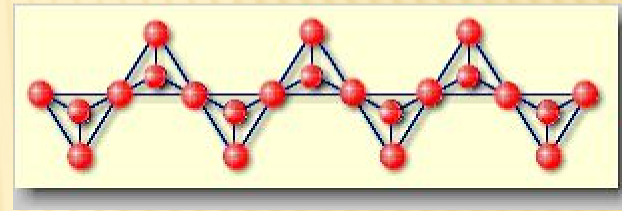


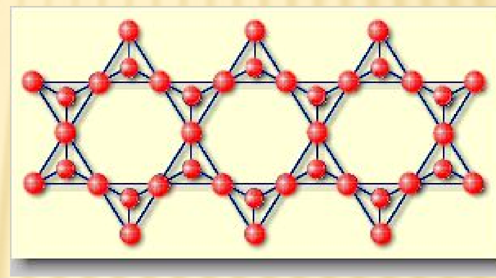
ROCK FORMING SILICATE MINERALS

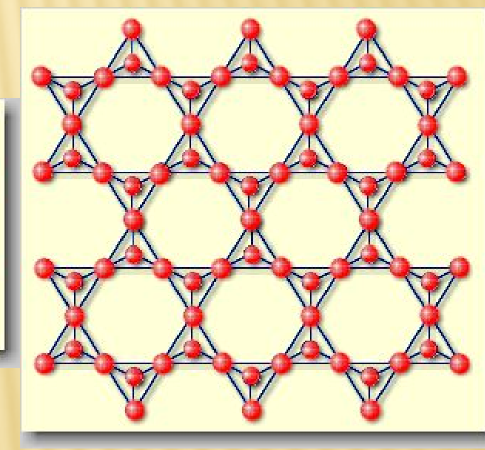
- The rock-forming silicates (and most other silicate minerals) fall into five classes, based on five ways in which tetrahedra share oxygens.

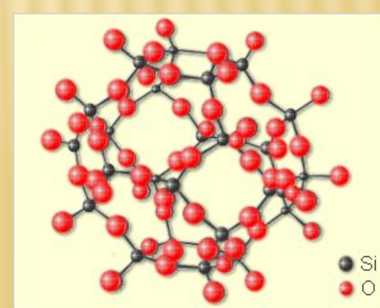
- Each class contains at least one of the rock-forming mineral groups.







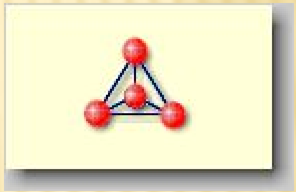




SILICATE MINERALS

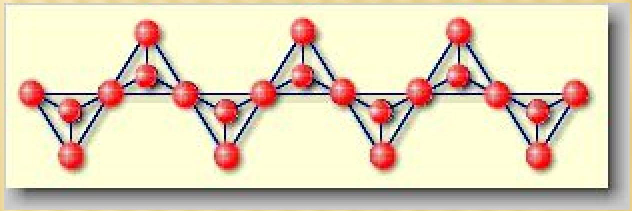
- In independent tetrahedra silicates, adjacent tetrahedral do not share oxygens.

- Olivine is an independent tetrahedra mineral that occurs in small quantities in basalt of both continental and oceanic crust .



- Mantle is composed mainly of Olivine and Pyroxenes

- In the single-chain silicates, each tetrahedron links to two others by sharing oxygens, forming a continuous chain of tetrahedral.



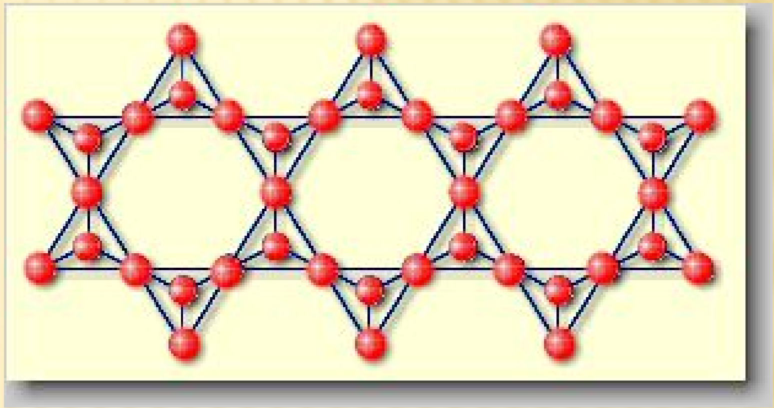
- The pyroxenes are a group of similar minerals with single chain structures.

- Pyroxenes are a major component of both oceanic crust and the mantle and are also abundant in some continental rocks.

SILICATE STRUCTURE

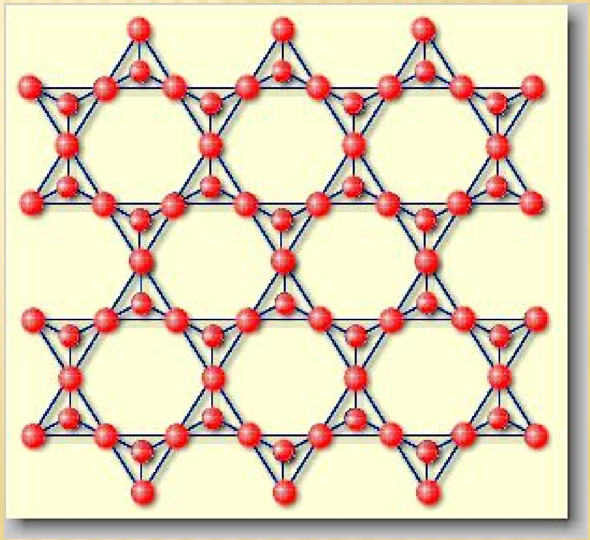
- The **double-chain silicates** consist of two single chains crosslinked by the sharing of additional oxygens between them.

- The **amphiboles** are a group of double-chain silicates with similar properties. They occur commonly in many continental rocks.



SILICATE MINERALS

- In the sheet silicates, each tetrahedron shares oxygens with three others in the same plane, forming a continuous sheet.
- All of the atoms within each sheet are strongly bonded, but each sheet is only weakly bonded to those above and below. Therefore, sheet silicates have excellent cleavage.
- The micas are sheet silicates and typically grow as plate-shaped crystals, with flat surfaces.
- Mica is common in continental rocks.
- The clay minerals are similar to mica in structure, composition, and platy habit.
- Clay minerals are abundant near the Earth's surface and are an important component of soil and of sedimentary rocks.



SILICATE MINERALS

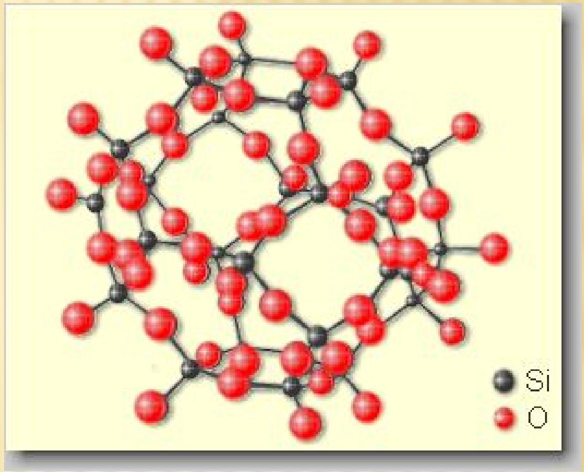
- In the **framework silicates**, each tetrahedron shares all four of its oxygens with adjacent tetrahedral.

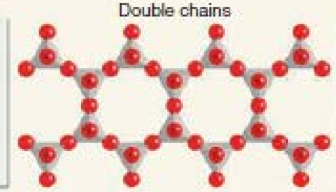
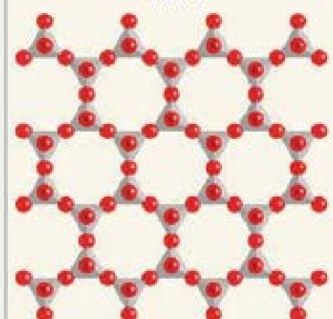
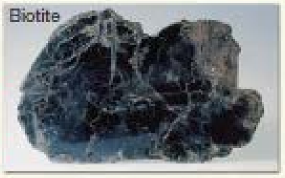
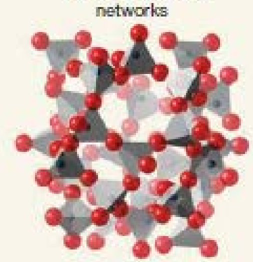
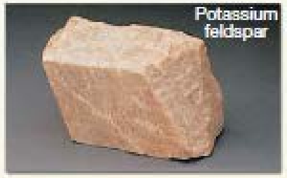
- Because tetrahedra share oxygens in all directions, minerals with the framework structure tend to grow blocky crystals that have similar dimensions in all directions.

- **Feldspar** and **Quartz** have framework structures.

- Feldspars make up more than 50 percent of the earth's crust.

- Quartz is the only common silicate mineral that contains no cations other than silicon; it is pure SiO2

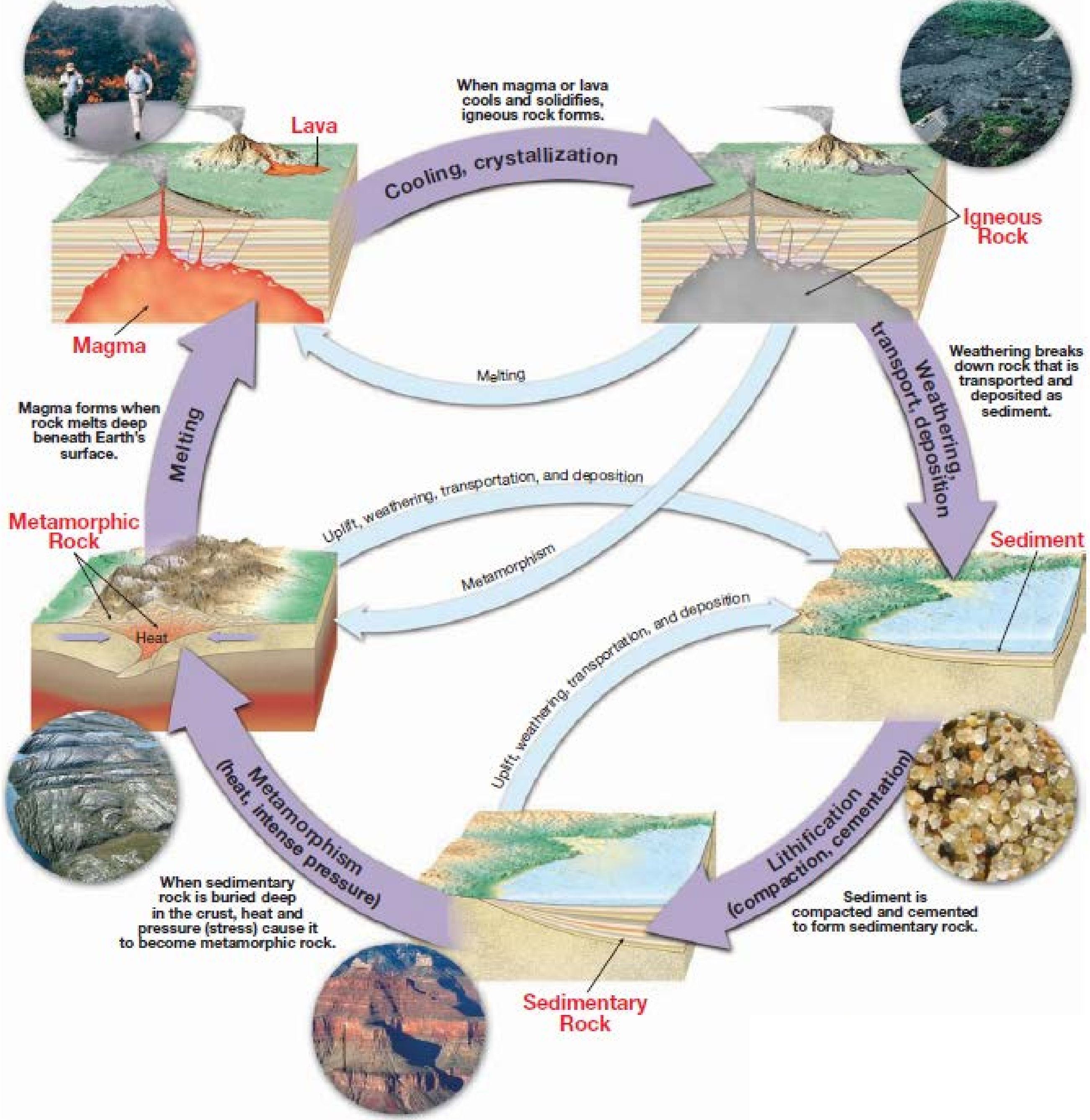


Mineral/Formula	Cleavage	Silicate Structure	Example
Olivine group $(Mg, Fe)_2SiO_4$	None	Single tetrahedron 	
Pyroxene group (Augite) $(Mg,Fe)SiO_3$	Two planes at 90°	Single chains 	
Amphibole group (Hornblende) $Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	Two planes at 60° and 120°	Double chains 	
Micas: **Biotite**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

UNIT 3

IGNEOUS ROCKS

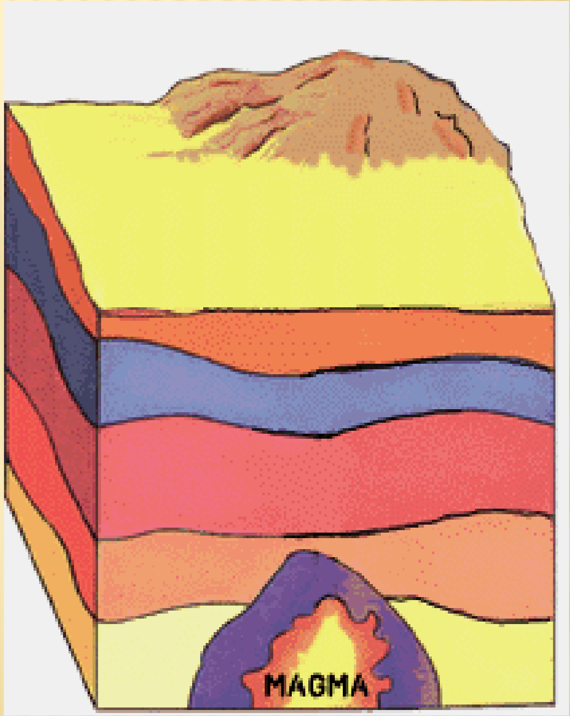
ROCK CYCLE


Lava
When magma or lava cools and solidifies, igneous rock forms.
Cooling, crystallization
Igneous Rock
Magma
Melting
Weathering breaks down rock that is transported and deposited as sediment.
Weathering, transport, deposition
Magma forms when rock melts deep beneath Earth's surface.
Melting
Uplift, weathering, transportation, and deposition
Metamorphic Rock
Metamorphism
Sediment
Heat
Uplift, weathering, transportation, and deposition
Metamorphism (heat, intense pressure)
Lithification (compaction, cementation)
When sedimentary rock is buried deep in the crust, heat and pressure (stress) cause it to become metamorphic rock.
Sediment is compacted and cemented to form sedimentary rock.
Sedimentary Rock

ROCK TYPES

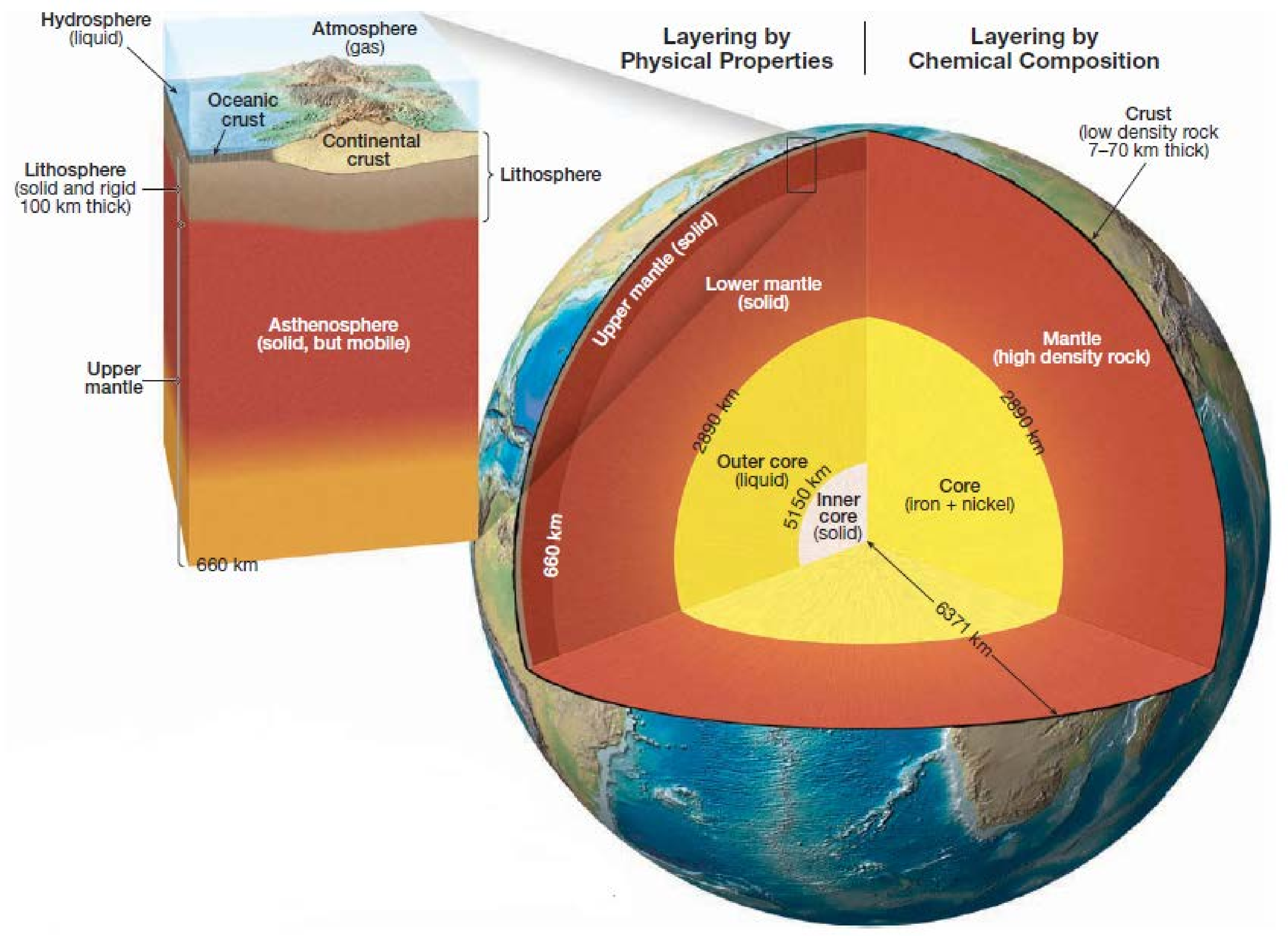
- The Earth is almost entirely rock to a depth of 2900 kilometers, where the solid mantle gives way to the liquid outer core.

- Geologists group rocks into three categories on the basis of how they form:



- Igneous rocks,
- Sedimentary rocks, and
- Metamorphic rocks

ORIGIN OF THE MAGMA



- In the asthenosphere (between depths of about 100 to 350 kilometers), the temperature is so high that rocks melt in certain environments to form magma

FORMATION OF MAGMA

- Under certain conditions, rocks of the upper mantle and lower crust melt, forming a hot liquid called magma.
- An igneous rock forms when magma solidifies.
- About 95 percent of the Earth's crust consists of igneous rock and metamorphosed igneous rock.
- Granite and basalt are two common and familiar igneous rocks.

FORMATION OF MAGMA

- Three different processes melt the asthenosphere:

1. **rising temperature,**
2. **decreasing pressure** and
3. **addition of water**

FORMATION OF MAGMA

- Rising Temperature
- A solid melts when it becomes hot enough. Therefore an increase in temperature melts a hot rock.
- Most magma originates when essentially solid rock, located in the crust and upper mantle, melts. The most obvious way to generate magma from solid rock is to raise the temperature above the rock's melting point.
- The temperatures gets higher as we go deeper inside the earth. Although the rate of temperature change varies considerably from place to place, it averages about 25 °C per kilometer in the upper crust.
- This increase in temperature with depth, known as the geothermal gradient, is somewhat higher beneath the oceans than beneath the continents.
- Tectonic processes exist that can increase the geothermal gradient sufficiently to trigger melting.

FORMATION OF MAGMA

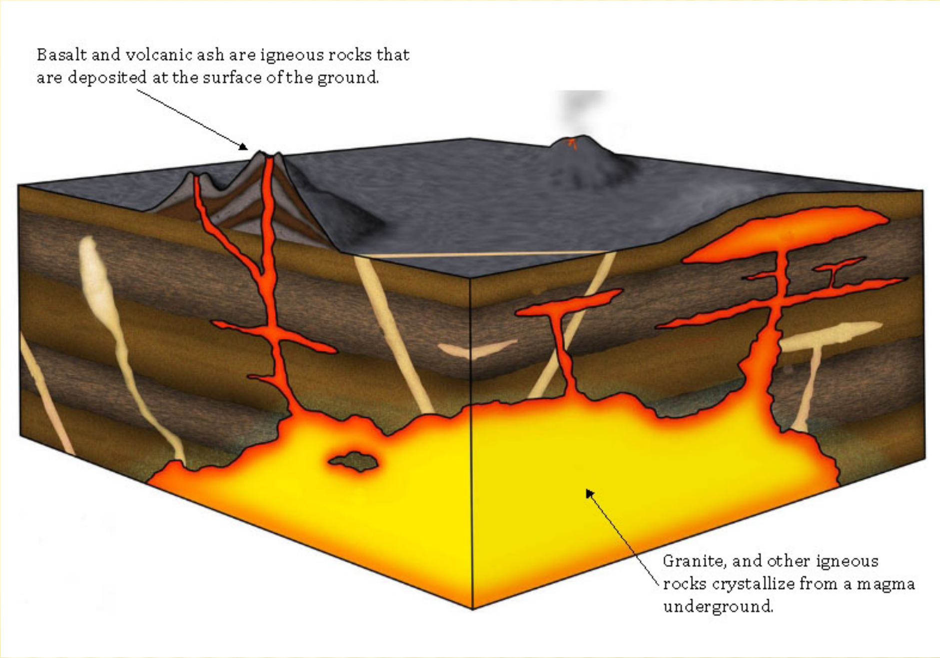
- Decreasing Pressure
- If temperature were the only factor that determined whether or not rock melts, our planet would be a molten ball covered with a thin, solid outer shell.
- This, of course, is not the case. The reason is that pressure also increases with depth.
- Melting, which is accompanied by an increase in volume, occurs at higher temperatures at depth because of greater confining pressure.
- Consequently, an increase in confining pressure causes an increase in the rock’s melting temperature. Conversely, reducing confining pressure lowers a rock’s melting temperature. When confining pressure drops sufficiently, decompression melting is triggered.

FORMATION OF MAGMA

- Addition of Water
- Another important factor affecting the melting temperature of rock is its water content.
- Volatiles cause rock to melt at lower temperatures. Further, the effect of volatiles is magnified by increased pressure.
- Deeply buried "wet" rock has a much lower melting temperature than "dry" rock of the same composition.
- Therefore, in addition to a rock's composition, its temperature, depth (confining pressure), and water content determine whether it exists as a solid or liquid.

NATURE OF MAGMA

- Magma is the completely or partially molten material, which on cooling solidifies to form an igneous rock.
- Once a magma is formed it rises towards the surface as its is less dense than the surrounding rocks.
- Sometimes these magma may reach the earth's surface in the form of volcanoes. Magma that reaches the earth's surface is known as Lava.



COMPONENTS OF THE MAGMA

- Most magma consists of 3 distinct parts: a liquid component, a solid component and a gaseous phase.
- The melt is mostly made up of the ions of Silicon and Oxygen which readily combines to form Silica (SiO_2). Less amounts of Aluminum, Potassium, Calcium, Sodium, Iron and Magnesium are also found.
- The solid component if any are silicate minerals that have already crystallized from the melt. As the magma cools, the size and the number of crystals increase. During the last stage of cooling, the magma body is mostly a crystalline solid with only minor amounts of melt.
- Water (H_2O), carbon dioxide (CO_2) and Sulfur Dioxide (SO_2) are the most common gases found in the magma. Theses gaseous components also known as the volatiles are dissolved within the melt.
- Volatiles remain a part of the magma until the magma body crystallizes or it moves near the surface (low pressure), at which time any remaining volatile freely moves away.

CHARACTERISTICS OF THE MAGMA

- Temperature: The temperature of magma varies from about 600ºC to 1400ºC, depending on its chemical composition and the depth at which it forms.

- Generally, basaltic magma forms at great depth and has a temperature near the high end of this scale.

- Granitic magmas, which form at shallower depths, tend to lie near the cooler end of the scale.

Composition	Source Material	Viscosity	Temperature
Basaltic Magma	Upper Mantle	Low	1200 °C
Andesitic Magma	Oceanic Crust	Inetermediate	800-1000 °C
Granitic Magma	Continental Crust	High	750-850 °C

CHARACTERISTICS OF THE MAGMA

- Chemical Composition: Because oxygen and silicon are the two most abundant elements in the crust and mantle, nearly all magmas are silicate magmas.

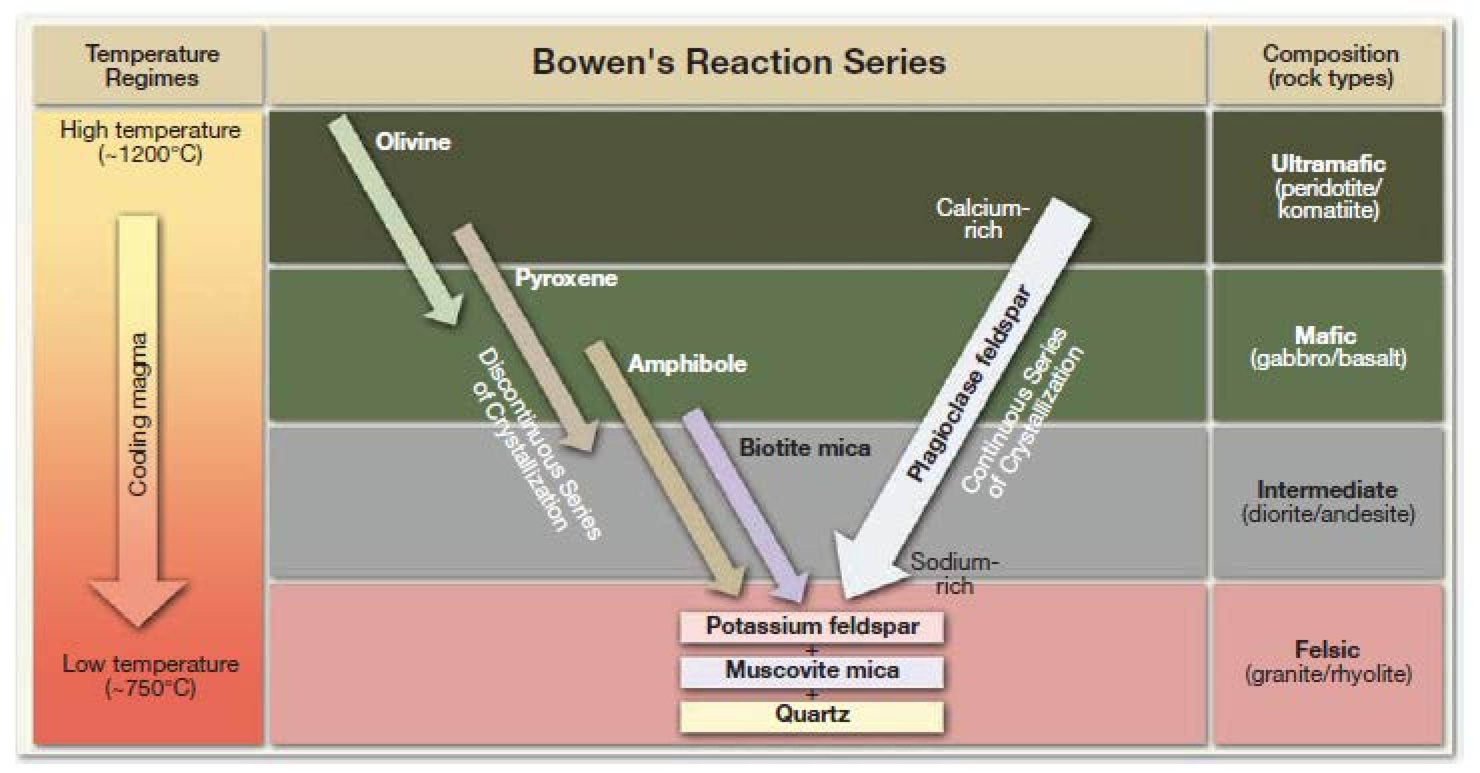
- In addition to oxygen and silicon, they also contain lesser amounts of the six other common elements of the Earth's crust: aluminum, iron, magnesium, calcium, potassium, and sodium.

- The main variations among different types of magmas are differences in the relative proportions of these eight elements.

- For example, basaltic magma contains more iron and magnesium than granitic magma, but granitic magma is richer in silicon, potassium, and sodium. A few rare magmas are of carbonate composition.

EVOLUTION OF MAGMA

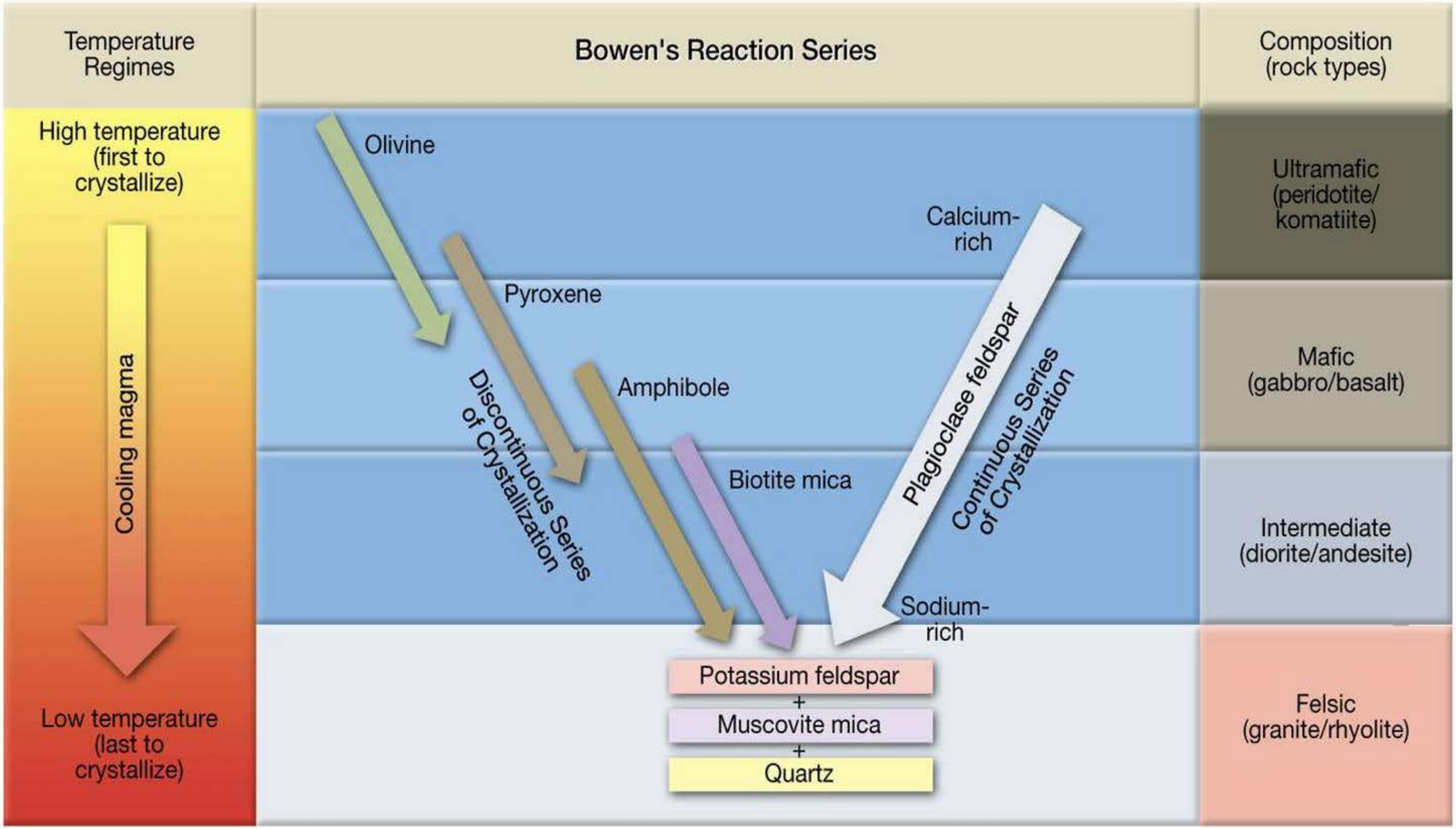
- A large variety of Igneous rocks are found on the earth but a single magma can lead to the formation of different types of igneous rocks.
- This idea was first investigated by geologist Norman L. Bowen (1887–1956).
- The order of crystallization of the different minerals from the magma came to be known as the Bowen Reaction series which allows geologists to predict chemical composition and texture based upon the temperature of a cooling magma.



EVOLUTION OF MAGMA

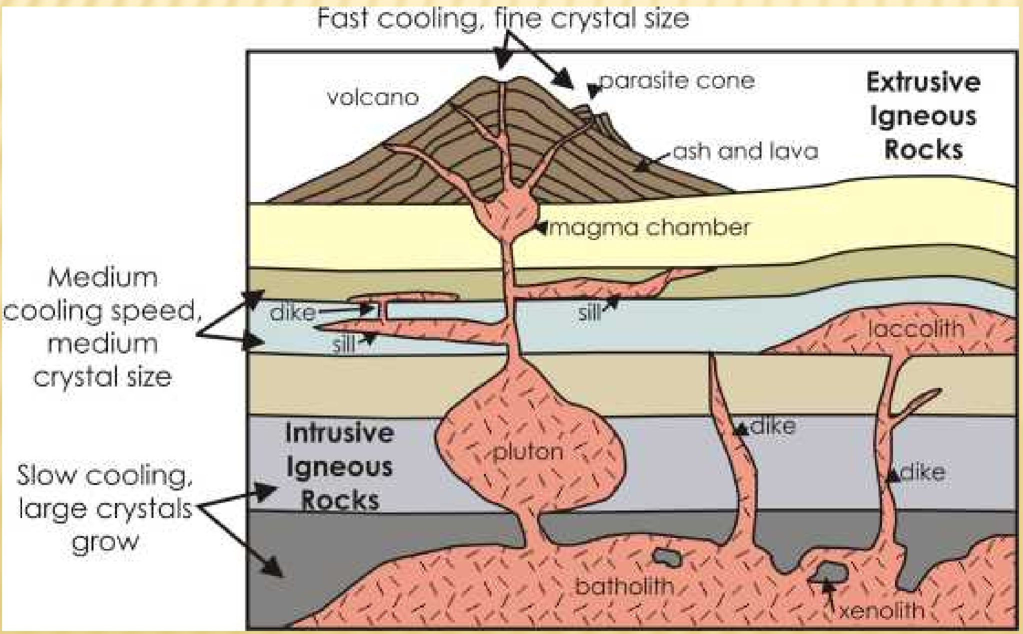
- Bowen's reaction series is usually diagramed as a "Y" with horizontal lines drawn across the "Y
- The horizontal temperature lines divide the "Y" into four compositional sections.
- Mineral formation is not possible above 1800°C.
- Between 1100°C and 1800°C, rocks are ultramafic in composition.
- Between 900°C and 1100°C, rocks are mafic in composition.
- Between 600°C and 900°C, rocks are intermediate in composition. Below 600°C, felsic rocks form.
- The upper arms of the "Y" represent two different series. By convention, the left upper arm represents the discontinuous series. The upper right arm represents the continuous series.
- The continuous series describes the evolution of the plagioclase feldspars as they evolve from being calcium-rich to more sodium-rich.
- The discontinuous series describes the formation of the mafic minerals olivine, pyroxene, amphibole, and biotite mica. These minerals are associated with the mafic and intermediate types of rocks.
- At lower temperatures, the branches merge and we obtain the minerals common to the felsic rocks - orthoclase feldspar, muscovite mica, and quartz.

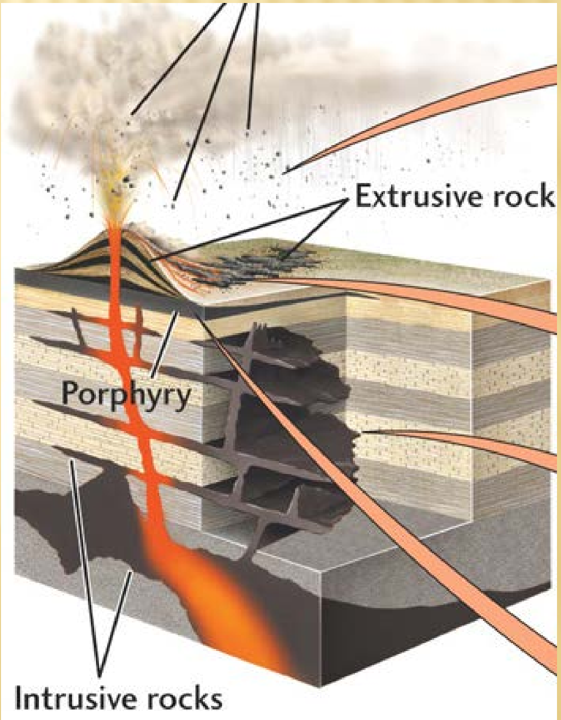
BOWEN REACTION SERIES



EXTRUSIVE AND INTRUSIVE IGNEOUS ROCKS

- Igneous rocks which are formed when the molten magma solidifies at the earth's surface are known as Extrusive Igneous Rocks or Volcanic Rocks.
- Sometimes the magma loses its mobility before reaching the surface and crystallizes at depths. Igneous rocks which are formed by the crystallization of the molten magma beneath the earth's surface or at depths are known as Intrusive Igneous Rocks or Plutonic Rocks.





TEXTURE OF IGNEOUS ROCKS

- The texture of a rock refers to the size, shape, and arrangement of its mineral grains, or crystals.

- Some igneous rocks consist of mineral grains that are too small to be seen with the naked eye; others are made up of thumb-size or even larger crystals.

- Volcanic /extrusive igneous rocks are usually fine grained, whereas plutonic/intrusive igneous rocks are medium or coarse grained.

FACTORS AFFECTING CRYSTAL SIZE

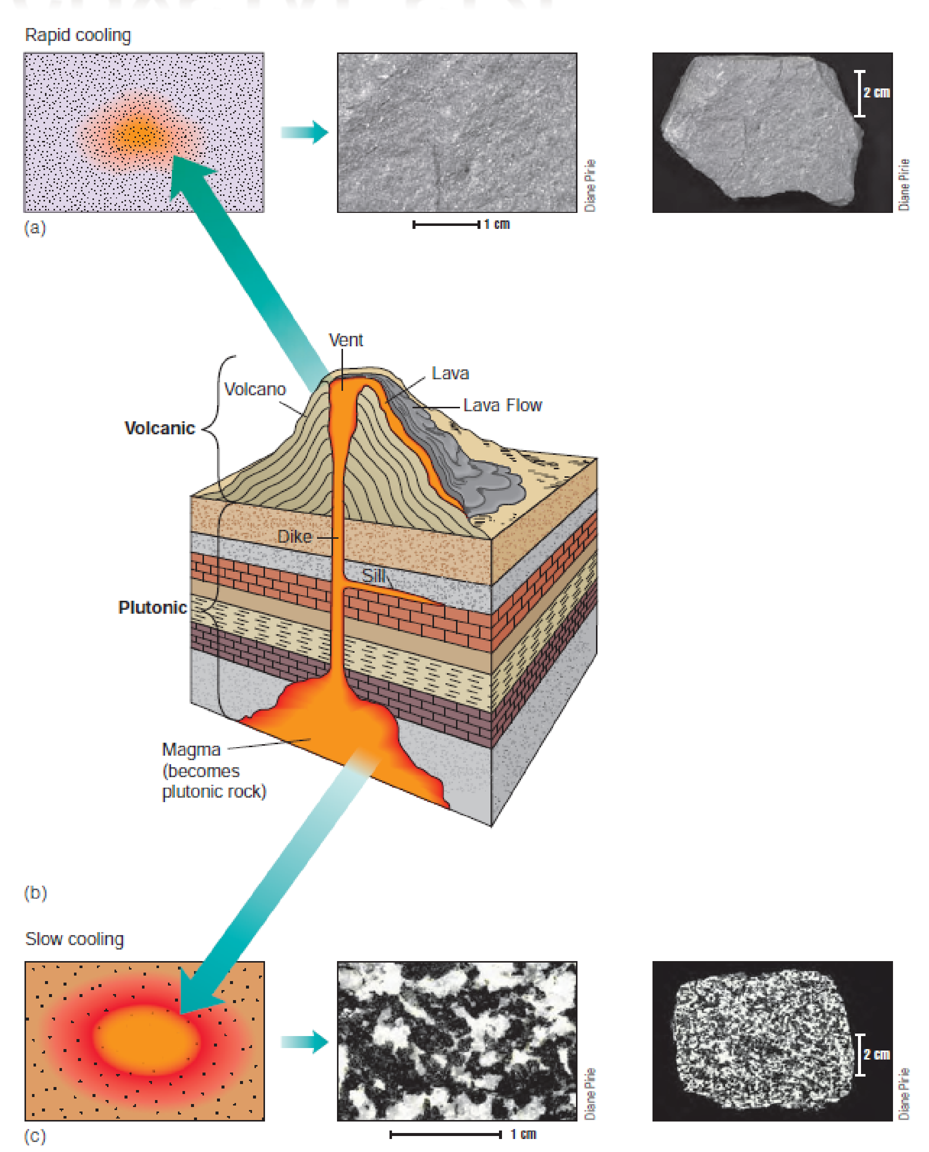
- A magma at depths, slowly loses its heat to the surrounding. The cooling of the magma may take tens or even thousands of years as fewer but large crystals are formed.

- On the other hand if the magma cools rapidly for example on the earth's surface, the crystals do not get time to increase in size and the result is a rock with small intergrown crystals.

- Sometimes the magma cools so rapidly that the ions do not get time to arrange themselves and the magma solidifies to form glass. There is no internal arrangement of ions in Glass.

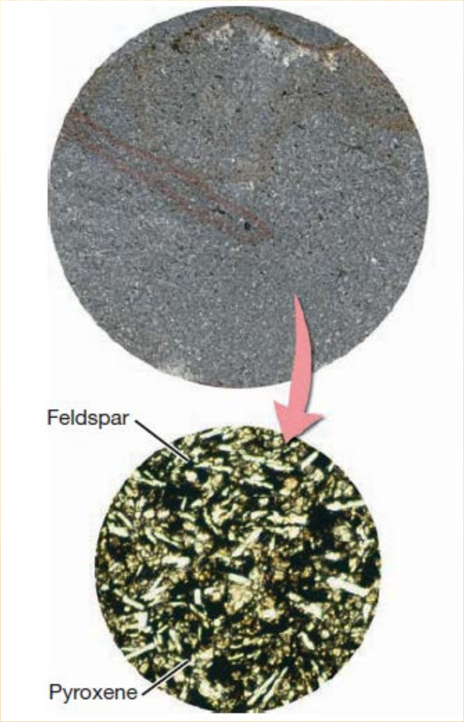
FACTORS AFFECTING CRYSTAL SIZE

- Three factors influence the textures of igneous rocks:
- (1) the rate at which molten rock cools;
- (2) the amount of silica present and
- (3) the amount of dissolved gases in the magma.
- Among these, the **rate of cooling** tends to be the dominant factor.



APHANITIC TEXTURE

- When the magma reaches the earth's surface, it undergoes rapid cooling as a result the crystals do not get a chance to grow in size.
- The resulting igneous rocks have a fine grained texture which is known as Aphanitic texture.
- The mineral grains in rocks having Aphanitic texture are so small that they can be seen only with the aid of a microscope

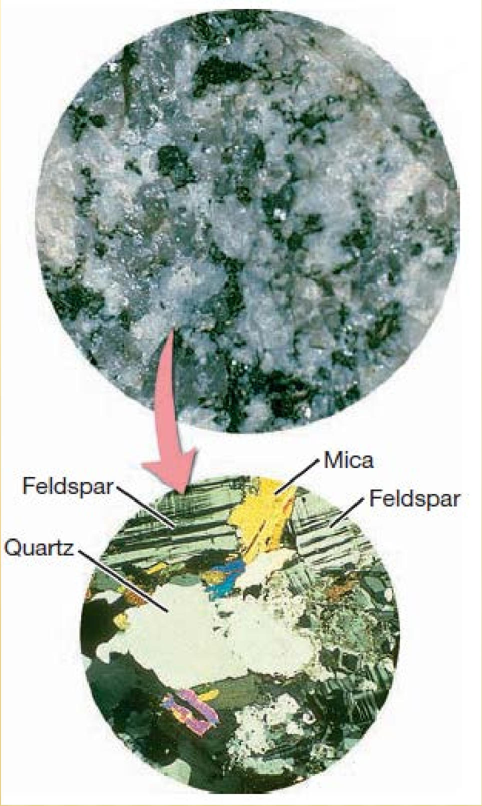


PHANERITIC TEXTURE

- **Phaneritic textured** rocks are comprised of large crystals that are clearly visible to the eye with or without a hand lens or binocular microscope.

- The entire rock is made up of large crystals, which are generally 1/2 mm to several centimeters in size; no fine matrix material is present.

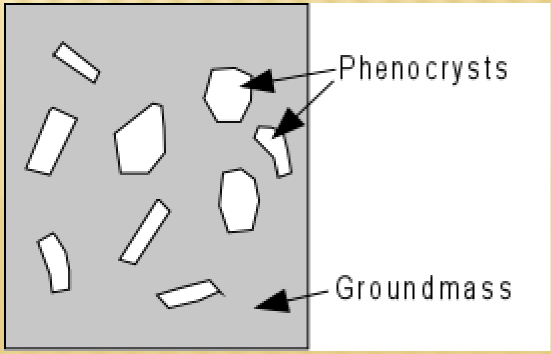
- This texture forms by slow cooling of magma deep underground in the plutonic environment.



PORPHYRITIC TEXTURE

- If magma rises slowly through the crust before erupting, some crystals may grow while most of the magma remains molten.

- If this mixture of magma and crystals then erupts onto the surface, it solidifies quickly, forming porphyry, a rock with the large crystals, called **phenocrysts**, embedded in a **fine-grained matrix/ground mass**. Such a texture is known as **porphyritic texture**

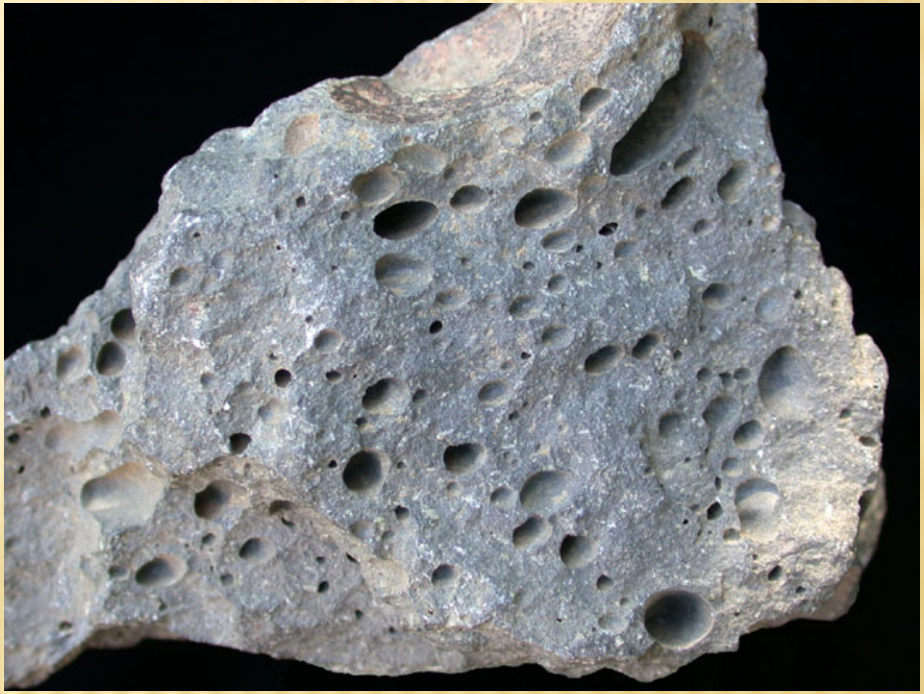


GLASSY TEXTURE

- Glassy textured igneous rocks are non-crystalline meaning the rock contains no mineral grains.
- Glass results from cooling that is so fast that minerals do not have a chance to crystallize.
- This may happen when magma or lava comes into quick contact with much cooler materials near the Earth's surface.
- Pure volcanic glass is known as obsidian.

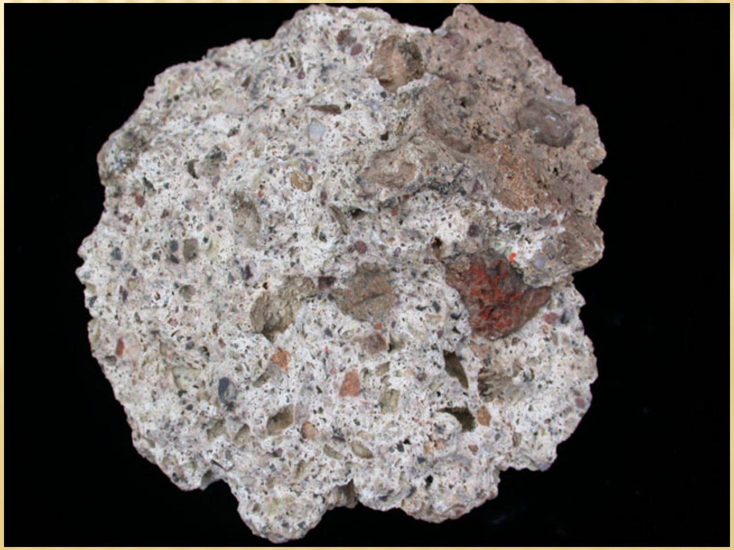
VESICULAR TEXTURE

- Vesicular texture refers to vesicles (holes, pores, or cavities) within the igneous rock.
- Vesicles are the result of gas expansion (bubbles), which often occurs during volcanic eruptions.
- Pumice and scoria are common types of vesicular rocks.
- The image to the right shows a basalt with vesicles, hence the name "vesicular basalt".



PYROCLASTIC TEXTURE

- Some igneous rocks are formed from the consolidation of individual rock fragments that are ejected during a volcanic eruption.
- These particles may consist of fine ash, large angular blocks or molten blobs.
- The rocks composed of these rock fragments are said to have a **pyroclastic texture.**

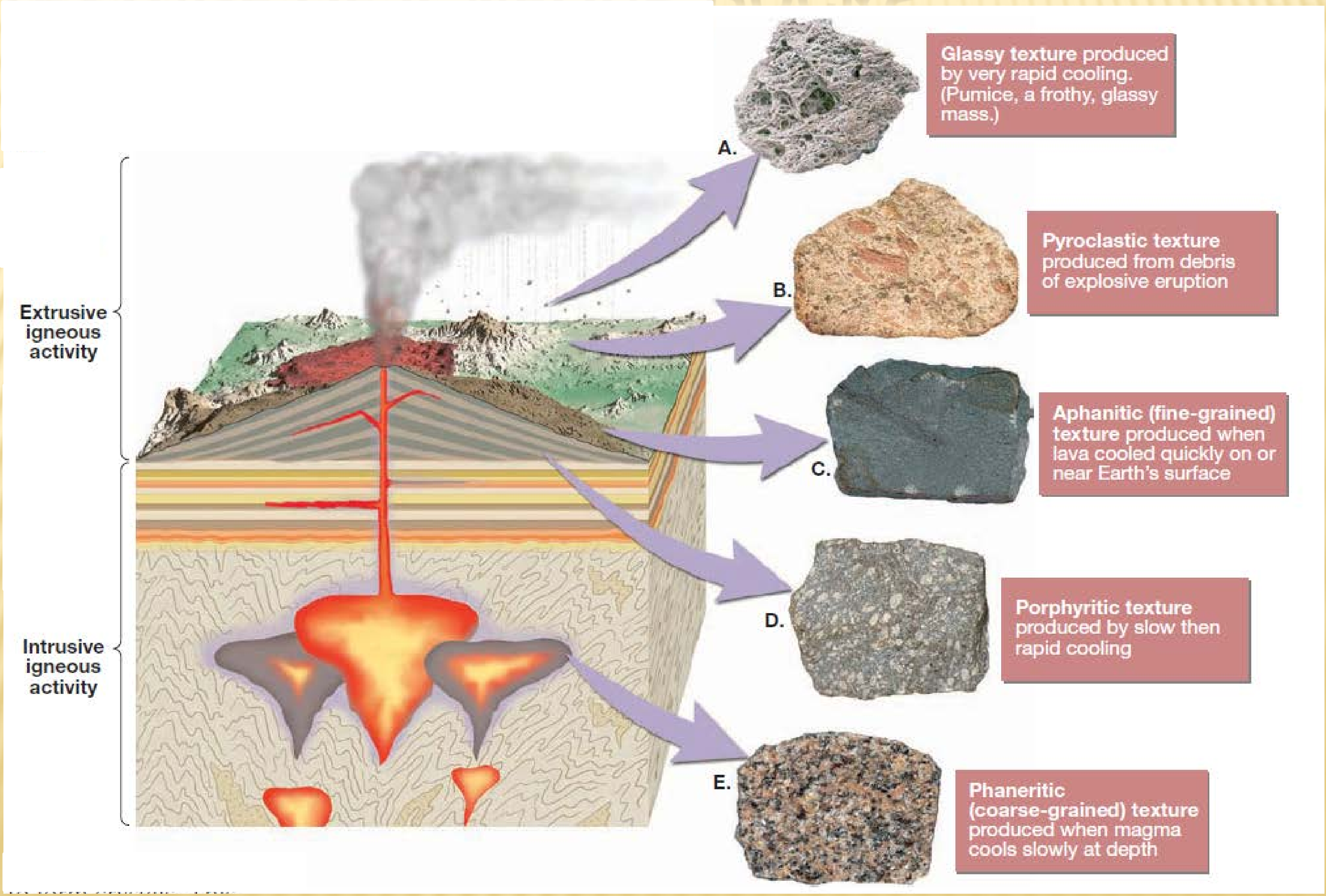


PEGMATITIC TEXTURE

- Under special conditions certain course grained igneous rocks called pegmatites are formed.

- These rocks which are composed up of interlocking crystals which are generally more than a centimeter in diameter are said to have a pegmatitic texture.

TEXTURE OF IGNEOUS ROCKS



IGNEOUS ROCKS COMPOSITION

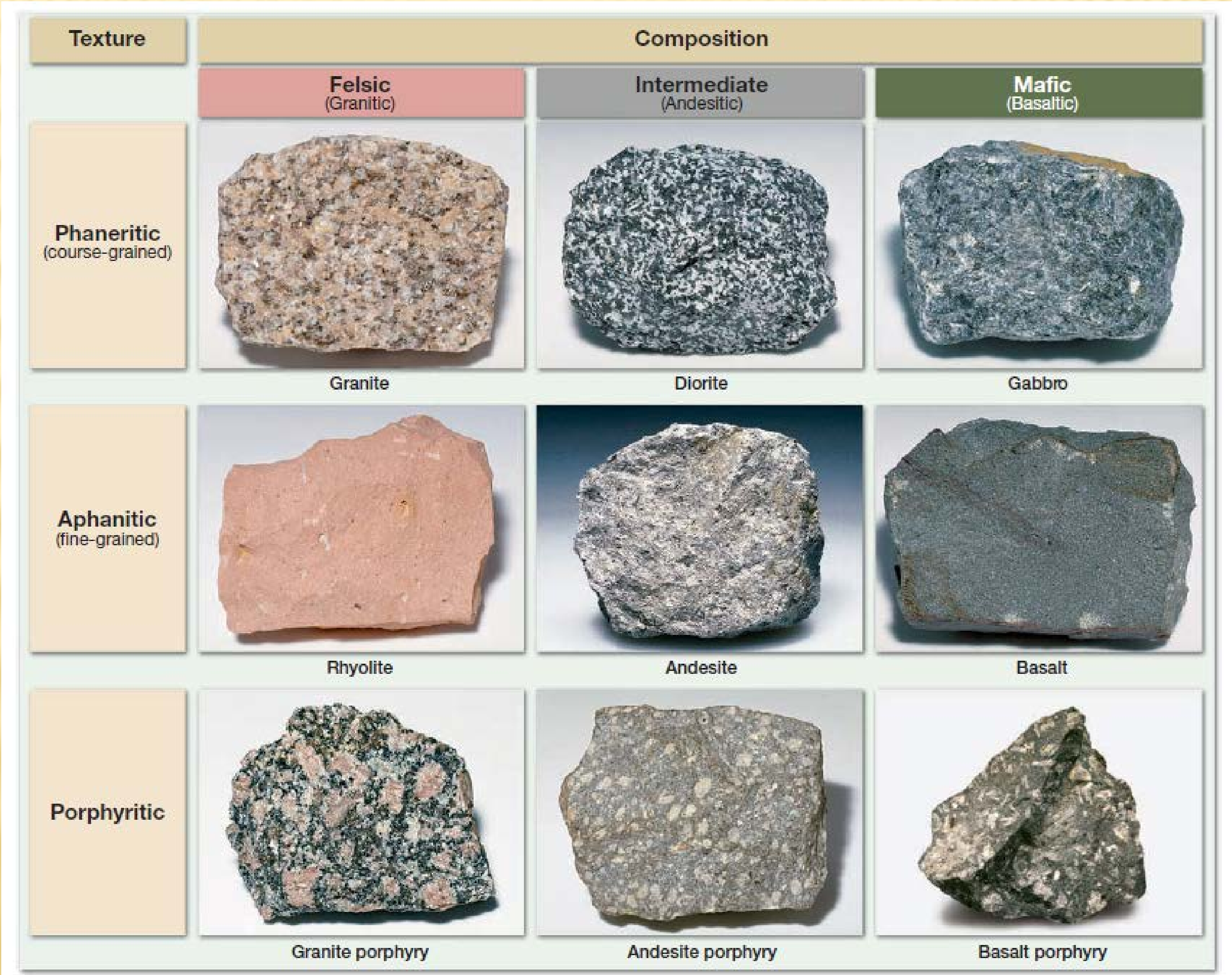
- Igneous rocks are composed up of silicate minerals. Chemical analysis shows that Silica (Si) and Oxygen (O) is the most abundant constituent of igneous rocks.
- As the magma cools it solidifies to form the two major group of silicate minerals.
- The dark or (ferromagnesian) silicates are rich in iron, magnesium and are low in silica.
- Olivine, pyroxene, amphibole and biotite mica is common dark silicate minerals found on the earth.
- The light (nonferromagnesian) silicates contain greater amounts of potassium, sodium and calcium.
- These minerals are also rich in silica content. The light silicate minerals include feldspars, muscovite mica and quartz.

FERROMAGNESIAN AND NON-FERROMAGNESIAN MINERALS

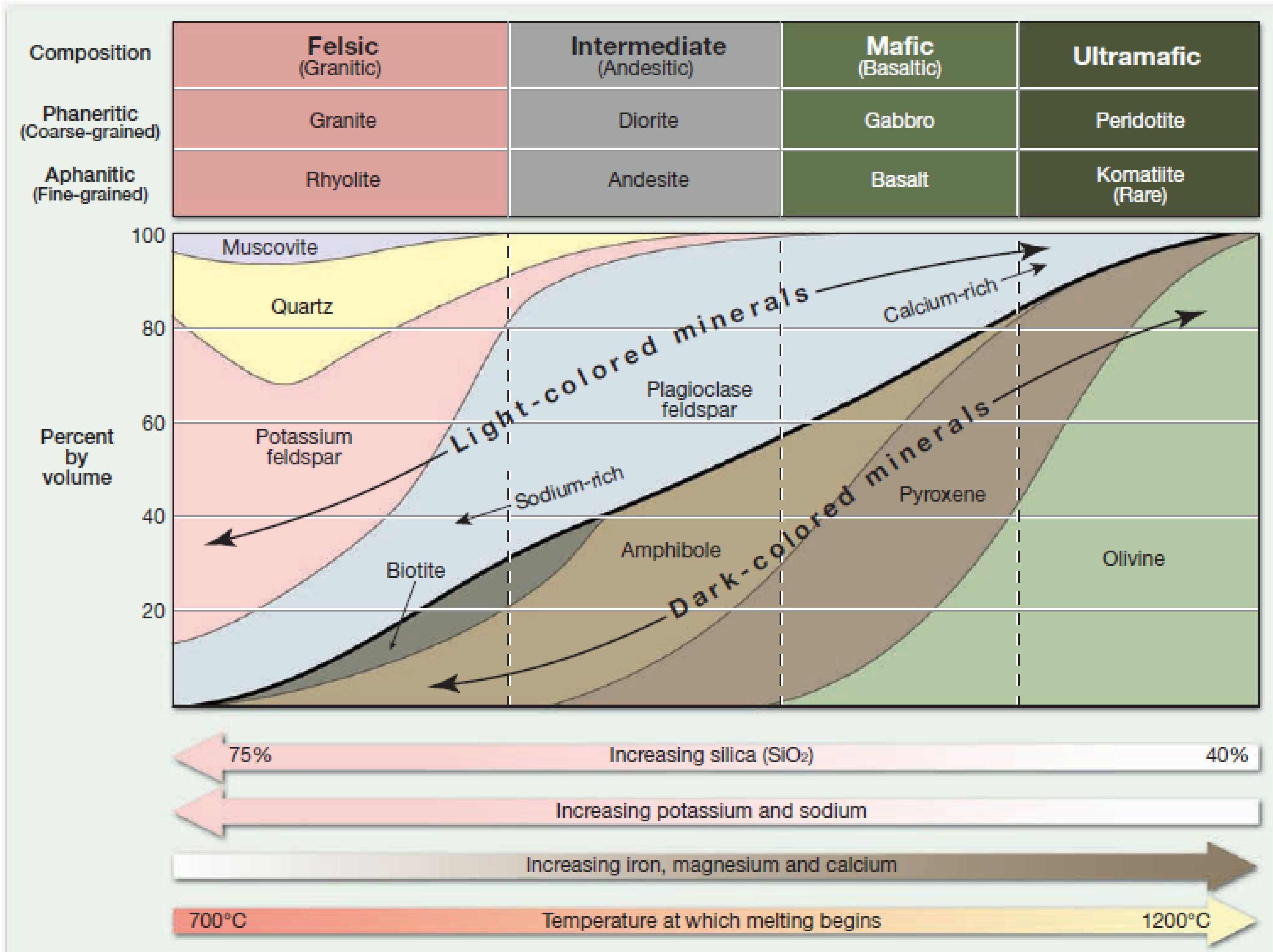
NAMING IGNEOUS ROCKS

- Geologists use both the minerals and texture to classify and name igneous rocks.
- The various igneous textures result mainly from the different cooling histories, whereas the mineral composition of an igneous rock is the result of the chemical makeup of the parent magma.
- Two igneous rocks having the same mineral composition but different textures will have a different name.

CLASSIFICATION OF IGNEOUS ROCKS



MINERALOGY OF COMMON IGNEOUS ROCKS



FELSIC (GRANITIC) IGNEOUS ROCKS

- Granite is the best known of all igneous rocks.
- Granite (and metamorphosed granitic rocks) are the most common rocks in continental crust.
- Granite has a phaneritic texture and is composed up of 25 percent Quartz and about 65 percent feldspar mostly the potassium and sodium rich varieties.
- The remaining 10 percent is made up of muscovite, biotite and some amphibole.

FELSIC (GRANITIC) IGNEOUS ROCKS

- **Rhyolite** is the extrusive equivalent of granite and like granite is composed essentially of light colored silicate minerals.

- Rhyolite has an aphanitic texture and frequently contains glass fragments and voids indicating rapid cooling in the surface environment.

FELSIC (GRANITIC) IGNEOUS ROCKS

- Obsidian is a dark colored glass rock that usually forms when silica rich lava is quenched quickly.

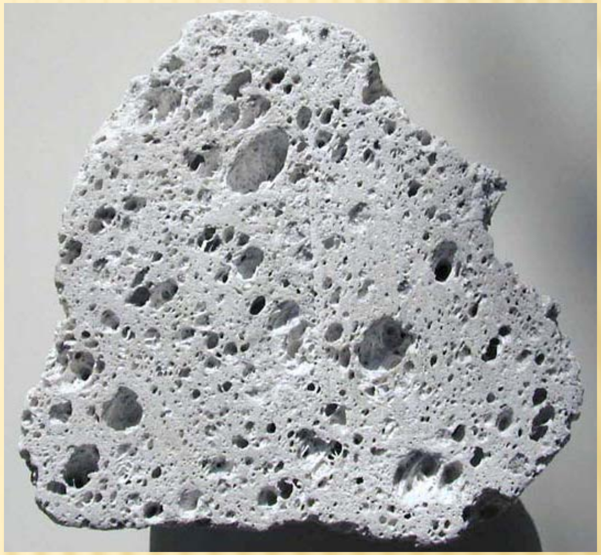
- This means that there is no crystals formation in obsidian and it consists of unordered ions.

- Though obsidian appears dark in color but its chemical composition is similar to that of granites.

FELSIC (GRANITIC) IGNEOUS ROCKS

- Pumice is a volcanic igneous rock that like obsidian has a glassy texture but is formed when large amounts of gas escape through lava.

- Because of the large percentage of voids, many samples of pumice will float when placed in water.



INTERMEDIATE (ANDESITIC) IGNEOUS ROCKS

- Andesite is a volcanic rock intermediate in composition between basalt and granite.

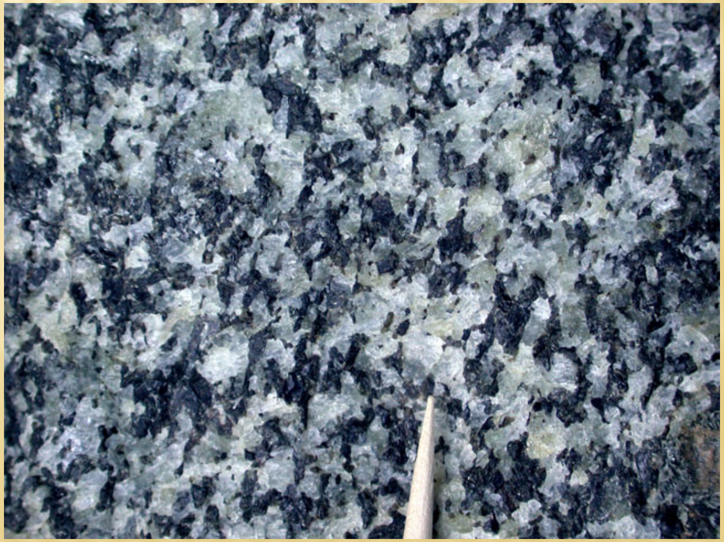
- It is commonly gray or green and consists of plagioclase and dark minerals (usually biotite, amphibole, or pyroxene).

- Andesite is a volcanic rock and is typically very fine grained.

- Andesite and Rhyolite sometimes appear similar but microscopic examination shows that Rhyolite is composed up of about 25 percent quartz whereas Andesite contains only minor amount of Quartz.

INTERMEDIATE (ANDESITIC) IGNEOUS ROCKS

- Diorite is the plutonic equivalent of andesite.
- It is a coarse grained intrusive igneous rock that forms from the same magma as andesite.
- It can be distinguished from granite by the absence of visible Quartz crystals and because it contains a higher percentage of dark silicate minerals.
- The mineral makeup of diorite is primarily sodium rich plagioclase feldspar and amphibole, with lesser amounts of biotite.



MAFIC (BASALTIC) IGNEOUS ROCKS

- Basalt is a very dark green to black fine-grained volcanic rock.
- It is composed primarily of pyroxene and calcium-rich plagioclase feldspar, with lesser amounts of olivine and amphibole present.
- Basalt is the most common extrusive igneous rock.

MAFIC (BASALTIC) IGNEOUS ROCKS

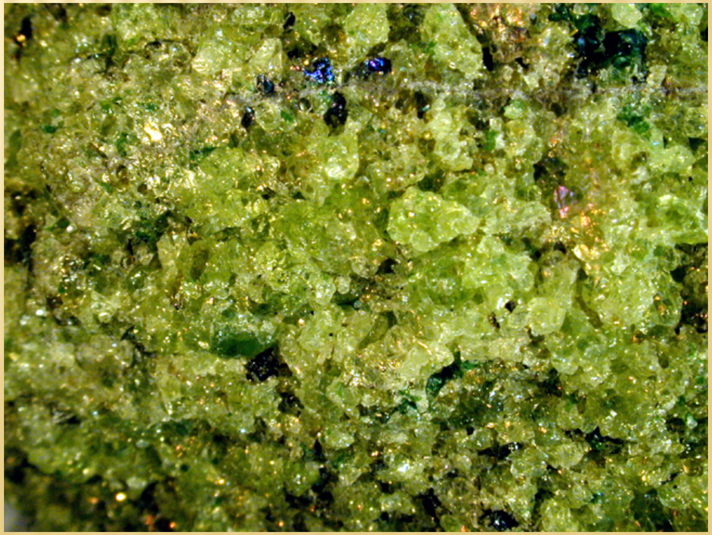
- Gabbro is the intrusive equivalent of basalt.

- Like basalt, it is very dark green to black in color and composed primarily of pyroxenes and calcium rich plagioclase feldspars.

- Gabbro is uncommon at the Earth's surface, although it is abundant in deeper parts of oceanic crust, where basaltic magma crystallizes slowly.

ULTRAMAFIC IGNEOUS ROCKS

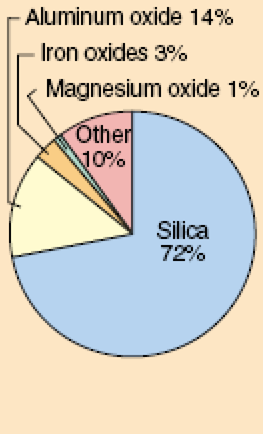
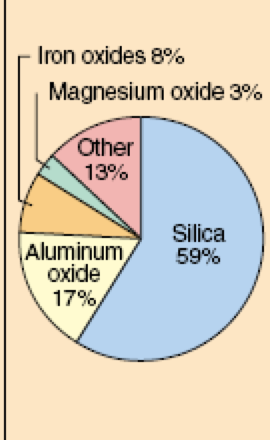
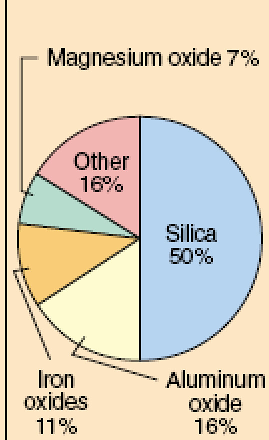
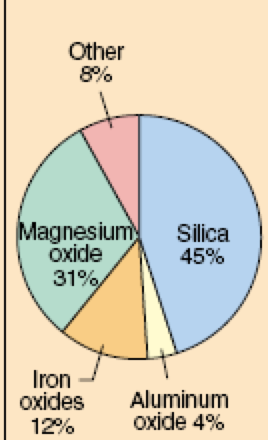
- Peridotite is an ultramafic igneous rock that makes up most of the upper mantle but is rare in the Earth's crust.
- It is coarse grained and composed of olivine, and it usually contains pyroxene, amphibole, or mica but no feldspar.



NAMING IGNEOUS ROCKS

Chemical Composition		**Felsic** (Granitic)	**Intermediate** (Andesitic)	**Mafic** (Basaltic)	**Ultramafic**
Dominant Minerals		Quartz Potassium feldspar Sodium-rich plagioclase feldspar	Amphibole Sodium- and calcium-rich plagioclase feldspar	Pyroxene Calcium-rich plagioclase feldspar	Olivine Pyroxene
Accessory Minerals		Amphibole Muscovite Biotite	Pyroxene Biotite	Amphibole Olivine	Calcium-rich plagioclase feldspar
TEXTURE Phaneritic (coarse-grained)		**Granite**	**Diorite**	**Gabbro**	**Peridotite**
Aphanitic (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)			
Pyroclastic (fragmental)		**Tuff** (fragments less than 2 mm) **Volcanic Breccia** (fragments greater than 2 mm)			
Rock Color (based on % of dark minerals)		0% to 25%	25% to 45%	45% to 85%	85% to 100%

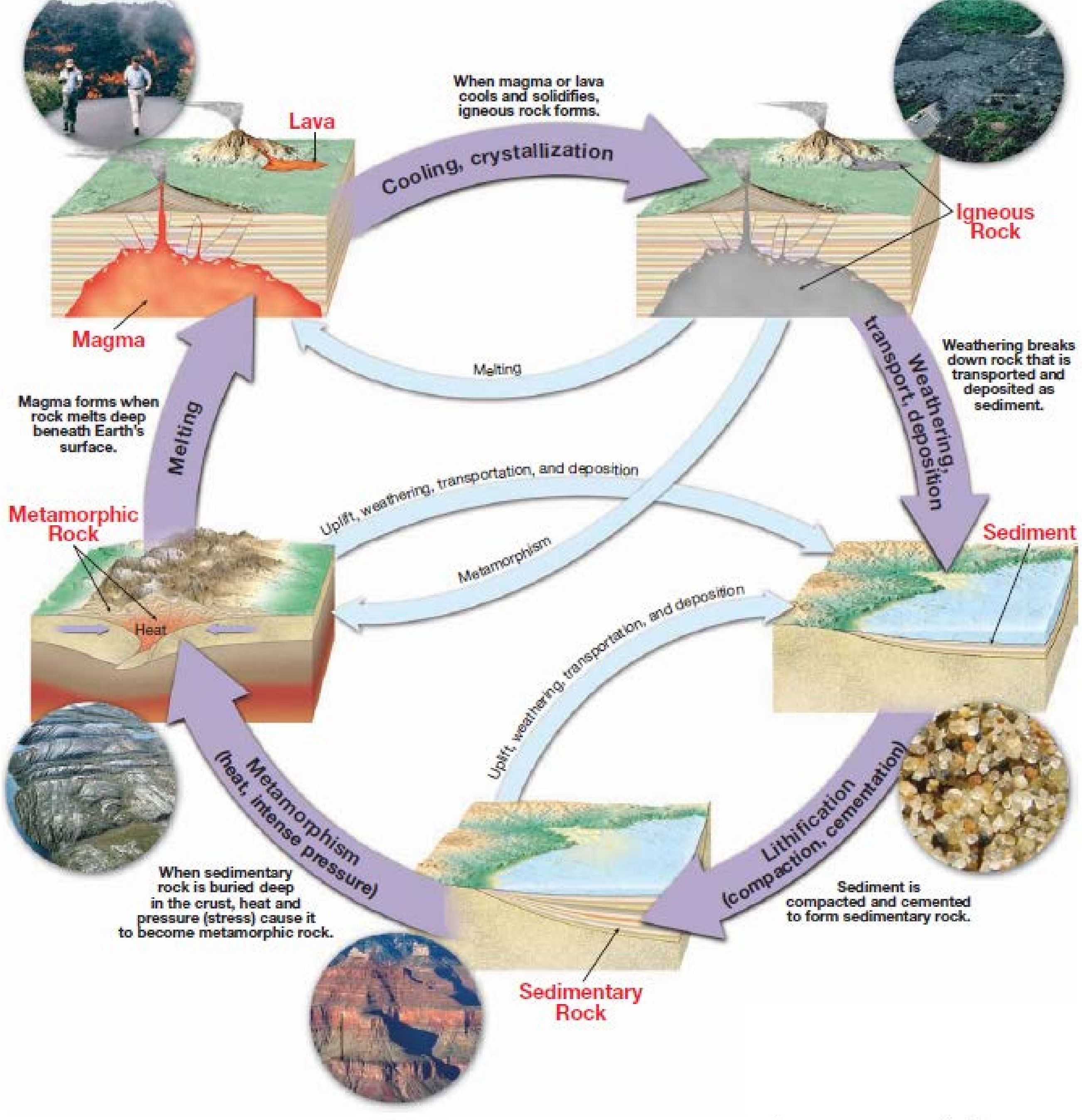
IGNEOUS ROCK CLASSIFICATION

Descriptive Terms	Felsic (granitic)	Intermediate (andesitic)	Mafic (basaltic)	Ultramafic
Intrusive Extrusive	Granite Rhyolite	Diorite Andesite	Gabbro Basalt	Peridotite
Composition				
Major minerals	Quartz Potassium feldspar Sodium feldspar (plagioclase)	Amphibole Intermediate plagioclase feldspar	Calcium feldspar (plagioclase) Pyroxene	Olivine Pyroxene
Minor minerals	Muscovite Biotite Amphibole	Pyroxene	Olivine Amphibole	Calcium feldspar (plagioclase)
Most common color	Light colored	Medium gray or medium green	Dark gray to black	Very dark green to black

UNIT 4

SEDIMENTARY ROCKS

ROCK CYCLE



Lava
When magma or lava cools and solidifies, igneous rock forms.
Cooling, crystallization
Igneous Rock
Magma
Melting
Weathering breaks down rock that is transported and deposited as sediment.
Weathering, transport, deposition
Magma forms when rock melts deep beneath Earth's surface.
Melting
Uplift, weathering, transportation, and deposition
Metamorphic Rock
Metamorphism
Sediment
Heat
Uplift, weathering, transportation, and deposition
Metamorphism (heat, intense pressure)
Lithification (compaction, cementation)
When sedimentary rock is buried deep in the crust, heat and pressure (stress) cause it to become metamorphic rock.
Sediment is compacted and cemented to form sedimentary rock.
Sedimentary Rock

WHAT ARE SEDIMENTS

- Sediments are loose Earth materials (unconsolidated materials) such as sand which are transported by the action of water, wind, glacial ice and gravity.
- These materials are accumulate on the land surface, (such as in river and lake beds), and / or on the ocean floor and form sedimentary rocks

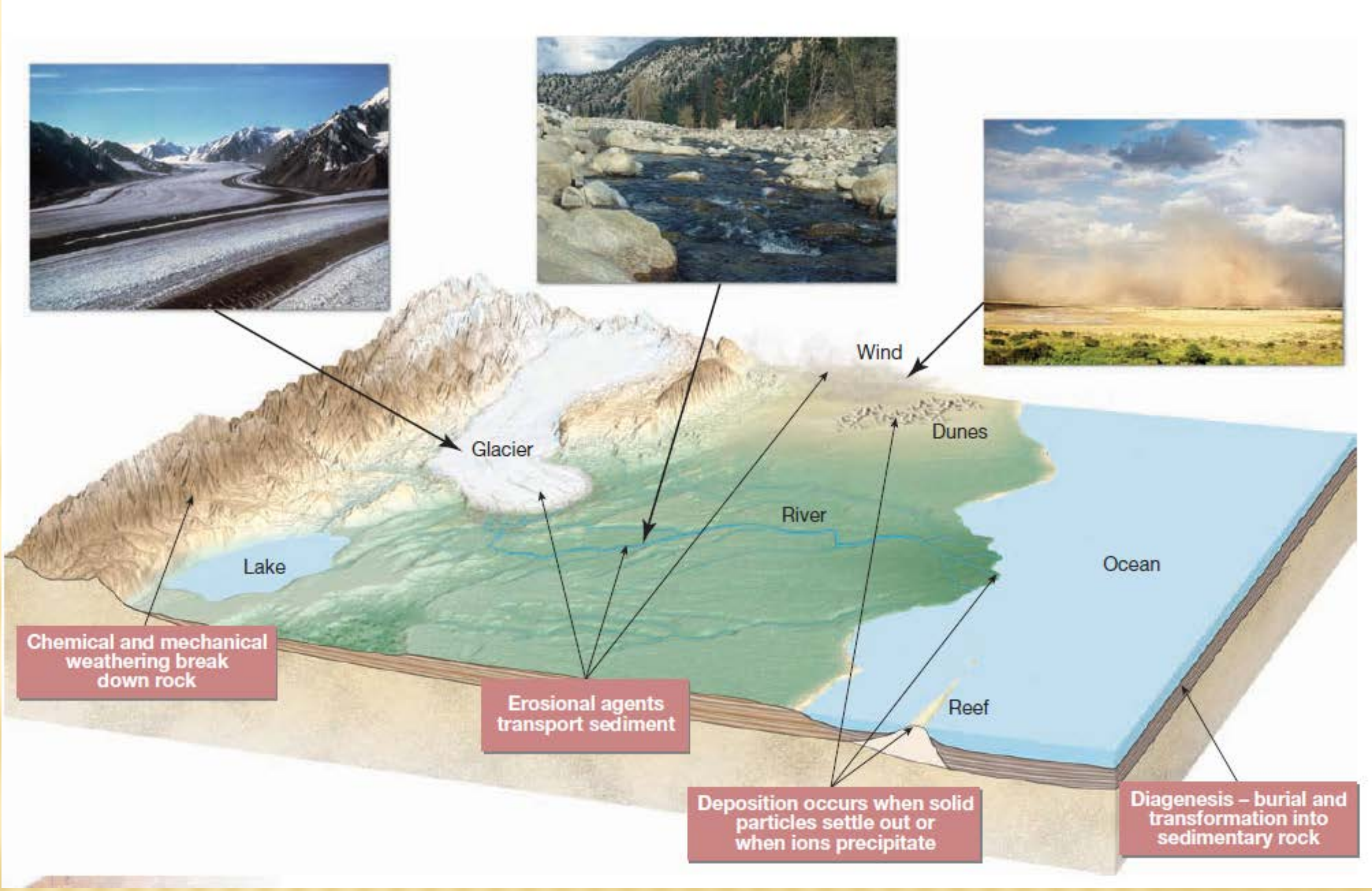



FORMATION OF SEDIMENTARY ROCKS

- Weathering begins the process. It involves the physical disintegration and chemical decomposition of preexisting igneous, metamorphic, and sedimentary rocks.
- Then they are eroded from the site of weathering and moved downslope by gravity, a process termed mass wasting and are transported by wind, water, ice, and mass wasting.
- Transportation moves these materials from the sites where they originated to locations where they accumulate.
- Finally sediment settles out and accumulates after transport : This process is known as deposition.
- As deposition continues, older sediments are buried beneath younger layers and are gradually converted to sedimentary rock by compaction and cementation. This and other changes are referred to as diagenesis (Changes that take place in texture, composition, and other physical properties after sediments are deposited).

FORMATION OF SEDIMENTARY ROCKS

- WEATHERING
- TRANSPORTATION
- DEPOSITION
- DIAGENESIS
  - COMPACTION
  - CEMENTATION

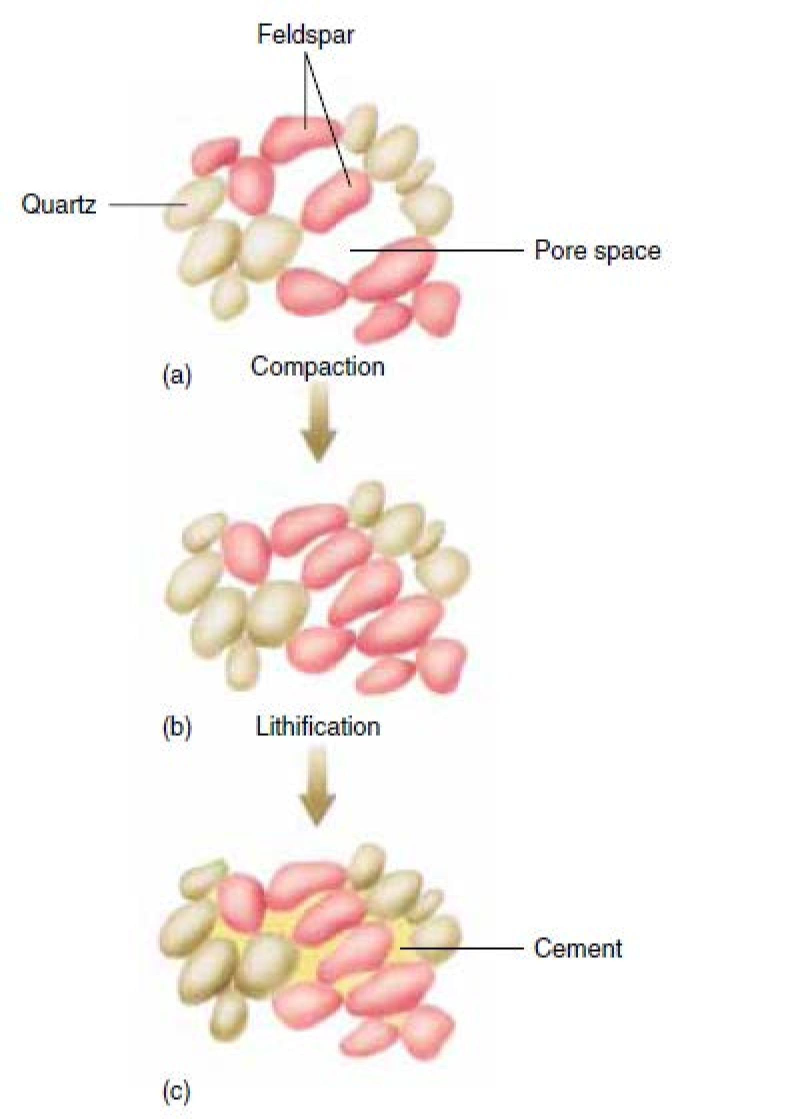


WHAT ARE SEDIMENTARY ROCKS

- The loose sediments after their deposition become compact and hard to form sedimentary rock.
- Sedimentary rocks make up only about 5 percent of the Earth's crust but since they are formed on the Earth's surface, they cover about 75 percent of continents.

DIAGENESIS

- Diagenesis refers to all of the physical, chemical, and biological changes that occur after sediments are deposited and during and after the time they are turned into sedimentary rock.
- Diagenesis includes lithification.
- Burial promotes diagenesis because as sediments are buried, they are subjected to increasingly higher temperature and pressure.
- Diagenesis occurs within the upper few kilometers of earth's crust as temperatures that are generally less than 150 degree C to 200 degree C.
- Lithification refers to processes that convert loose sediment to hard rock
- Two of the most important processes involved in lithification are compaction and cementation.



TYPES OF SEDIMENTARY ROCKS

- Because there are a variety of ways that the products of weathering are transported, deposited, and transformed into solid rock, three categories of sedimentary rocks are recognized.

- As the overview reminded us, sediment has two principal sources. First, it may be an accumulation of material that originates and is transported as solid particles derived from both mechanical and chemical weathering. Deposits of this type are termed detrital, and the sedimentary rocks that they form are called detrital sedimentary rocks.

- The second major source of sediment is soluble material produced largely by chemical weathering. When these ions in solution are precipitated by either inorganic or biologic processes, the material is known as chemical sediment, and the rocks formed from it are called chemical sedimentary rocks.

- The third category is organic sedimentary rocks. The primary example is coal. This black combustible rock consists of organic carbon from the remains of plants that died and accumulated on the floor of a swamp.

CLASTIC/DETRITAL SEDIMENTARY ROCKS

- Detrital sedimentary rocks consists of grains and particles that were eroded from weathered rocks and then were transported and deposited in loose, unconsolidated layers at the Earth's surface.
- Detrital sediments are named according to particle size.
- Gravel includes all rounded particles larger than 2 millimeters in diameter.
- Sand ranges from 1/16 to 2 millimeters in diameter.
- Silt varies from 1/256 to 1/16 millimeter.
- Clay is less than 1/256 millimeter in diameter. Mud is wet silt and clay.

PARTICLE SIZE CLASSIFICATION OF DETRITAL ROCKS

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

0 10 20 30 40 50 60 70 mm

COMMON DETRITAL SEDIMENTARY ROCKS

- Conglomerate consists largely of gravels.
- The particle size in conglomerate varies from 2 mm to more than 256 mm.
- In a conglomerate the particles are rounded.
- Conglomerates are poorly sorted and the openings between the particles are filled with sand or mud.

COMMON DETRITAL SEDIMENTARY ROCKS

- If the large particles are angular rather than rounded, the rock is called breccia.

COMMON DETRITAL SEDIMENTARY ROCKS

- Sandstone is the name given to any rock in which sand size particles are dominant.
- Most sandstones are quartz sandstone and contain more than 90 percent quartz.
- Arkose is a sandstone comprising 25 percent or more feldspar grains, with most of the remaining grains being quartz.
- Graywacke is poorly sorted sandstone with considerable quantities of silt and clay in its pores.

COMMON DETRITAL SEDIMENTARY ROCKS

- Shale is a sedimentary rock consisting of silt and clay sized particle. They consist of clay minerals and small amount of quartz.

- The tiny particles in shale indicate that deposition has taken place in water in a very quiet and non turbulent environment.

- Shale has a finely layered structure called fissility, along which the rock splits easily.

- The layered structure in shale is also sometimes known as laminae.

COMMON DETRITAL SEDIMENTARY ROCKS

- **Mudstone** also has the same particle size as that of shale but is a non-fissile and breaks as chunks or blocks.

COMMON DETRITAL SEDIMENTARY ROCKS

- Siltstone is lithified silt.
- The main component of most siltstones is quartz, although clays are also commonly present.
- Siltstones often show layering but lack the fine fissility of shales because of their lower clay content.

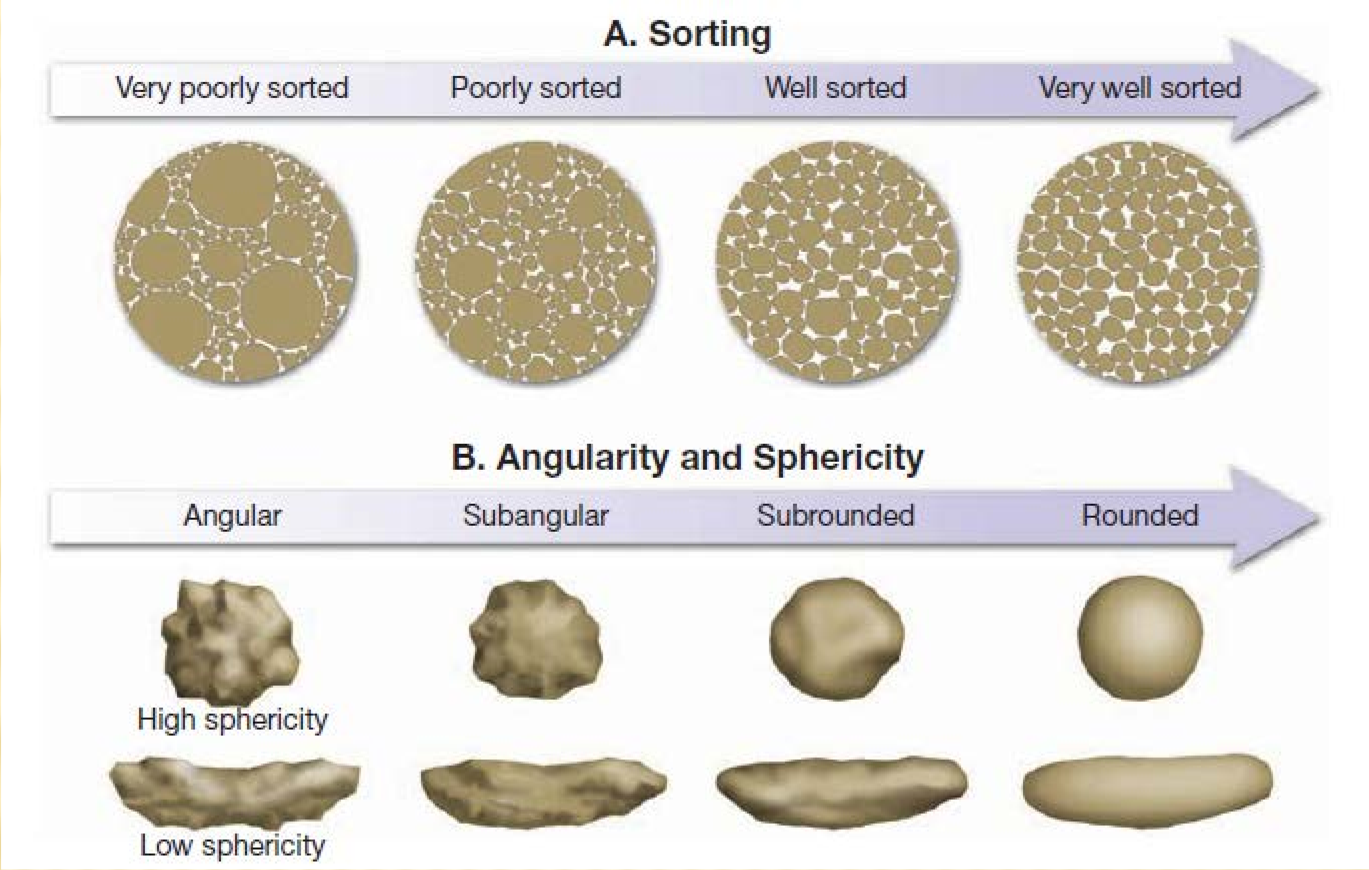
PARTICLE SIZE AND SHAPE OF DETRITAL SEDIMENTARY ROCKS

- Particle size of a detrital sedimentary rock indicates the depositional environment and the strength of the transporting water current.

- Shallow environment and strong currents will result in the formation of coarse grained sedimentary rocks.

- Calm and deep depositional environment will help in the formation of fine grained sedimentary rocks.

PARTICLE SIZE AND SHAPE OF DETRITAL SEDIMENTARY ROCKS



- Particle shape in detrital sedimentary rocks determines how far the particles travelled before getting deposited to form sedimentary rocks.

- Round particles will indicate long transportation where as angular particles indicate a short transportation history.

CHEMICAL SEDIMENTARY ROCKS

- In contrast to detrital sedimentary rocks which form from the solid product of weathering, chemical sedimentary rocks are formed from materials that is carried in solution to lakes and seas.

- Chemical sediments form from water which are saturated with dissolved cations and anions. Crystallization occurs when these ions develop covalent or ionic bonds and thus create chemical compounds, producing minerals such as calcite and salt.

- The precipitation of the material can take place in two ways.

1. Organic processes such as activities of water dwelling organisms.
2. Inorganic processes such as evaporation and chemical activities.

CHEMICAL SEDIMENTARY ROCKS

- **Limestone** represents about 10 percent of the total volume of all sedimentary rocks and is the most abundant in chemical sedimentary rocks.

- It is composed mainly of the mineral calcite ($CaCO_3$) and can be formed either by inorganic means or as a result of biochemical processes.

CHEMICAL SEDIMENTARY ROCKS

- **Dolostone** is closely related to limestone and consists mainly of the mineral dolomite which is calcium magnesium carbonate.

- Although dolostone can form by direct precipitation from seawater, it is thought that most of them are formed when magnesium in the sea water replaces some of the calcium in limestones.

CHEMICAL SEDIMENTARY ROCKS

- **Coquina** is bioclastic limestone consisting wholly of coarse shell fragments cemented together.

- **Chalk** is a very fine-grained, soft, white bioclastic limestone made of the shells and skeletons of microorganisms that float near the surface of the oceans.

- When they die, their remains sink to the bottom and accumulate to form chalk.

CHEMICAL SEDIMENTARY ROCKS

- Chert is a name used for a number of very compact and hard rock made up of microcrystalline silica.

- Microscopic examination of bedded chert often shows that it is made up of the remains of tiny marine organisms that make their skeletons of silica rather than calcium carbonate.

CHEMICAL SEDIMENTARY ROCKS

- Evaporites form when evaporation concentrates dissolved ions to the point at which they precipitate from solution.

- The most common minerals found in evaporite deposits are gypsum ($CaSO_4 \cdot 2H_2O$) and halite (NaCl).

CHEMICAL SEDIMENTARY ROCKS

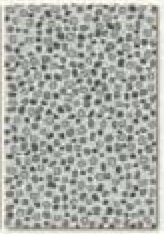
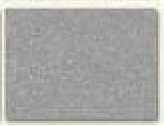
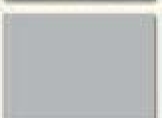
- Corals are an example of organisms that are capable of creating large quantities of marine limestones.

- Corals are capable of forming massive structures which are known as coral reefs.

ORGANIC SEDIMENTARY ROCKS

- When plants die, their remains usually decompose by reaction with oxygen.
- However, in warm swamps and in other environments where plant growth is rapid, dead plants accumulate so rapidly that the oxygen is used up long before the decay process is complete.
- The undecayed or partially decayed plant remains form peat.
- As peat is buried and compacted by overlying sediments, it converts to coal, a hard, black, combustible rock.

Detrital Sedimentary Rocks

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

Chemical and Organic Sedimentary Rocks

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

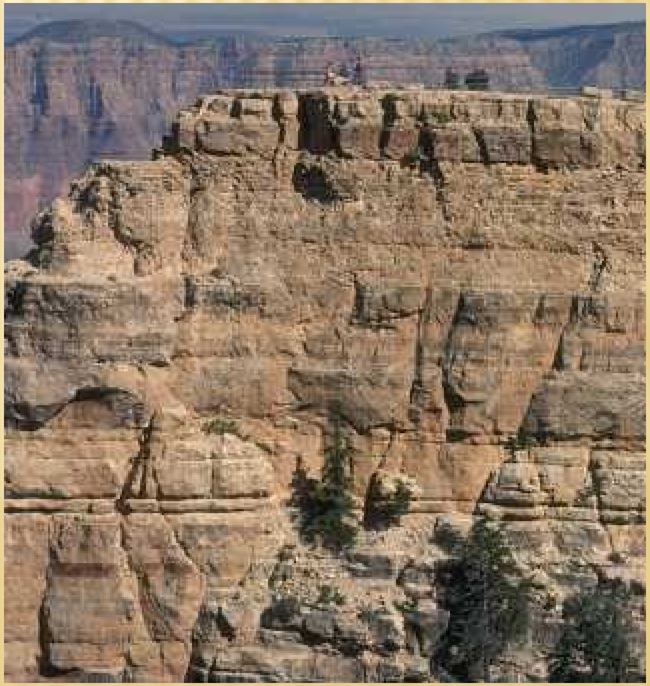
SEDIMENTARY STRUCTURES

- Nearly all sedimentary rocks contain sedimentary structures, features that developed during or shortly after deposition of the sediment.

- These structures help us understand how the sediment was transported and deposited.

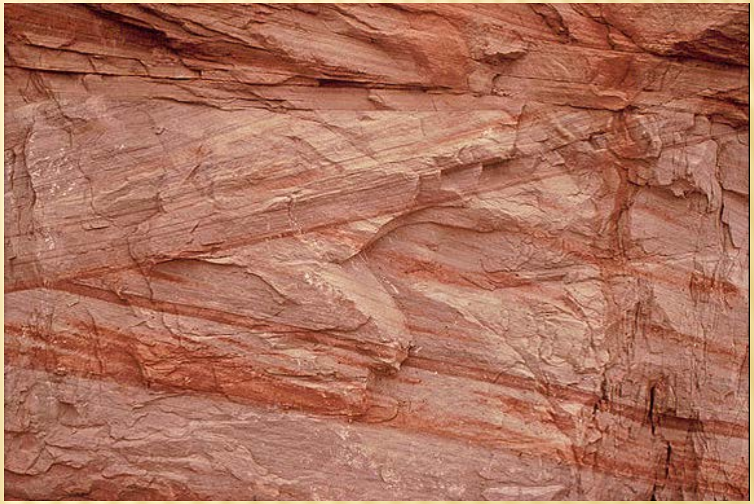
BEDDING OR STRATIFICATION

- Sedimentary rocks form as layer upon layer of sediment accumulates in various depositional environments.
- These layers, called strata or beds, are probably the single most common and characteristic feature of sedimentary rocks.
- Each stratum/layer is unique. The variations in texture, composition, and thickness reflect the different conditions under which each layer was deposited.



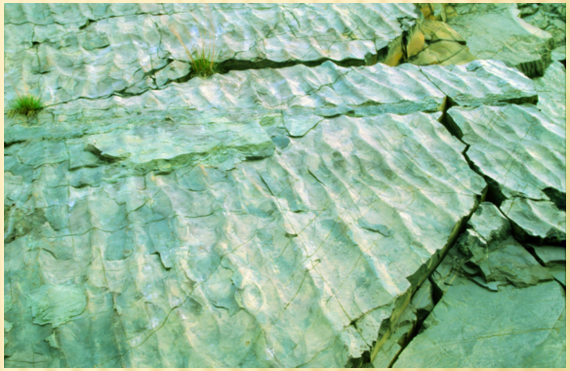
CROSS BEDDING AND GRADED BEDDING

- Sediments usually accumulate as particles that settle from a fluid, most strata are originally deposited as horizontal layers.
- There are circumstances, however, when sediments do not accumulate in horizontal beds and are inclined to the horizontal.
- When this occurs, it is called cross-bedding and is most characteristic of sand dunes, river deltas.
- Graded beds represent another special type of bedding. In this case the particles within a single sedimentary layer gradually change from coarse at the bottom to fine at the top.
- Graded beds are most characteristic of rapid deposition from water containing sediment of varying sizes.



RIPPLE MARKS

- Ripple marks are small, nearly parallel sand ridges and troughs that are also formed by moving water or wind.
- They are like dunes and sand waves, but smaller.
- If the water or wind flows in a single direction, the ripple marks become asymmetrical, like miniature dunes.
- In other cases, waves move back and forth in shallow water, forming symmetrical ripple marks in bottom sand.
- Ripple marks are often preserved in sandy sedimentary rocks.



MUD CRACKS

- Mud cracks are polygonal cracks that form when mud shrinks as it dries.
- They indicate that the mud accumulated in shallow water that periodically dried up.

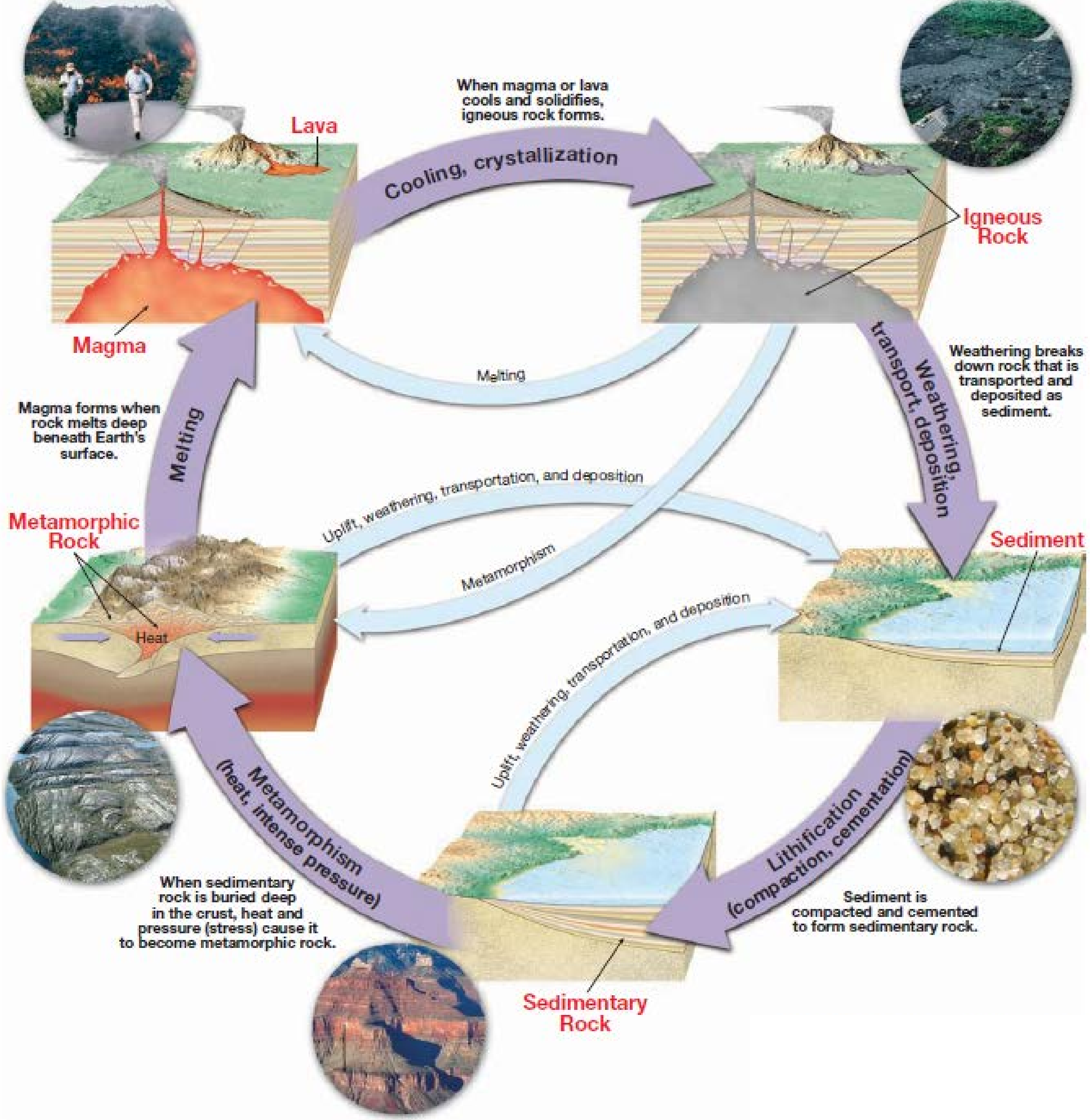
FOSSILS

- Fossils are another feature of the sedimentary rocks that are formed during the time of deposition of these rocks.
- Fossils are the remains or impressions of plants or animals that were persevered in the crust of the earth due to natural causes.
- They are important tools for interpreting the geologic past.
- Knowing the nature of the life forms that existed at a particular time helps researchers decipher past environmental conditions.
- Further, fossils are important time indicators and play a key role in correlating rocks that are of similar ages but are from different places.

UNIT - 5

METAMORPHIC ROCKS

ROCK CYCLE



Lava
When magma or lava cools and solidifies, igneous rock forms.
Cooling, crystallization
Igneous Rock
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Weathering breaks down rock that is transported and deposited as sediment.
Weathering, transport, deposition
Magma forms when rock melts deep beneath Earth's surface.
Melting
Uplift, weathering, transportation, and deposition
Metamorphic Rock
Metamorphism
Sediment
Heat
Uplift, weathering, transportation, and deposition
Metamorphism (heat, intense pressure)
Lithification (compaction, cementation)
When sedimentary rock is buried deep in the crust, heat and pressure (stress) cause it to become metamorphic rock.
Sediment is compacted and cemented to form sedimentary rock.
Sedimentary Rock

WHAT IS METAMORPHISM

- Metamorphism (from the Greek words for "changing form") is the process by which rising temperature and changes in other environmental conditions transform rocks and minerals.
- In other word metamorphism is the transformation of one rock type into another.
- Metamorphism takes place where the pre-existing rocks are subjected to temperature and pressure unlike those in which they were formed.
- In response to these new conditions the rock gradually changes until it reaches a state of equilibrium with the new environment.
- Metamorphism is always gradual and it ranges from low grade metamorphism to high grade metamorphism.
- However rock should always be in the solid state during metamorphism.
- If the rocks melts at a certain point, then we enter the zone of igneous activity.

ENVIRONMENT OF METAMORPHISM

- Most metamorphism occurs in one of the three settings:

- Contact or thermal metamorphism occurs where hot magma intrudes cooler country rock. The country rock may be of any type—sedimentary, metamorphic, or igneous.

- The highest-grade metamorphic rocks form at the contact, closest to the magma. Lower-grade rocks develop farther out.

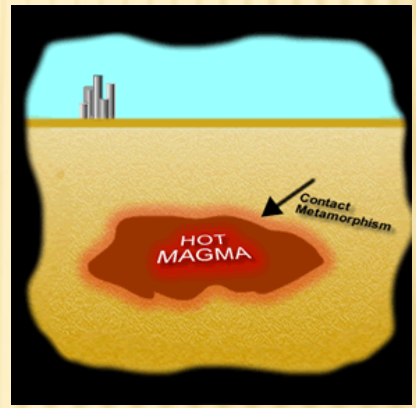
- The change is driven by the rise in temperature within the host rock surrounding an igneous intrusion.

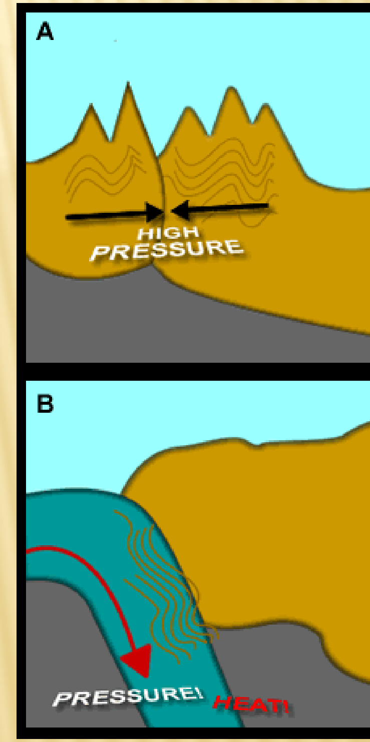
- Most contact metamorphic rocks are fine-grained, dense,tough rocks of various chemical compositions.

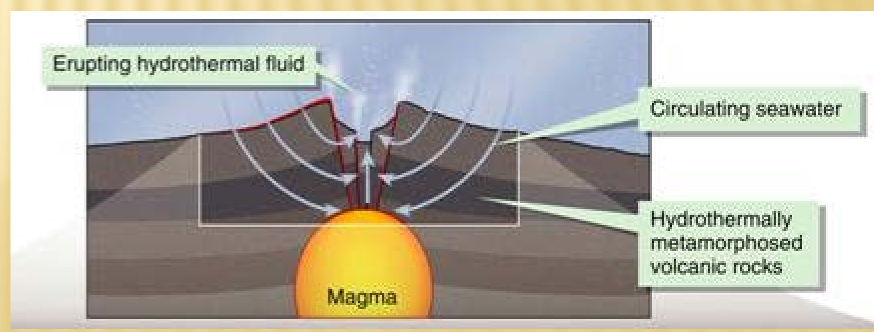
- Because directional pressure is not a major factor, these rocks are not generally foliated.

- Hydrothermal metamorphism (also called hydrothermal alteration and metasomatism) occurs when hot water and ions dissolved in the hot water react with a rock to change its chemical composition and minerals.

- Regional metamorphism occurs during the process of mountain building, great quantities of rocks are subjected to directed pressure and high temperatures associated with large scale deformation.







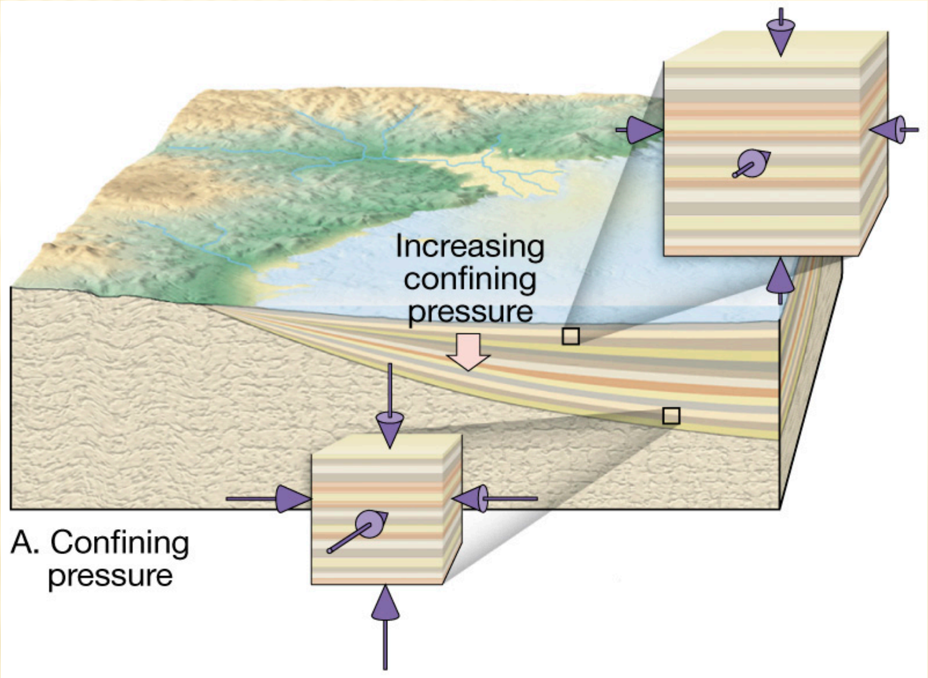
AGENTS OF METAMORPHISM

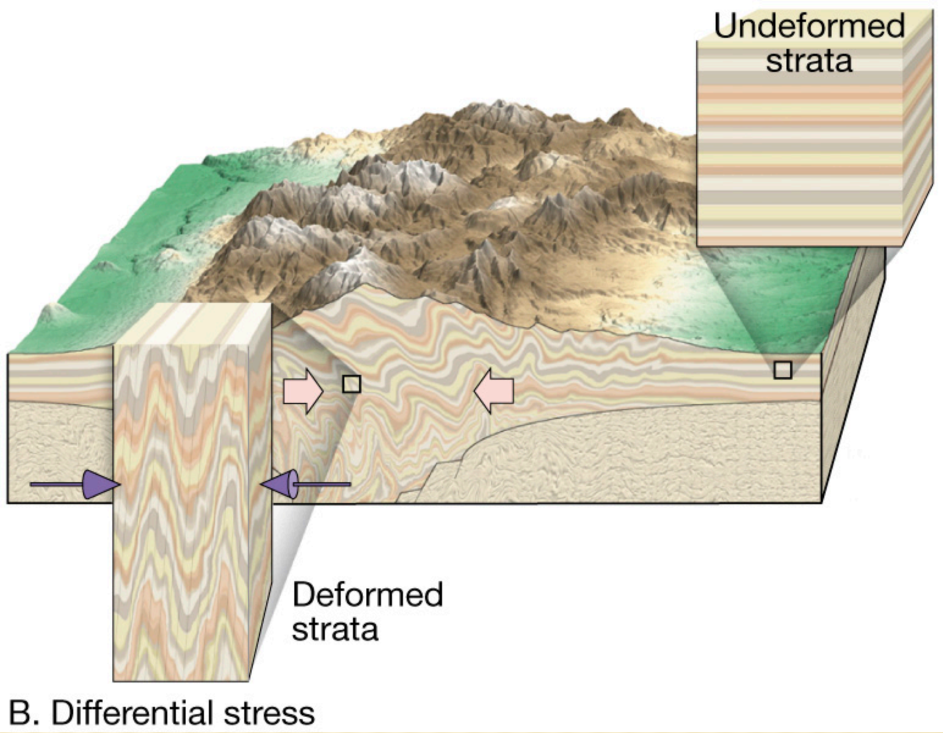
- Heat contributes to the process in two ways. First, atoms may combine differently at different temperatures.
- This means that a mineral stable at one temperature might become unstable at a higher (or lower) temperature and be converted to a different mineral with a more stable atomic structure.
- This may or may not involve changing the exact elemental composition.
- Second, heat makes practically all chemical reactions go faster, meaning that mineral transformations are much easier at higher temperature.

AGENTS OF METAMORPHISM

- Pressure also has two effects. As with heat, it can also control which minerals or forms of minerals are stable.
- Some minerals may be converted to minerals with similar composition but different atomic packing simply because pressure is increased.
- The exact nature of the pressure is not important in this case. Only the amount is important. Thus the confining or lithostatic pressure created by deep burial of rocks under sediment may have this effect as well as the directed pressure during mountain building processes.
- The second effect of pressure is to reorient minerals with linear or platy structure or to create a preferred orientation of them as they form.
- Thus elongate minerals such as amphiboles, or platy minerals such as clays or micas tend to align themselves parallel to each other when under pressure.
- This only happens when there is directed pressure; confining pressure does not accomplish it.

AGENTS OF METAMORPHISM

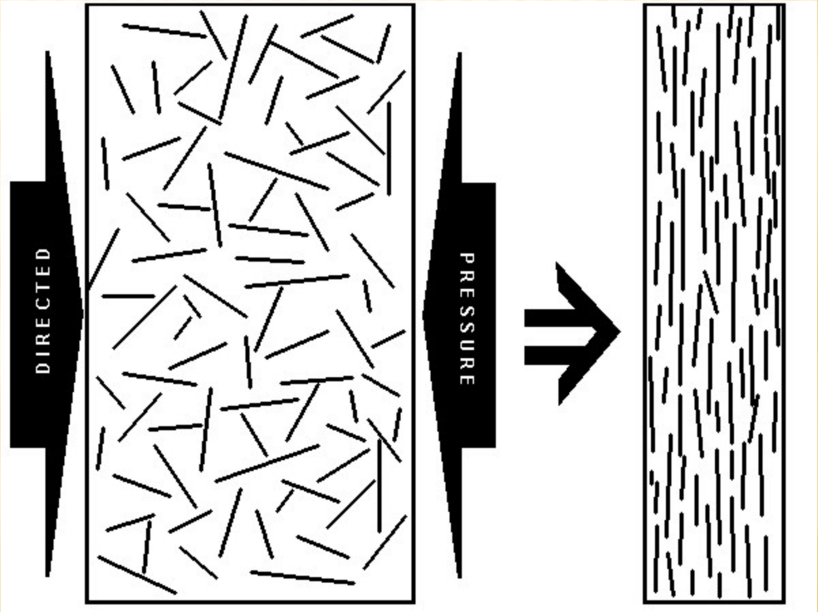




Confining Pressure and Directed Pressure

AGENTS OF METAMORPHISM

- The diagram illustrates the effect. A texture of this sort in a metamorphic rock is called foliation and the rocks are said to be foliated.



AGENTS OF METAMORPHISM

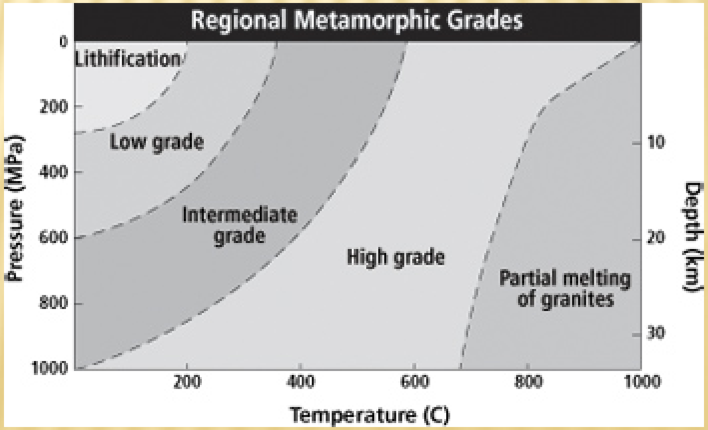
- Fluids serve only to speed up other metamorphic processes, or perhaps even allow them to happen at all.
- Chemical reactions require water, and most proceed much faster as the amount of water goes up.
- Dissolved ions in the fluid also make those mineral transformations that require chemical changes in the minerals to occur, whether by supplying needed ions or flushing away excess ones.

GRADE OF METAMORPHISM

- Different locations in the crust experience different levels of heat and pressure as result the rocks may experience different grades of metamorphism.

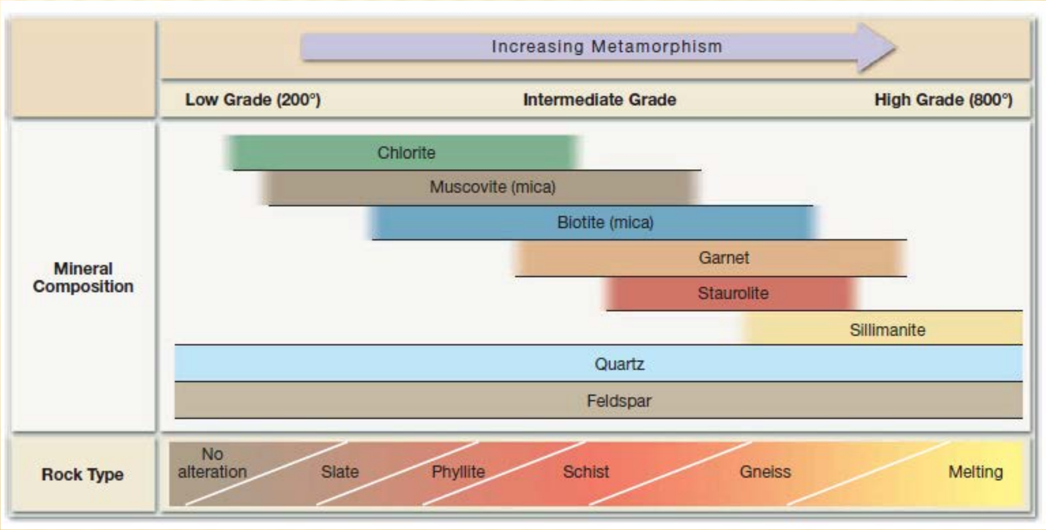
- The changes that occur during metamorphism are recorded in the form of texture and mineral assemblages.

- High grade metamorphic rocks are greatly altered from its original form and often have a completely different mineralogy than the parent rock.



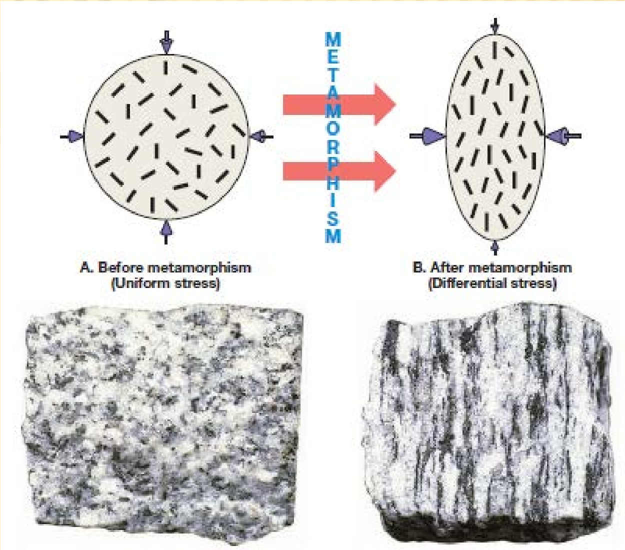
INDEX MINERALS

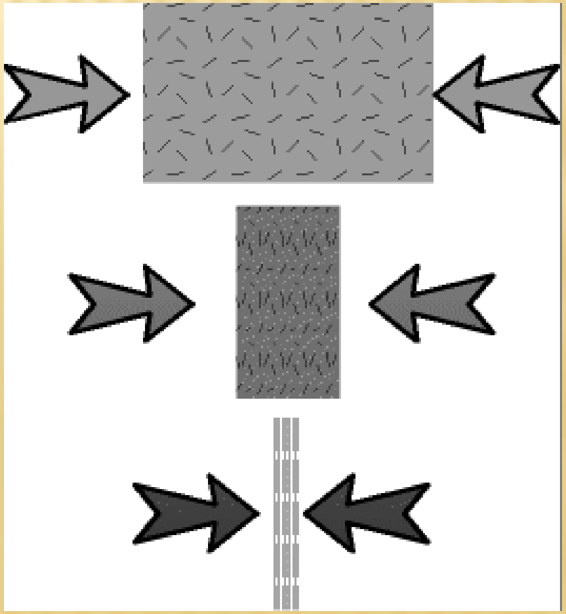
- Through the study of metamorphic rocks it has been found that some minerals are good indicators of the metamorphic environment in which they formed. These minerals are known as index minerals.
- Using these index minerals, geologists distinguish among different zones of regional metamorphism.
- For example, the mineral chlorite begins to form when temperatures are relatively low, less than 200 °C Thus, rocks that contain chlorite are referred to as low-grade.
- By contrast, the mineral sillimanite only forms in extreme environments where temperatures exceed 500 °C, and rocks containing it are considered high-grade.
- Quartz and Feldspar also appear in metamorphic products but since they are found in both low and high grade metamorphic rocks, they are not considered as index minerals.



METAMORPHIC ROCK TEXTURES

- Metamorphic rocks exhibit a variety of textures. They can be either foliated or granular.
- Foliation refers to any planar arrangement of mineral grains or structural features within a rock.
- Most metamorphic rocks form in the influence of a directed stress field. Because of this they develop conspicuous directional textures.
- As metamorphism proceeds, the sheet structure silicates (flat minerals with basal cleavage) such as mica (biotite and muscovite) and chlorite start to grow.
- The sheets orient themselves perpendicular to the direction of maximum stress.
- The new parallel mineral flakes produce a planar texture called foliation. (from the Latin folium - leaf).
- Foliation can be subtle or pronounced depending on the degree of metamorphism.

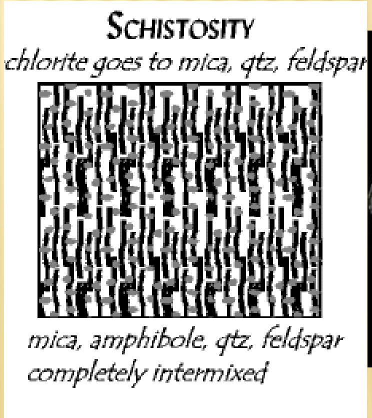




METAMORPHIC ROCK TEXTURES

- The foliated textures develop in the sequence listed below as temperature and pressure increases. Here we just define the textures. Below are descriptions and illustrations of how each texture develops.

- Slaty cleavage is formed as a result of parallel foliation (layering) of fine-grained platy minerals (chlorite) in a direction perpendicular to the direction of maximum stress. Exmaples of such rocks are Slate and Phyllite.

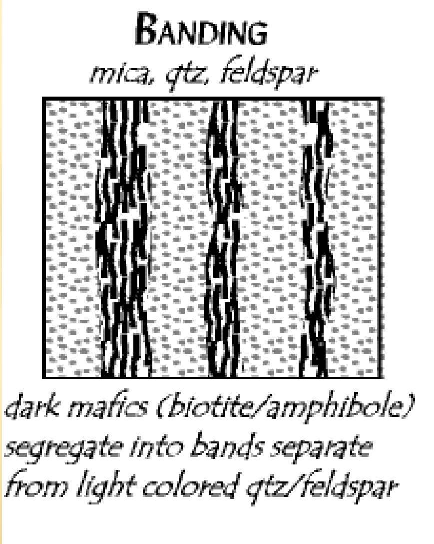


- Schistosity is formed as a result of the layering in a coarse grained, crystalline rock due to the parallel arrangement of platy mineral grains such as muscovite and biotite.

- Other minerals present are typically quartz and feldspar, plus a variety of other minerals such as garnet, staurolite, kyanite, sillimanite.

METAMORPHIC ROCK TEXTURES

- **Mineral Banding (Gneiss)** is the layering in a rock in which bands or lenses of granular minerals (quartz and feldspar) alternate with bands or lenses in which platy (mica) or elongate (amphibole) minerals predominate.



METAMORPHIC ROCK TEXTURES

- **Non foliated textures** are formed around igneous intrusions where the temperatures are high but the pressures are relatively low and equal in all directions (confining pressure).

- The original minerals within the rock recrystallize into larger sizes and the atoms become more tightly packed together, increasing the density of the rock.

- Examples of such rock types are **Quartzite** and **Marble**.

METAMORPHIC ROCK TEXTURES

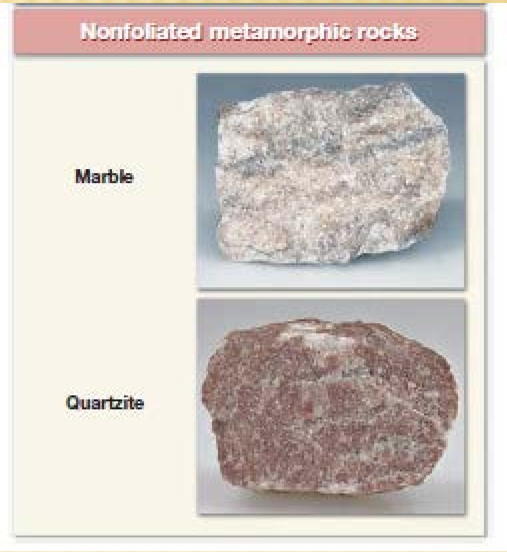
- When the parent rock is composed only of a single mineral, metamorphism changes the rocks into one composed of the same mineral but with a coarser texture.
- Example **Limestone changes to Marble** and **Quartz Sandstone changes to Quartzite**

METAMORPHIC ROCK TEXTURES

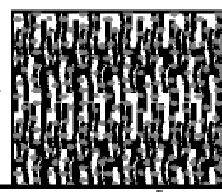
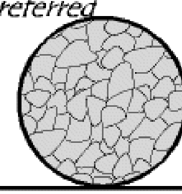
- In contrast, metamorphism of a parent rock containing several minerals usually forms a rock with new and different minerals and a new texture.
- For example, a typical shale contains large amounts of clay, as well as quartz and feldspar.
- When heated, some of those minerals decompose, and their atoms recombine to form new minerals such as mica, garnet, and a different kind of feldspar to form a rock called hornfels which has a different texture and as well as minerals than shale.

COMMON METAMORPHIC ROCKS

- Metamorphic Rocks are divided into two basic divisions
- 1. Foliated/Banded
- 2.Non-Foliated (also, granular or equidimensional)



Textural Classification of Metamorphic Rocks

	Foliated	Non-Foliated Granular	Types of Metamorphism
Chemistry	Complex composition with many different kinds of minerals.	Simple composition with only a few minerals, such as calcite ($CaCO_3$) and quartz (SiO_2).	
Mineralogy	Many new minerals produced with changes in T and P. Including chlorite, biotite, garnet, staurolite, kyanite, and sillimanite..	No new minerals produced. Calcite stays calcite and silica stays silica.	
Texture	Foliation = Slaty cleavage, schistosity, or banding. 	Granular, equidimensional grains with no preferred orientation. 	
Representative Rocks	Slates, Phyllites, Schists, and Gneisses. See "Development of Barrovian Metamorphic Rocks From A Shale Parent." Barrovian	Shale to Hornfels	Contact Only
		Qtz SS to Quartzite Limestone to Marble	Contact and Regional
		Basalt to Soapstone or Serpentinite	Hydrothermal

FOLIATED METAMORPHIC ROCKS

- Slate is a fine grained (less than 0.5 mm) foliated rock composed of mica flakes.
- Slate is dull colored and closely resembles shale.
- The most important characteristic of shale is its tendency to break into flat slabs.
- Slate is generally formed by low grade metamorphism of shale, mudstone or siltstone.
- Color of slate depends upon its mineral composition.
- Black slate contains organic material. Red slate contains Iron Oxide.
- Green slate contains chlorite.

FOLIATED METAMORPHIC ROCKS

- **Phyllite**: It represents a degree of metamorphism in between slate and schist.

- Its constituent platy minerals are larger than those in slate but still not large enough to be identified with the naked eye.

- Phyllite appears similar to slate but can be distinguished from slate by its glossy sheen and wavy surface.

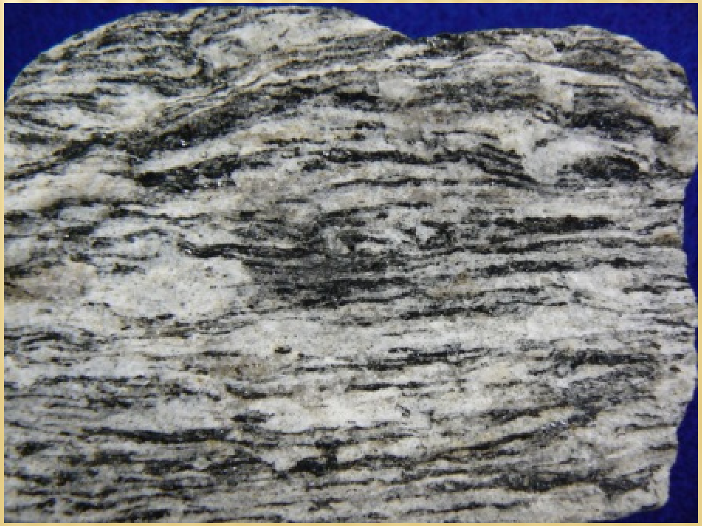
- Phyllite also breaks as a flat surface and is composed of fine crystals of muscovite or chlorite or both.

FOLIATED METAMORPHIC ROCKS

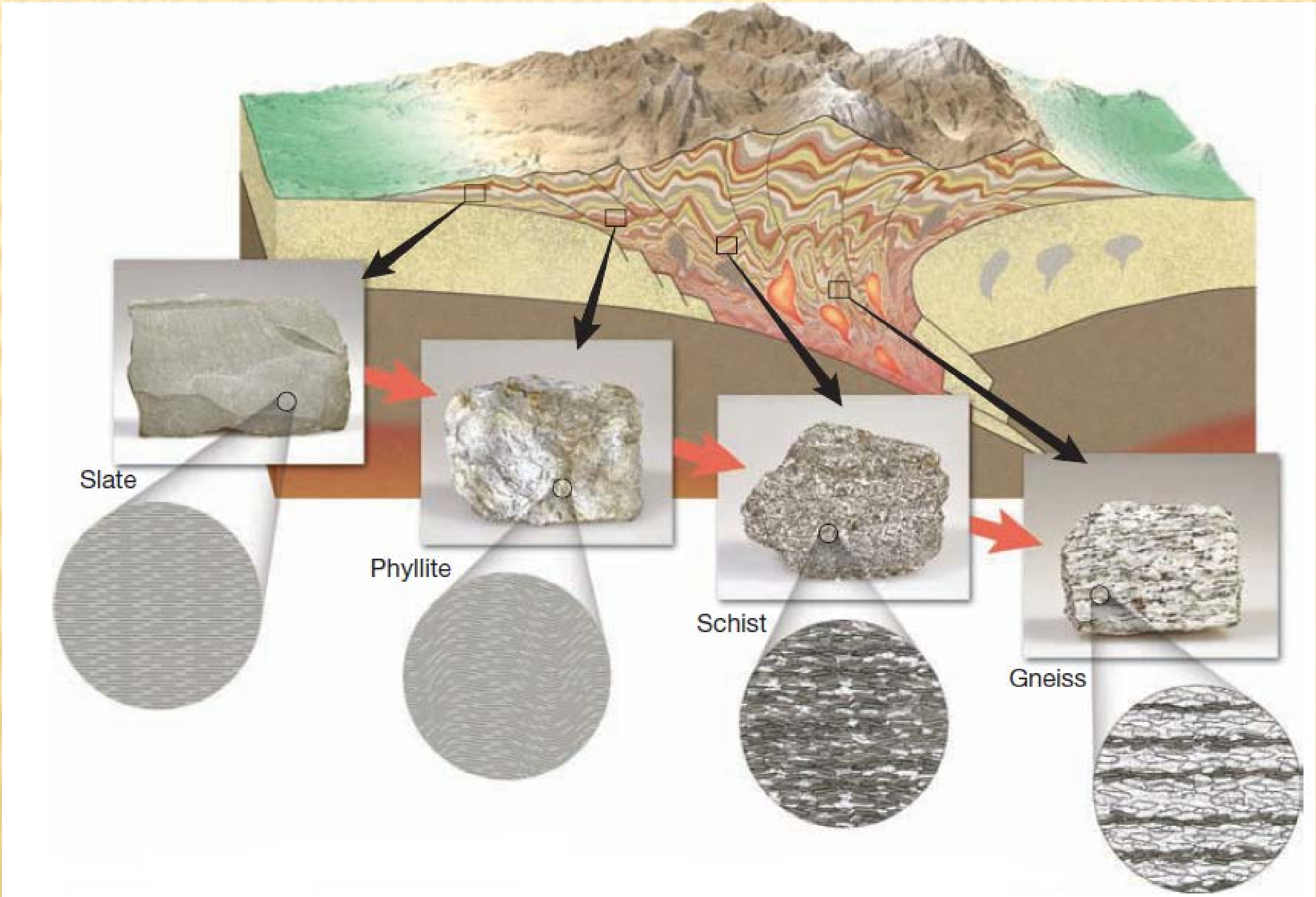
- Schists are medium to coarse grained metamorphic rocks in which platy minerals predominate.
- These minerals include muscovite and biotite.
- These platy minerals are arranged in a planar fashion that gives the rock its foliated texture.
- In addition to mica, schist also contains other minerals such as quartz and feldspars.
- Like slate, the parent rock for many schists are also shale which has undergone medium to high grade metamorphism during the process of mountain building.
- Schist is the name given to the texture of the metamorphic rock.
- To indicate the composition minerals names are used such as mica scist, talc schist, chlorite schist.

FOLIATED METAMORPHIC ROCKS

- **Gneiss** is the term applied to medium or coarse grained banded metamorphic rocks in which granular and elongated minerals predominate.
- The most common minerals in gneiss are Quartz. Potassium feldspar, Na feldspar.
- Gneiss also contains smaller amounts of biotite, muscovite and amphibole that develop a preferred orientation.
- During the high grade metamorphism the dark and light colored minerals segregate giving the gneisses their typical banded or layered appearance.
- Most gneisses have a felsic composition, however some of them are also formed by the high grade metamorphism of shale.

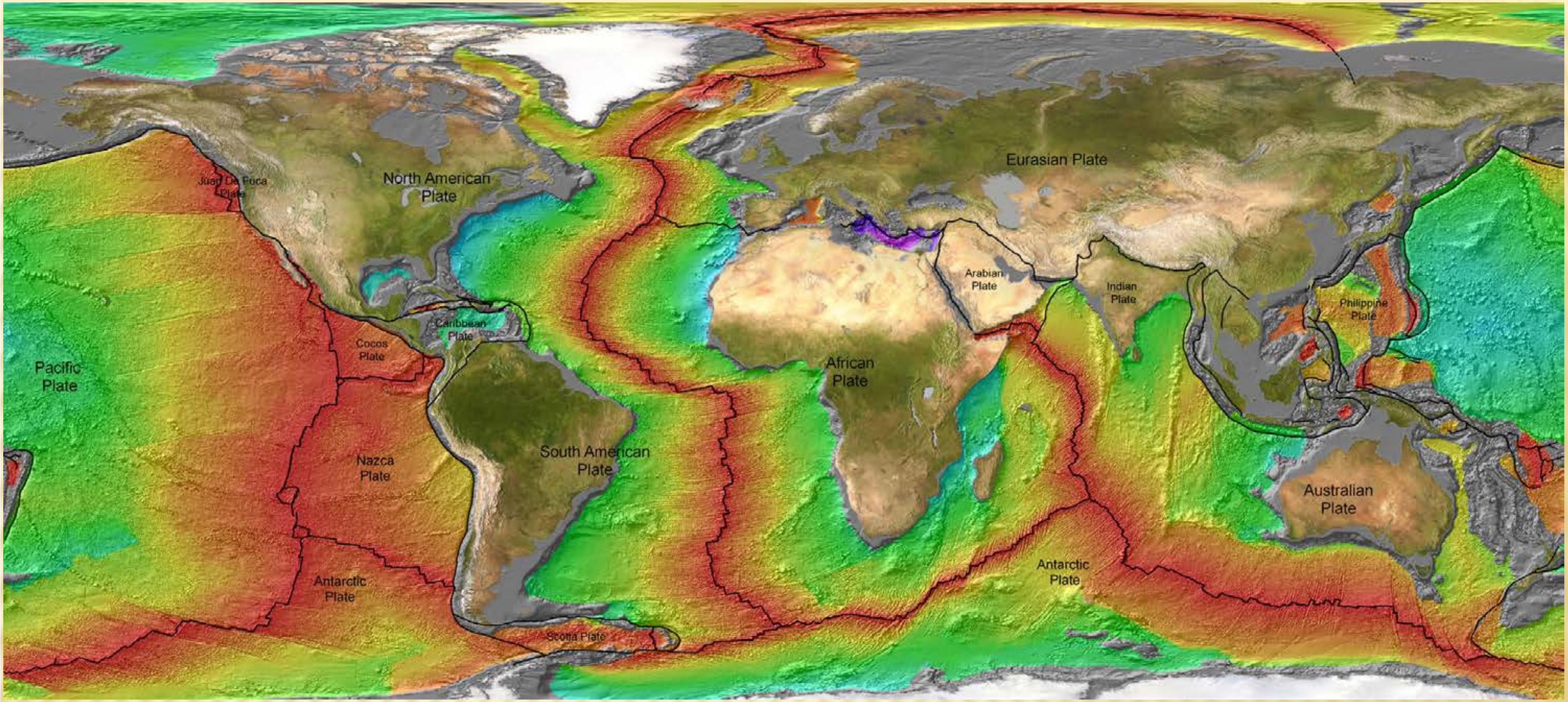


FOLIATED METAMORPHIC ROCKS



NON-FOLIATED METAMORPHIC ROCKS

- Marble: It is a coarse grained crystalline rock whose parent rock was limestone or dolostone.
- Pure marble is white and is composed entirely of the mineral calcite.
- The parent rocks from which marbles are formed often contain some impurities and this imparts color to marble.
- Marble can be pink, gray or even black in color.
- Quartzite: It is a very hard metamorphic rock formed from quartz sandstone.
- They are formed under moderate to high grade metamorphism.
- The crystals of quartz fuse together when they undergo metamorphism and as result the crystal size for quartzite is much bigger than its parent rock.



UNIT 6

PLATE TECTONICS

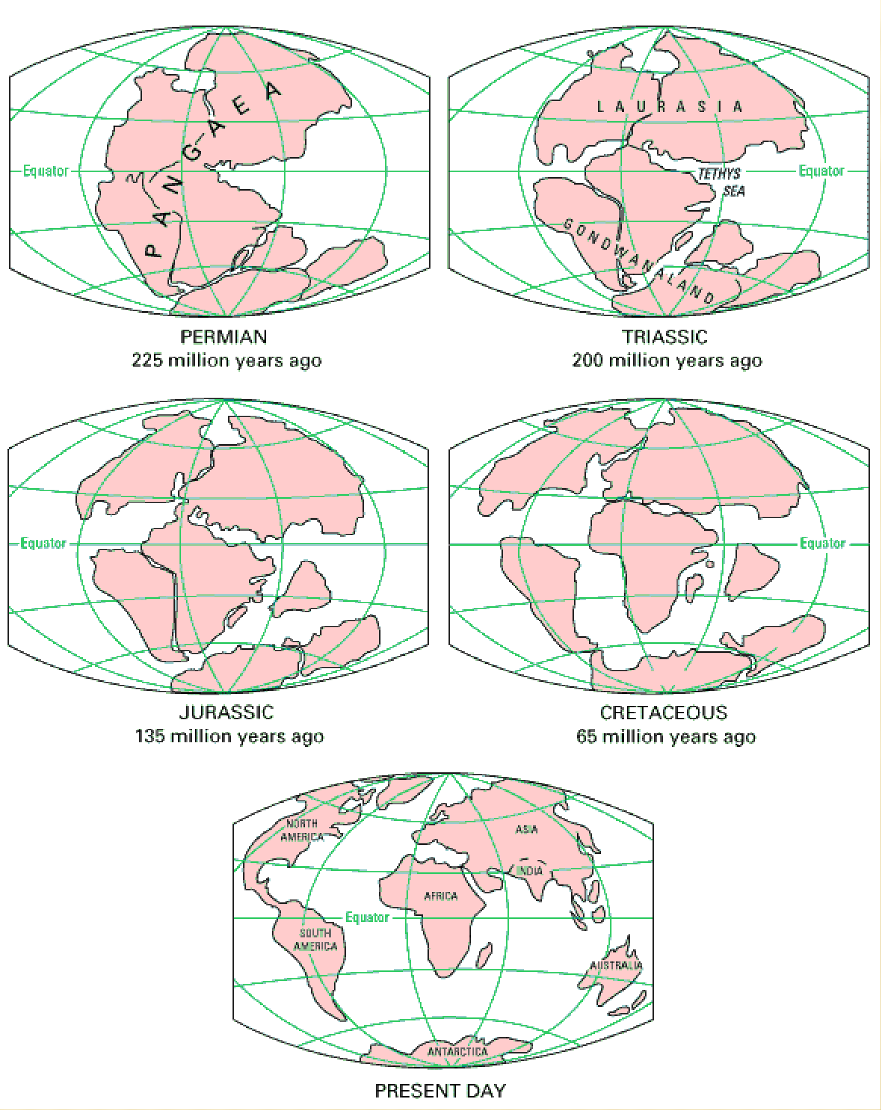
CONTINENTAL DRIFT

- Alfred Wegner proposed the theory that the crustal plates are moving over the mantle.

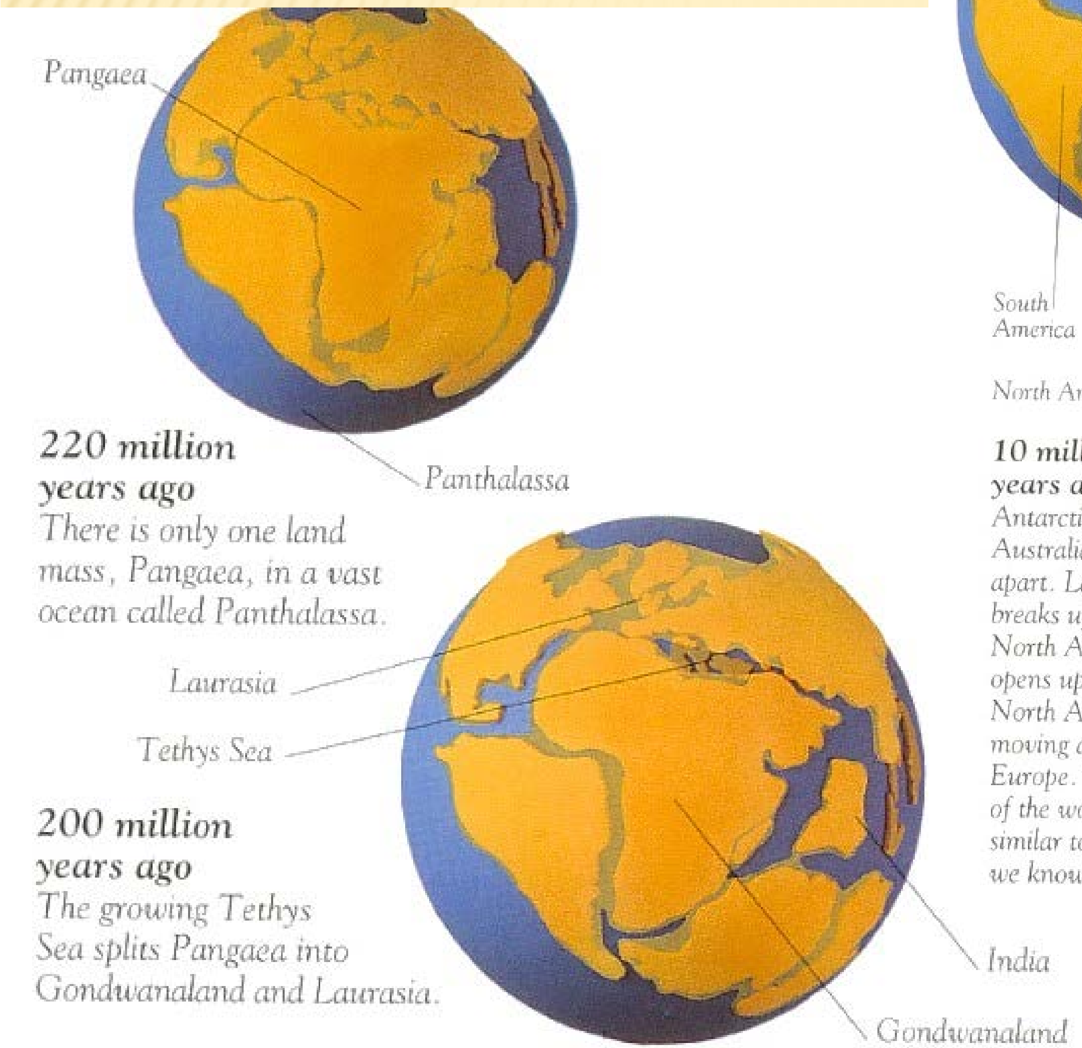
- He argued that today's continents once formed a single landmass, called Pangaea (Greek for "all land").

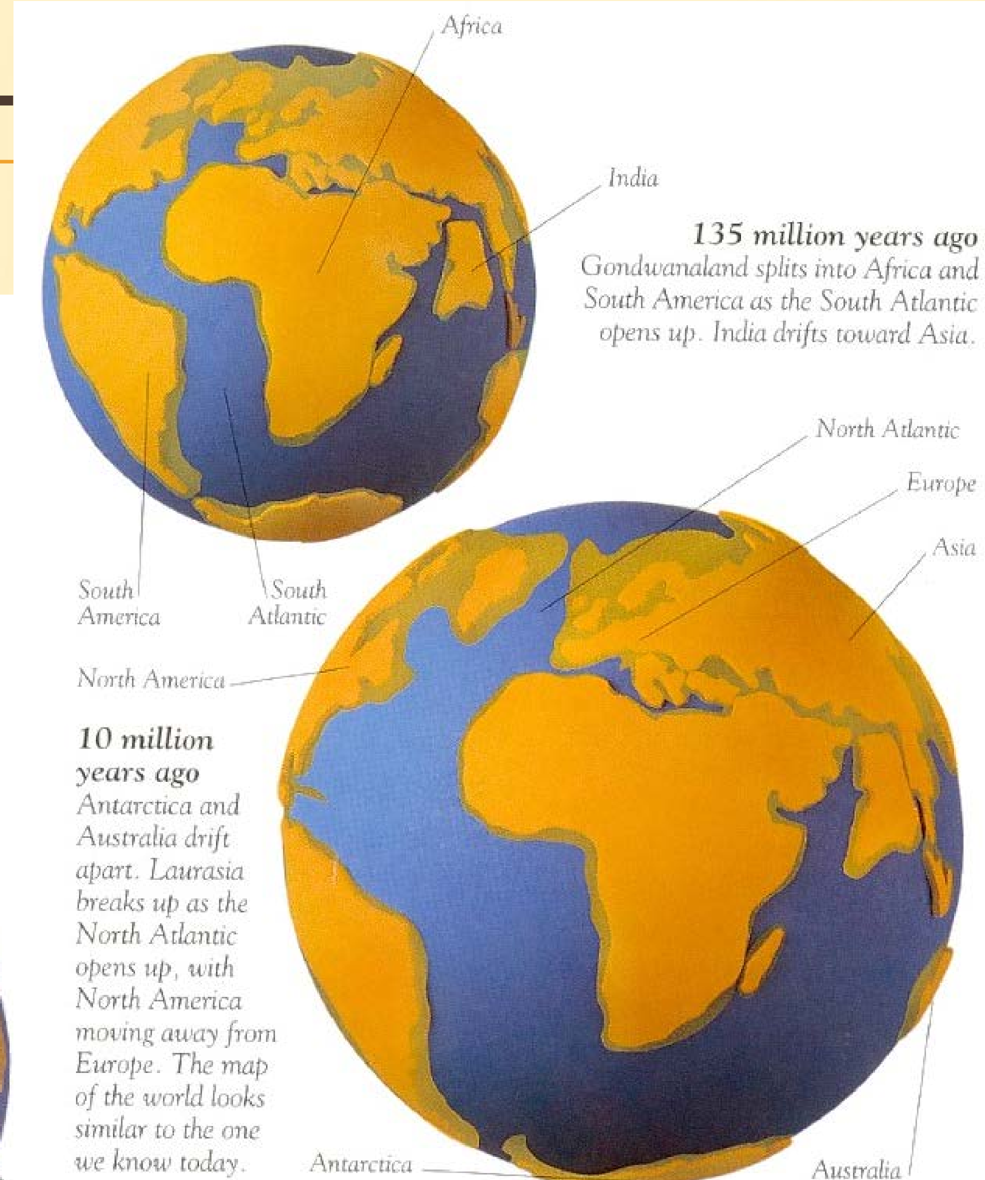
- It broke into pieces due to the weaknesses in the earth's crust as they were made up of less dense materials, which drifted centimeter by centimeter over millions of years until they arrived at where they are now.

- This was supported by fossil and rock type evidence; also matching of coastline shapes.



CONTINENTAL DRIFT

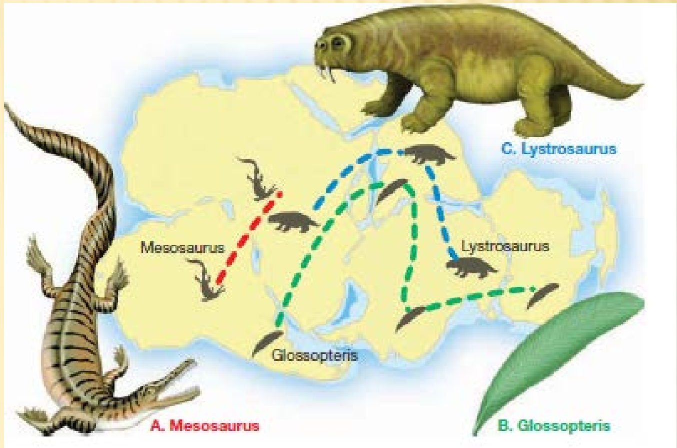


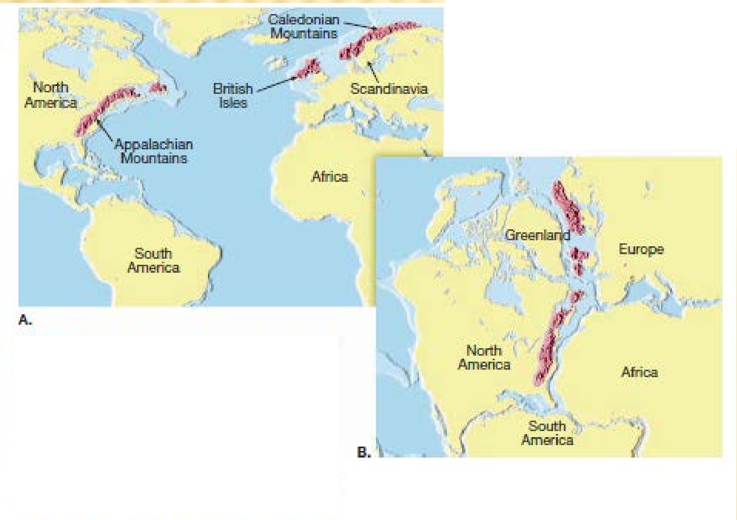


EVIDENCES OF CONTINENTAL DRIFT

The Continental Jigsaw Puzzle

Fossils Match across the Seas





Rock Types and Geologic Features

Ancient Climates

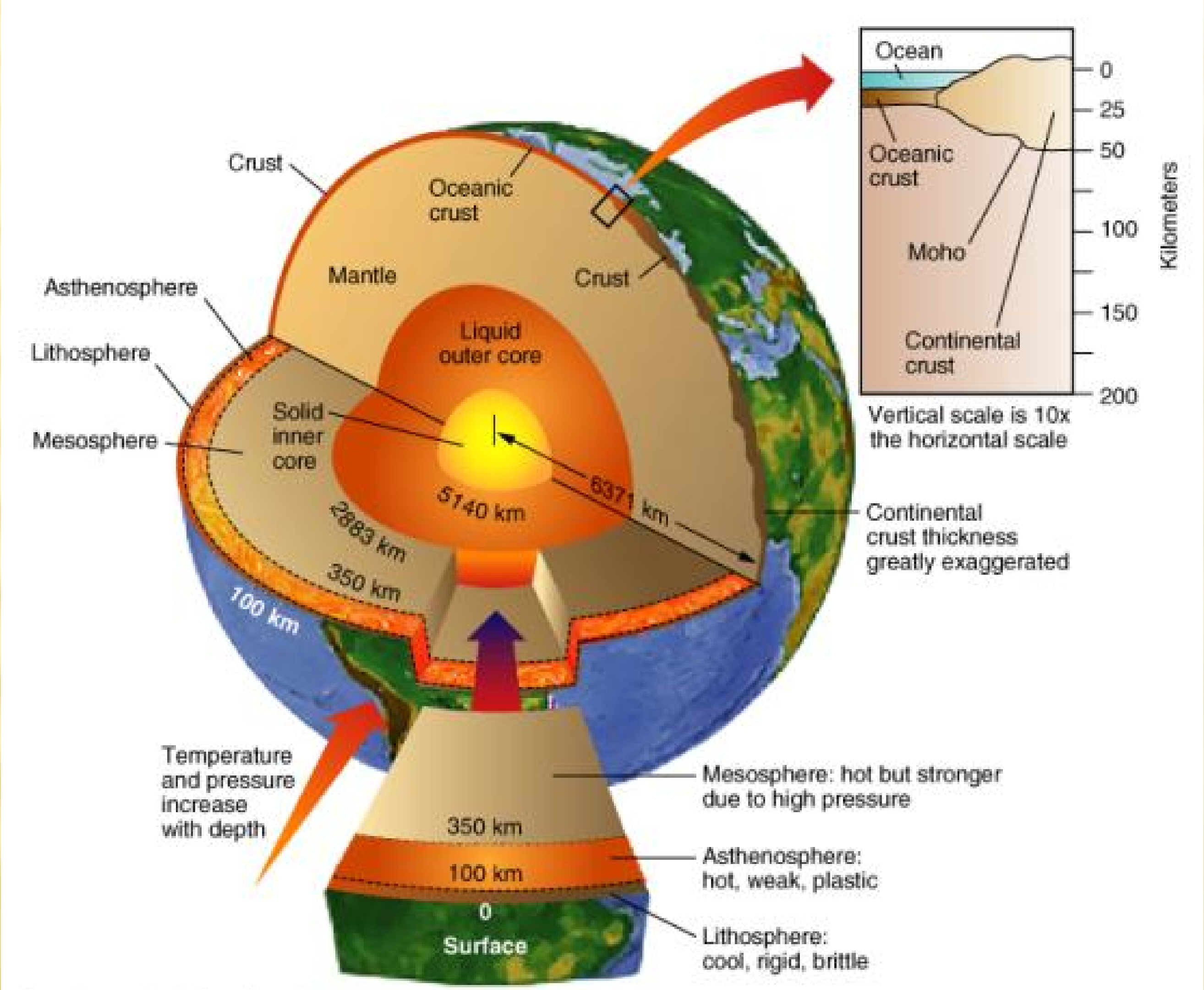
DRAWBACKS OF CONTINENTAL DRIFT HYPOTHESIS

- One of the main objections to Wegener's hypothesis was his inability to identify a credible mechanism for continental drift.
- Wegener proposed that gravitational forces of the Moon and Sun that produce Earth's tides were also capable of gradually moving the continents across the globe.
- However, the prominent physicist Harold Jeffreys correctly countered that tidal forces of the magnitude needed to displace the continents would bring Earth's rotation to a halt in a matter of a few years.
- Wegener also incorrectly suggested that the larger and sturdier continents broke through thinner oceanic crust, much like ice breakers cut through ice.
- However, no evidence existed to suggest that the ocean floor was weak enough to permit passage of the continents without the continents being appreciably deformed in the process.

THE PLATE TECTONIC THEORY

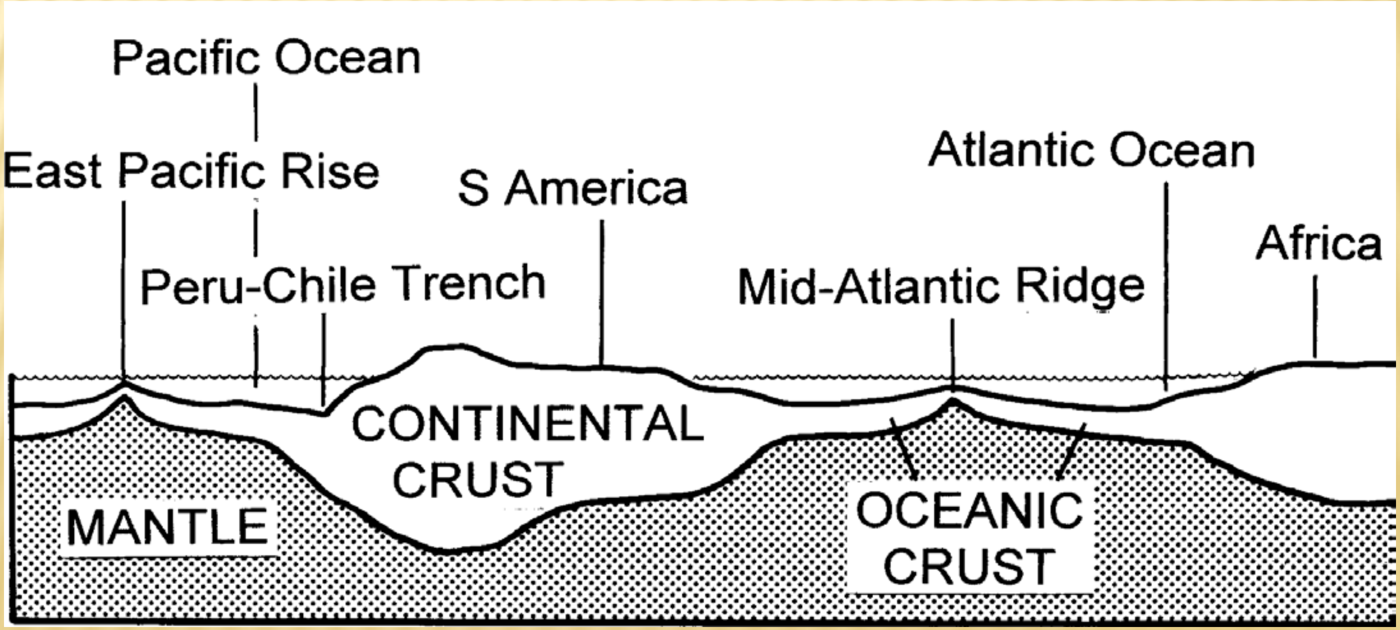
- By 1968, a far more encompassing theory than continental drift, known as plate tectonics.
- According to the plate tectonics model, the uppermost mantle and the overlying crust behave as a strong, rigid layer, known as the lithosphere, which is broken into segments commonly referred to as plates.
- The lithosphere is thinnest in the oceans where it varies from as little as a few kilometers along the axis of the oceanic ridge system to about 100 kilometers in the deep-ocean basins.
- By contrast, continental lithosphere is generally thicker than 100 kilometers and may extend to a depth of 200 to 300 kilometers beneath stable continental cratons.
- The lithosphere, in turn, overlies a weak region in the mantle known as the asthenosphere.
- The temperatures and pressures in the upper asthenosphere (100 to 200 kilometers in depth) are such that the rocks there are very near their melting temperatures and, hence, respond to stress by flowing.
- As a result, Earth's rigid outer shell is effectively detached from the layers below, which permits it to move independently.

THE EARTH LAYERS



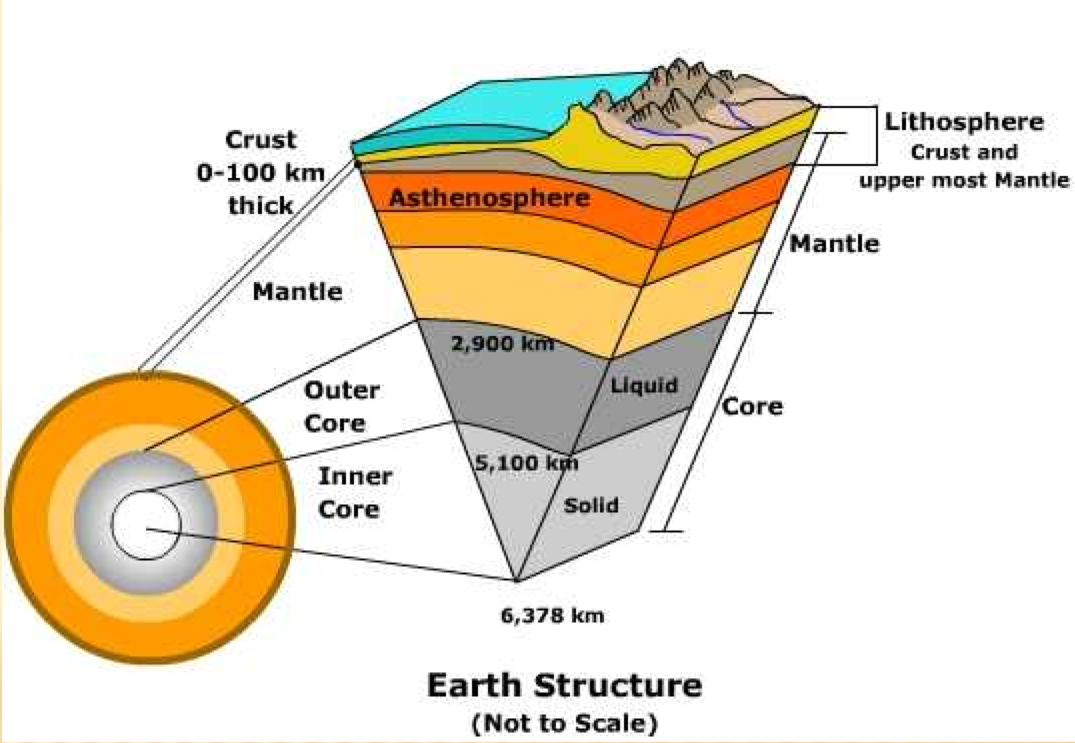
THE EARTH LAYERS

- Crust: The crust is the outermost and thinnest layer. Because the crust is relatively cool, it consists of hard, strong rock. Crust beneath the oceans differs from that of continents.
- Oceanic crust is 5 to 10 kilometers thick and is composed mostly of a dark, dense rock called basalt.
- In contrast, the average thickness of continental crust is about 20 to 40 kilometers, although under mountain ranges it can be as much as 70 kilometers thick.
- Continents are composed primarily of a light-colored, less dense rock called granite.



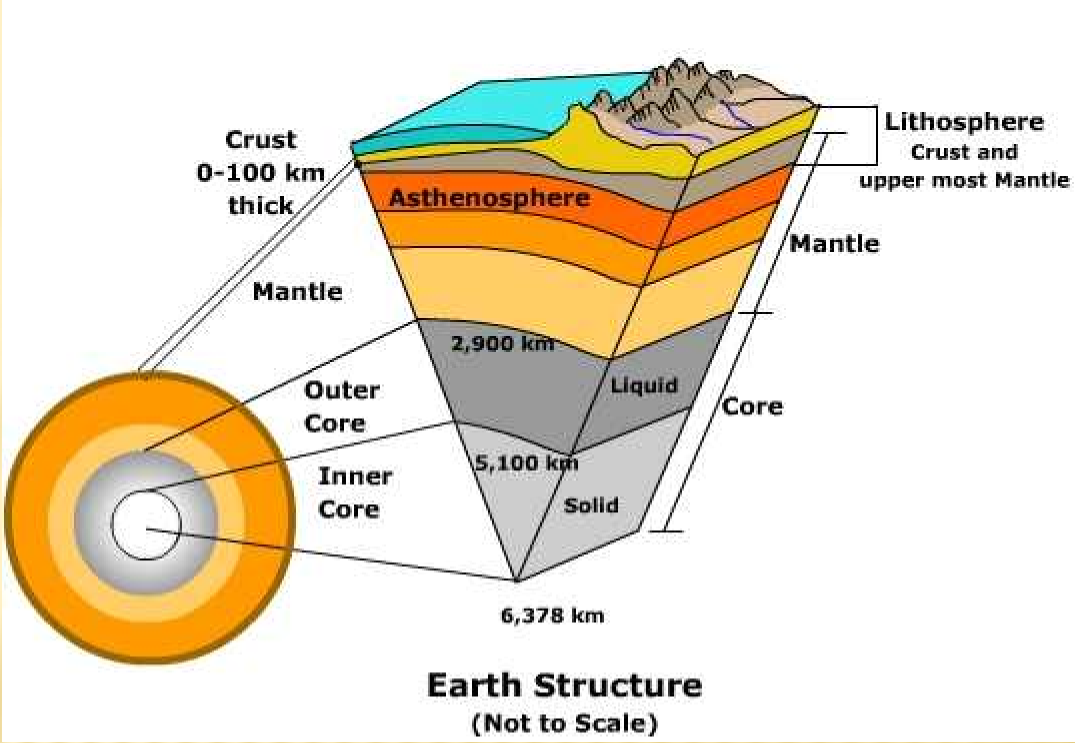
THE EARTH LAYERS

- Mantle: The mantle lies directly below the crust.
- It is almost 2900 kilometers thick and makes up 80 percent of the Earth's volume.
- Although the chemical composition may be similar throughout the mantle, Earth temperature and pressure increase with depth.
- These changes cause the strength of mantle rock to vary with depth, and thus they create layering within the mantle.
- The upper part of the mantle consists of two layers.



THE EARTH LAYERS

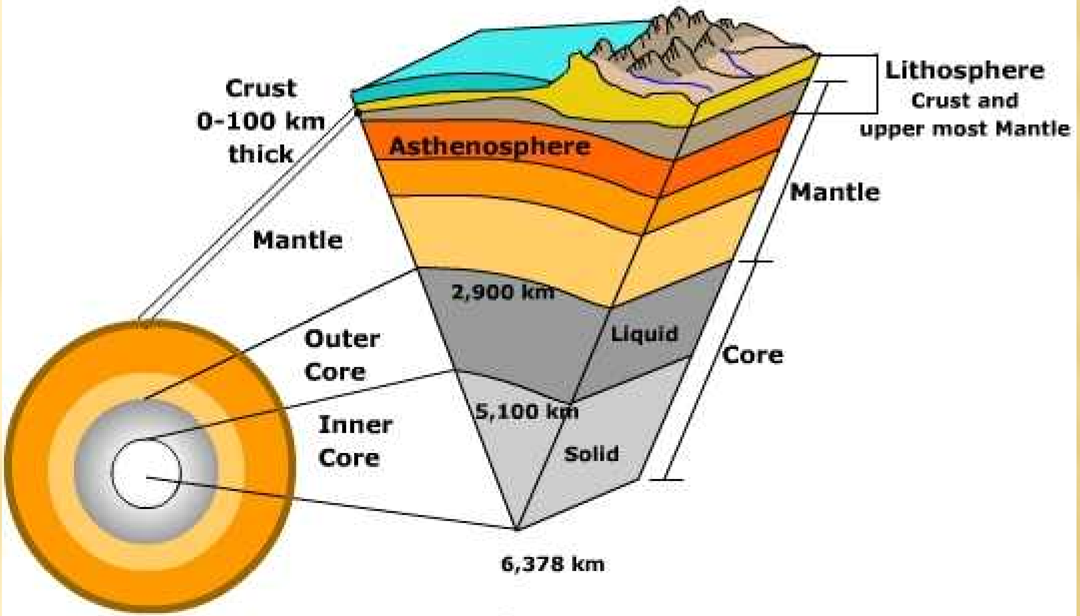
- The Lithosphere: The uppermost mantle is relatively cool and consequently is hard, strong rock.
- The outer part of the Earth, including both the uppermost mantle and the crust, make up the lithosphere (Greek for "rock layer").
- The lithosphere can be as thin as 10 kilometers where tectonic plates separate.
- However, in most regions, the lithosphere varies from about 75 kilometers thick beneath ocean basins to about 125 kilometers under the continents.
- A tectonic (or lithospheric) plate is a segment of the lithosphere.



THE EARTH LAYERS

- The Asthenosphere: At a depth varying from about 75 to 125 kilometers, the strong, hard rock of the lithosphere gives way to the weak, plastic asthenosphere.

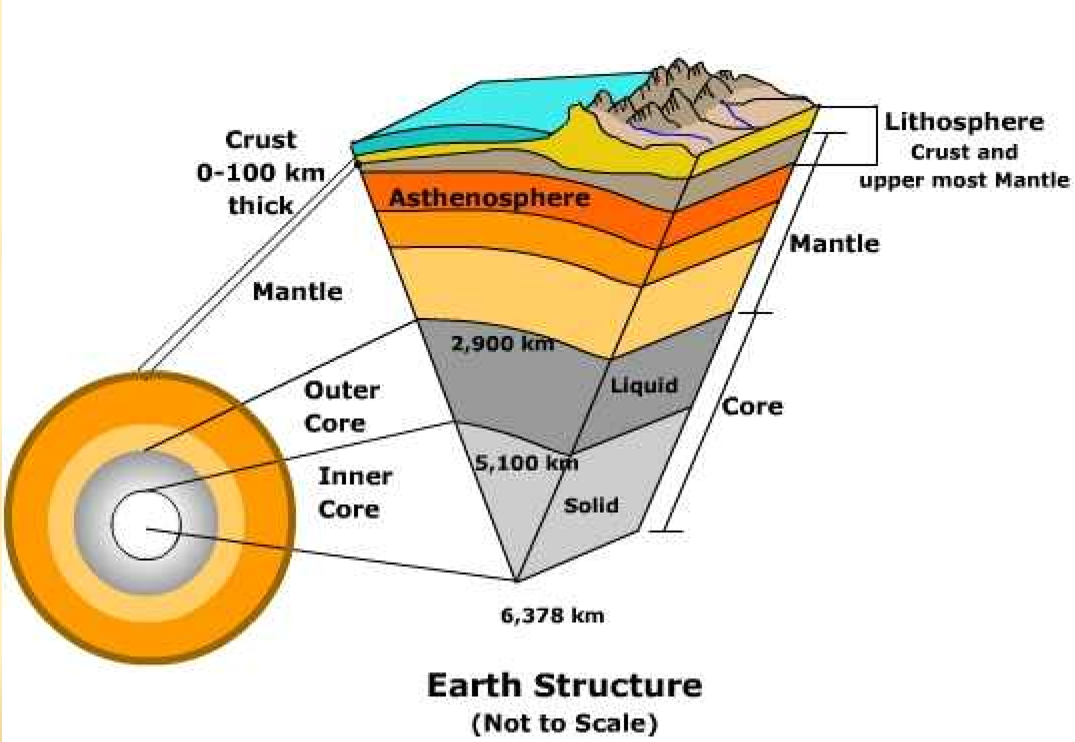
- The asthenosphere extends from the base of the lithosphere to a depth of about 350 kilometers.



Earth Structure
(Not to Scale)

THE EARTH LAYERS

- The Core: The core is the innermost of the Earth's layers.
- It is a sphere with a radius of about 3470 kilometers and is composed largely of iron and nickel.
- The outer core is molten because of the high temperature in that region.
- Near its center, the core's temperature is about 6000ºC, as hot as the Sun's surface.
- The pressure is greater than 1 million times that of the Earth's atmosphere at sea level.
- The extreme pressure overwhelms the temperature effect and compresses the inner core to a solid.



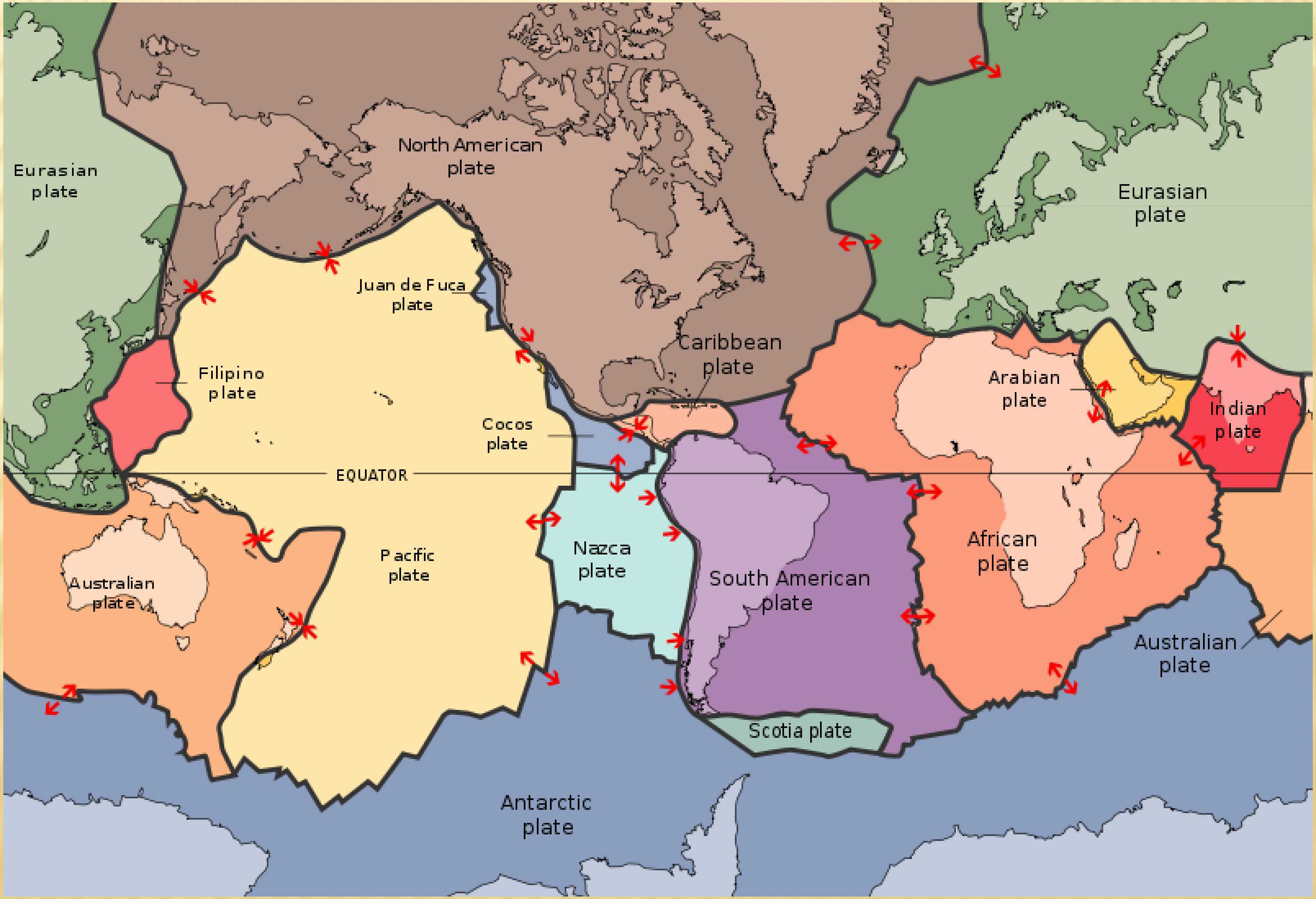
THE EARTH LAYERS

	LAYER	COMPOSITION	DEPTH	PROPERTIES
Crust	Oceanic crust Continental crust	Basalt Granite	5–10 km 20–70 km	Cool, hard, and strong Cool, hard, and strong
Lithosphere	Lithosphere includes the crust and the uppermost portion of the mantle	Varies; the crust and the mantle have different compositions	75–125 km	Cool, hard, and strong
Mantle	Uppermost portion of the mantle included as part of the lithosphere Asthenosphere Remainder of upper mantle Lower mantle	Entire mantle is ultramafic rock. Its mineralogy varies with depth	Extends to 350 km Extends from 350 to 660 km Extends from 660 to 2900 km	Hot, weak, and plastic, 1% or 2% melted Hot, under great pressure, and mechanically strong High pressure forms minerals different from those of the upper mantle
Core	Outer core Inner core	Iron and nickel Iron and nickel	Extends from 2900 to 5150 km Extends from 5150 km to the center of the Earth	Liquid Solid

PLATES AND PLATE TECTONICS

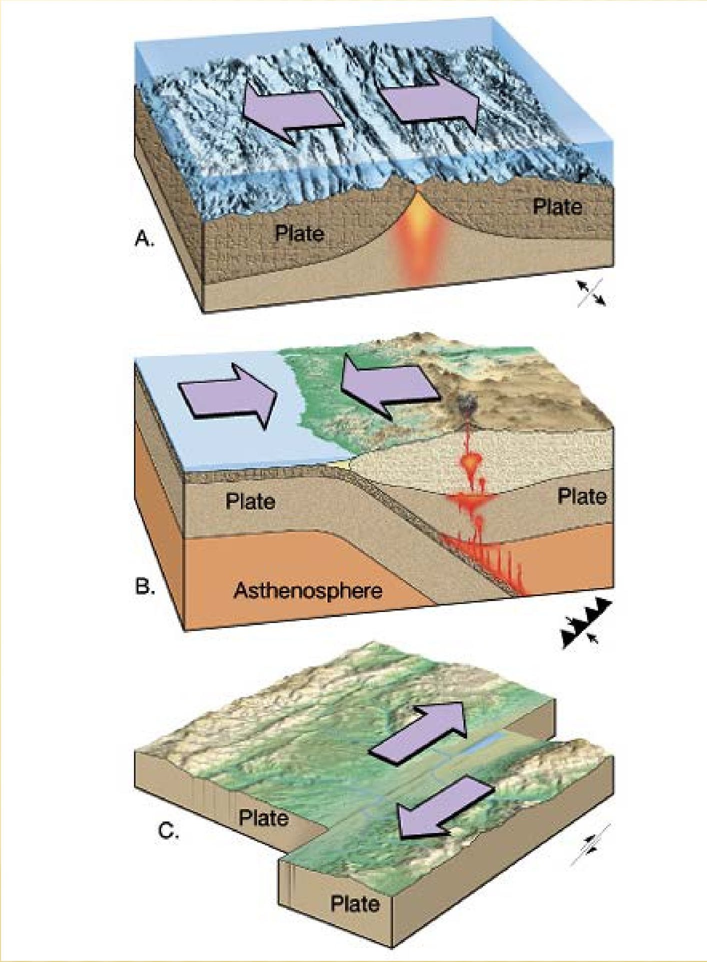
- In most places, the lithosphere is less dense than the asthenosphere. Consequently, it floats on the asthenosphere much as ice floats on water.
- The lithosphere is broken into seven large tectonic plates and several smaller ones.
- The plates move slowly, at rates ranging from less than 1 to about 16 centimeters per year.
- The great forces generated at a plate boundary build mountain ranges and cause volcanic eruptions and earthquakes.
- These processes and events are called tectonic activity.

TECTONIC PLATES

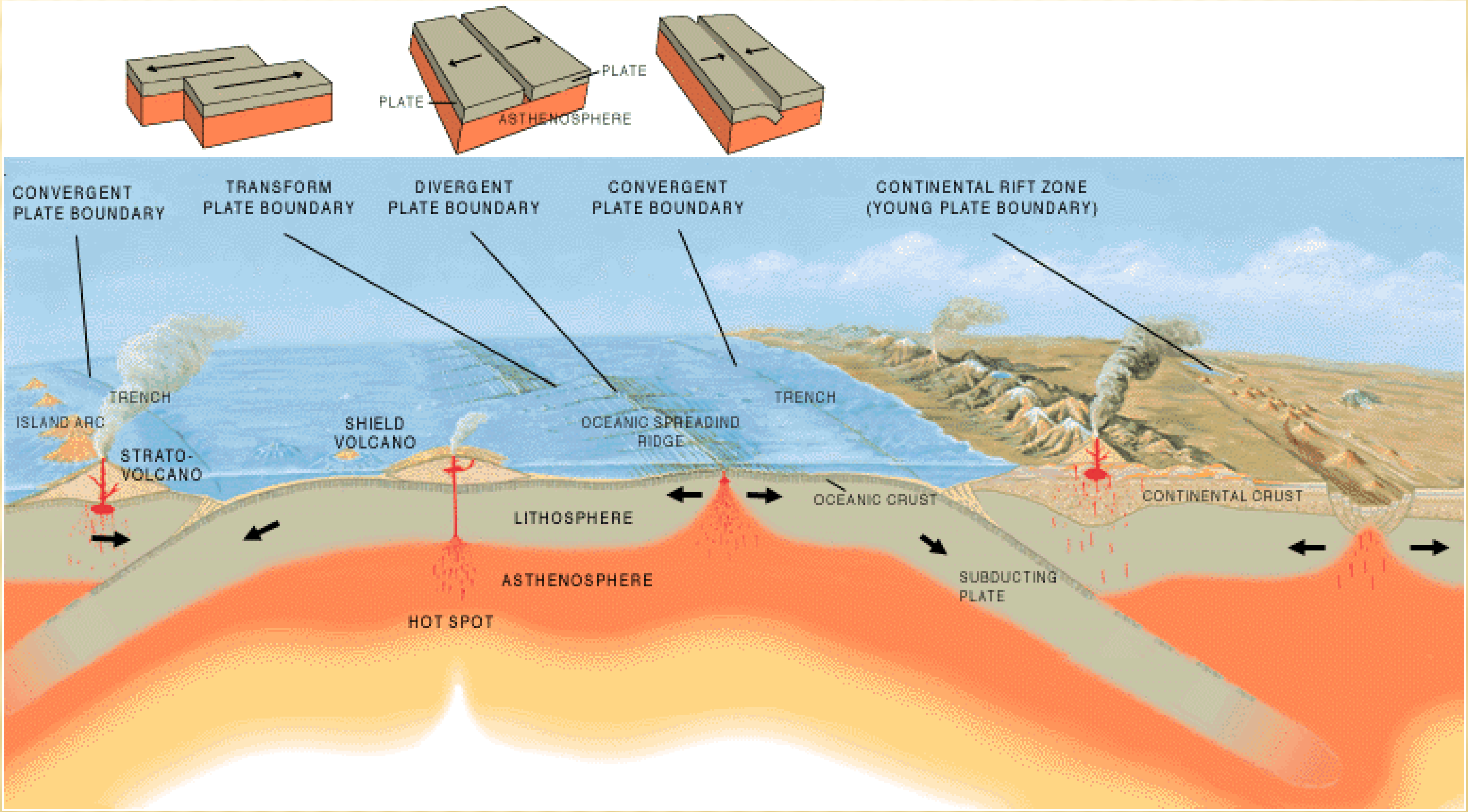


TYPES OF PLATE BOUNDARIES

- Neighboring plates can move relative to one another in three different ways.
- **Divergent boundaries (Constructive)** occur where two plates slide apart from each other. (A)
- **Convergent boundaries (Destructive) (or active margins)** occur where two plates slide towards each other commonly forming either a subduction zone (if one plate moves underneath the other) or a continental collision (if the two plates contain continental crust). (B)
- **Transform boundaries (Conservative)** occur where plates slide or, perhaps more accurately, grind past each other along transform faults. (C)

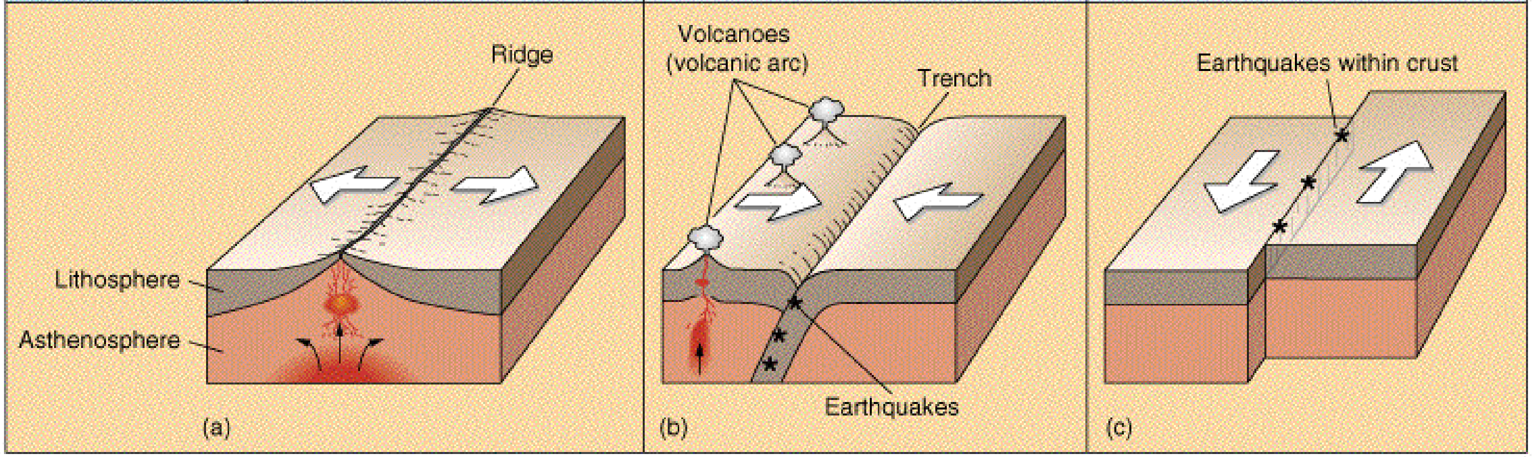


TYPE OF PLATE BOUNDARIES

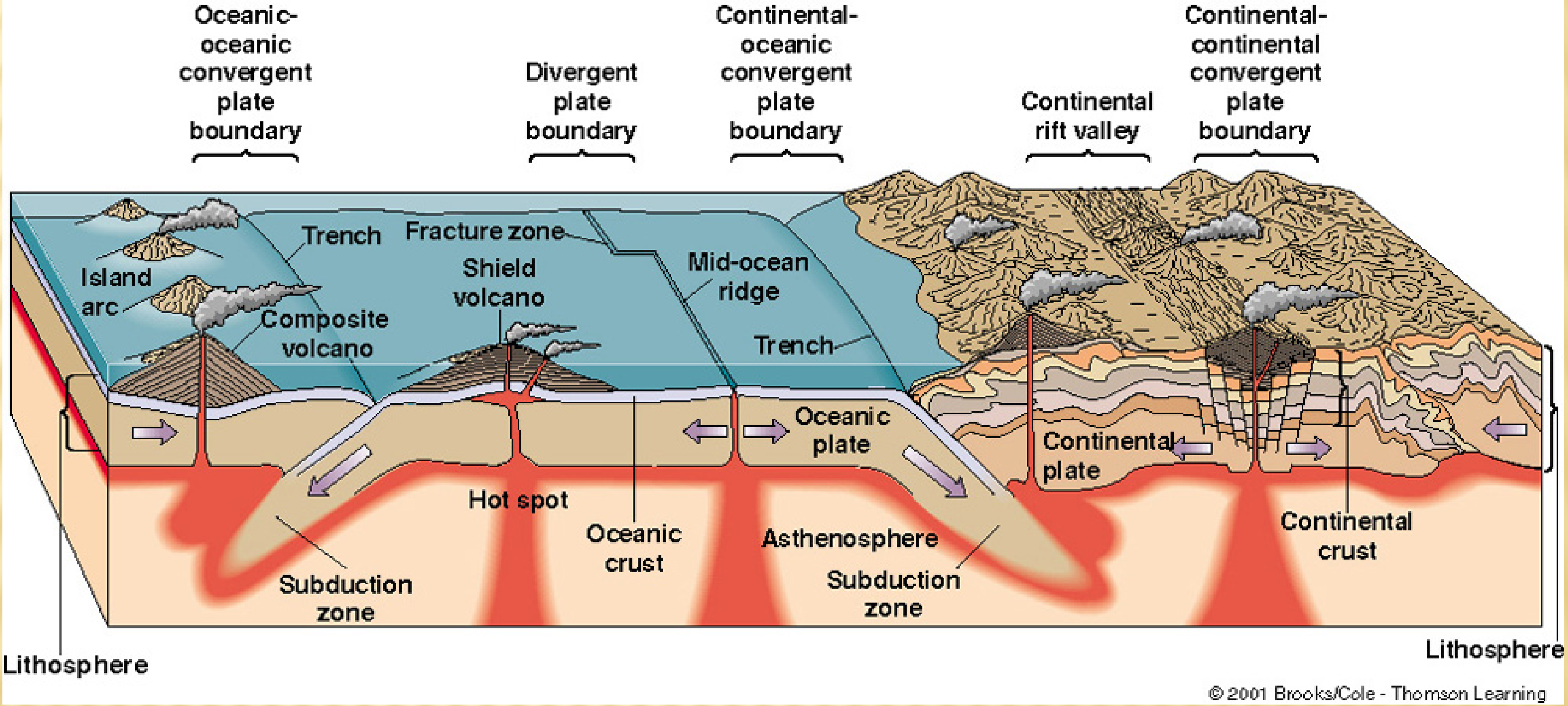


TYPE OF PLATE BOUNDARIES

Type of Margin	Divergent	Convergent	Transform
Motion	Spreading	Subduction	Lateral sliding
Effect	Constructive (oceanic lithosphere created)	Destructive (oceanic lithosphere destroyed)	Conservative (lithosphere neither created or destroyed)
Topography	Ridge/Rift	Trench	No major effect
Volcanic activity?	Yes	Yes	No

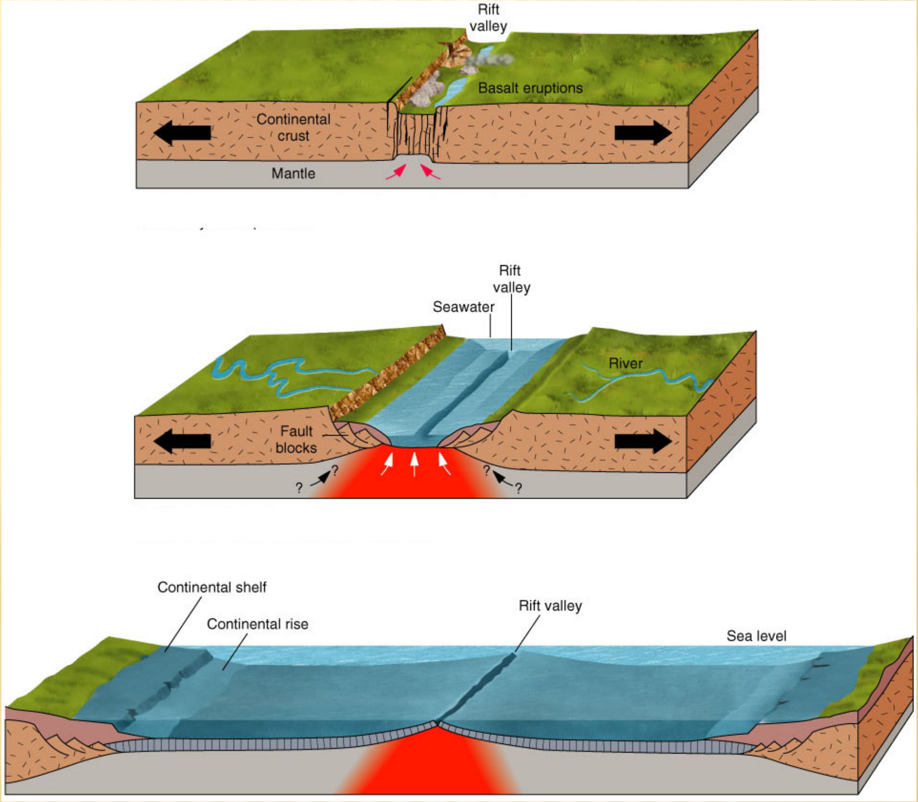


TYPE OF PLATE BOUNDARIES



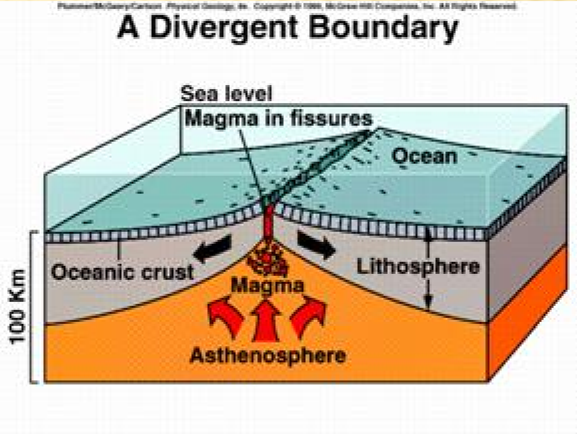
DIVERGENT PLATE BOUNDARIES

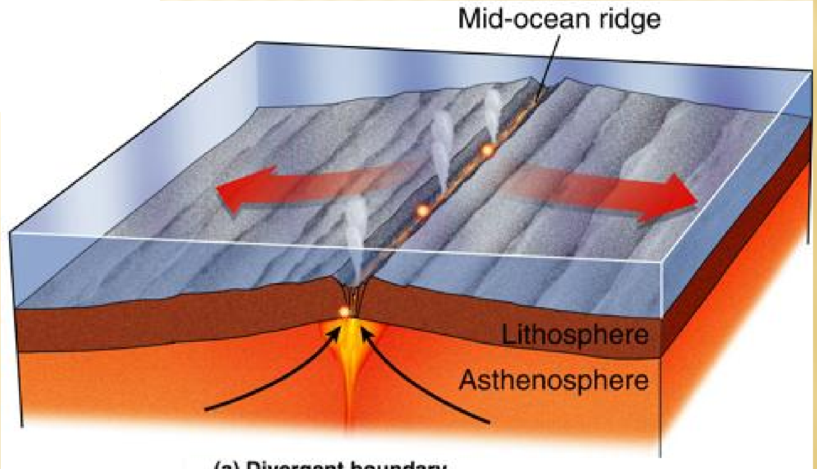
- At a divergent plate boundary, also called a spreading center and a rift zone, two lithospheric plates spread apart.
- The underlying asthenosphere then rises upward to fill the gap between the separating plates.
- As the asthenosphere rises between separating plates, some of it melts to form molten rock called magma.
- Most of this activity occurs beneath the seas because most divergent plate boundaries lie in the ocean basins.



THE MID-OCEANIC RIDGE: RIFTING IN THE OCEANS

- A spreading center lies directly above the hot, rising asthenosphere.
- The newly formed lithosphere at an oceanic spreading center is hot and therefore of low density.
- As a results, the sea floor at a spreading center floats to a high elevation, forming an undersea mountain chain called the **mid-oceanic ridge.**

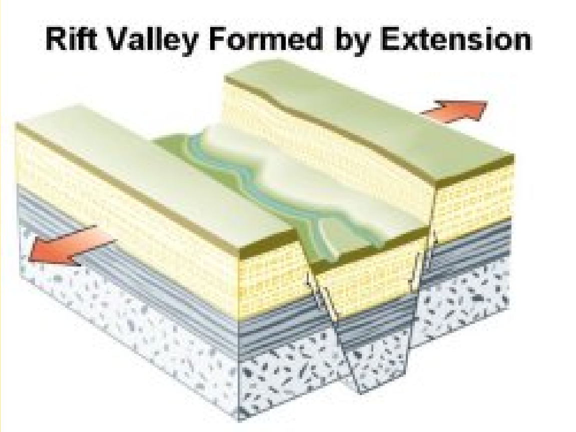


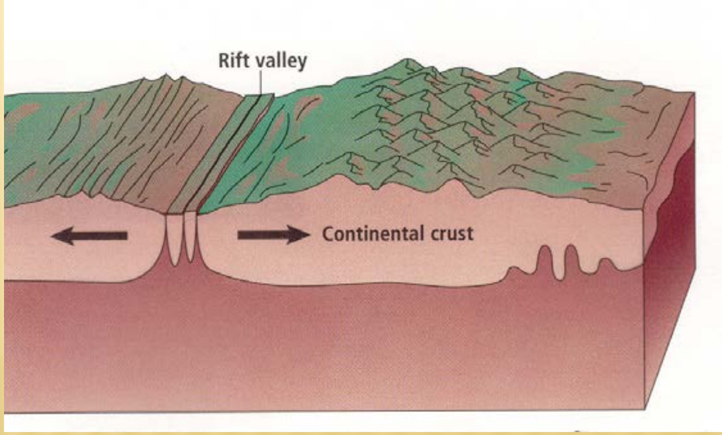


(a) Divergent boundary

SPLITTING CONTINENTS: RIFTING IN CONTINENTAL CRUST

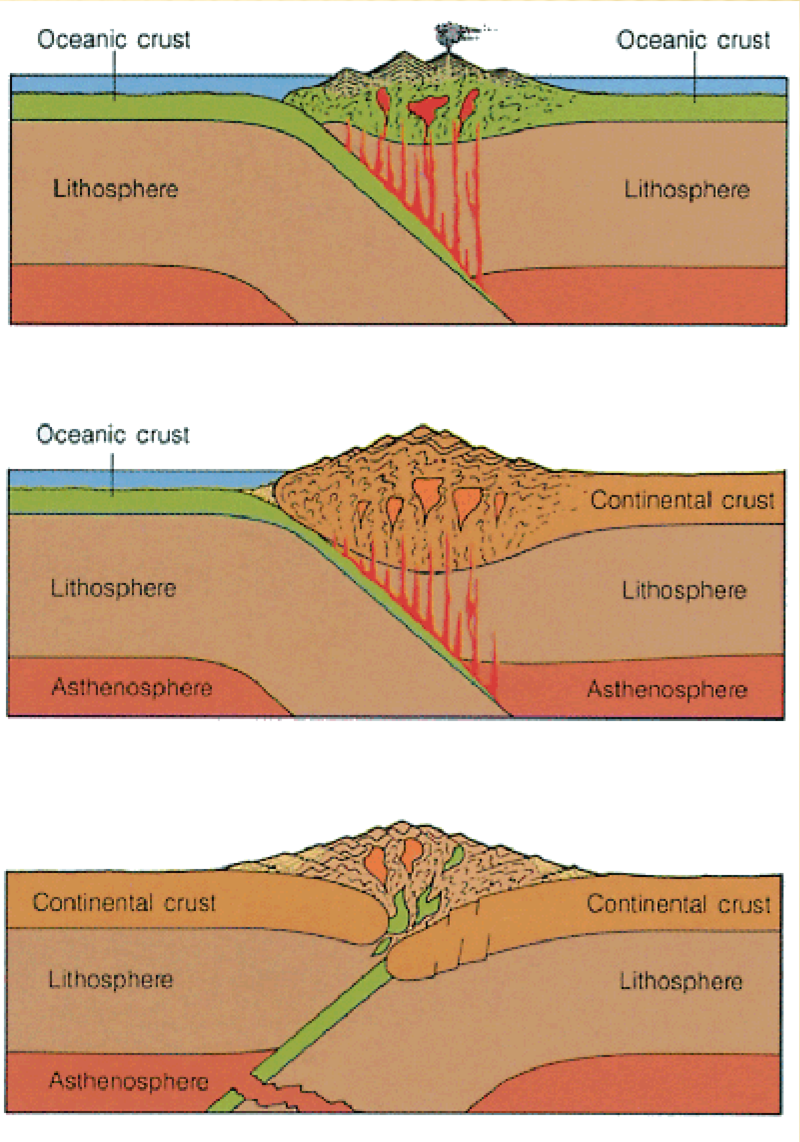
- A divergent plate boundary can rip a continent in half in a process called continental rifting.
- A rift valley develops in a continental rift zone because continental crust stretches, fractures, and sinks as it is pulled apart.
- Continental rifting is now taking place along a zone called the East African rift





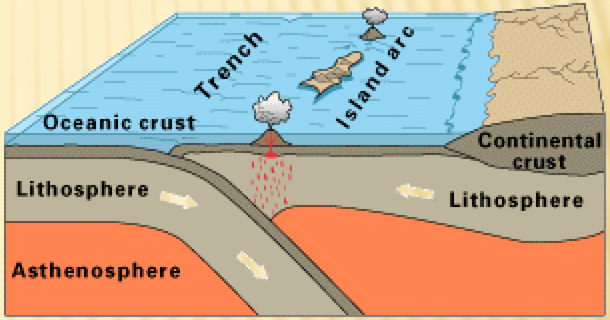
CONVERGENT PLATE BOUNDARIES

- At a convergent plate boundary, two lithospheric plates move toward each other. Convergence can occur in three different ways
- (1) between a plate carrying oceanic crust and another carrying continental crust,
- (2) between two plates carrying oceanic crust, and
- (3) between two plates carrying continental crust.
- Differences in density determine what happens where two plates converge. When two plates converge, the denser plate dives beneath the lighter one and sinks into the mantle. This process is called **subduction.**
- A **subduction zone** is a long, narrow belt where a lithospheric plate is sinking into the mantle.

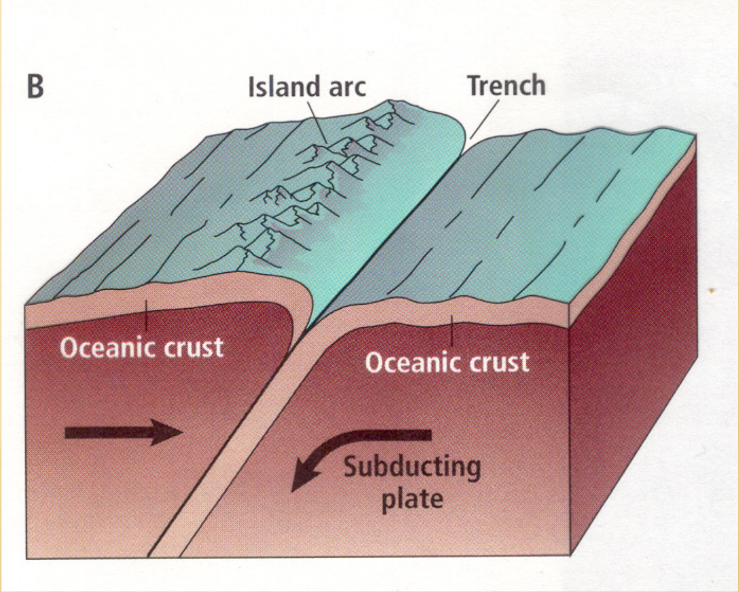


CONVERGENCE OF TWO PLATES CARRYING OCEANIC CRUST

- Newly formed oceanic lithosphere is hot, thin, and light.
- As it spreads away from the mid-oceanic ridge, it becomes older, cooler, thicker, and denser.
- Thus the density of oceanic lithosphere increases with its age. When two oceanic plates converge, the denser one sinks into the mantle.
- Convergence of two oceanic plates creates and island arc and trench. e.g. Japan

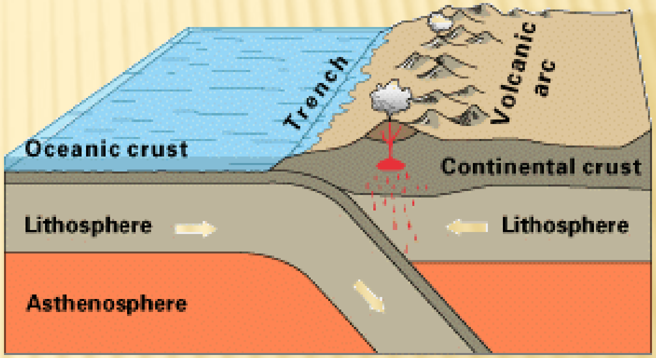


Oceanic-oceanic convergence

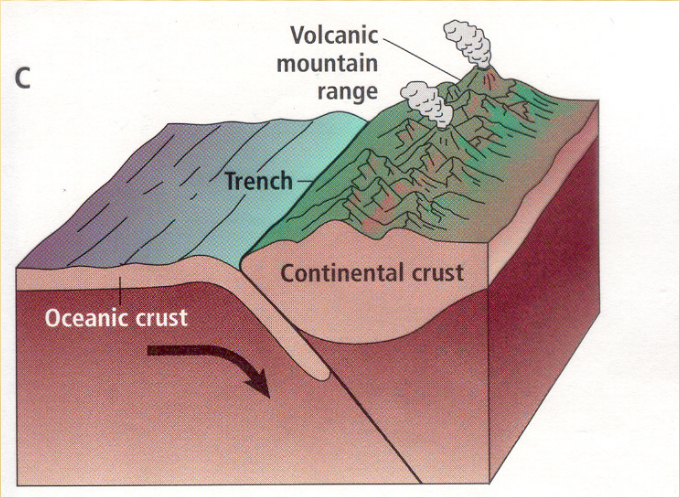


CONVERGENCE OF OCEANIC CRUST WITH CONTINENTAL CRUST

- When an oceanic plate converges with a continental plate, the denser oceanic plate sinks into the mantle beneath the edge of the continent.
- As a result, many subduction zones are located at continental margins.
- Convergent boundary of an oceanic and continental plates forms a volcanic mountain range and trenches. e.g. Andes Mountains

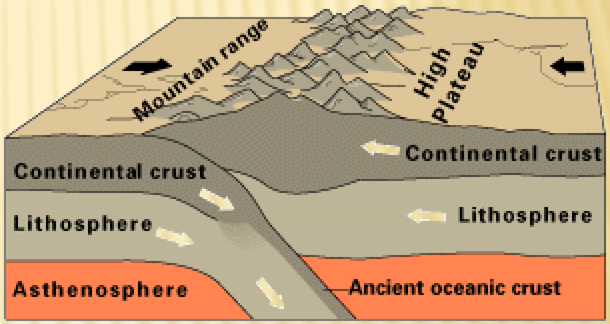


Oceanic-continental convergence

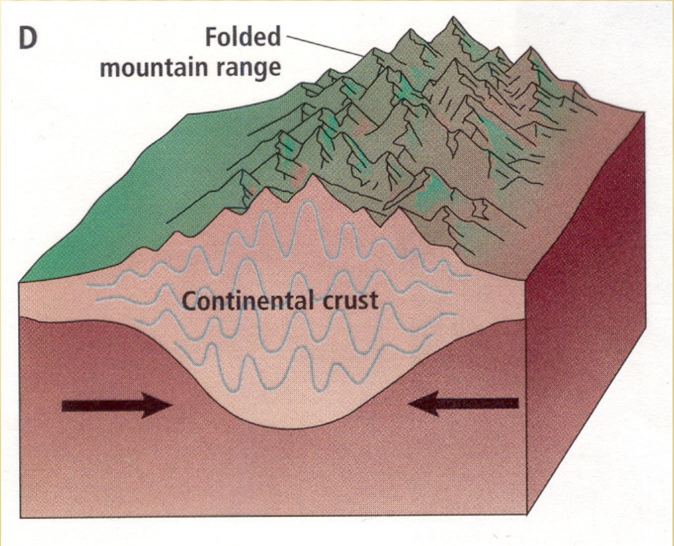


CONVERGENCE OF TWO PLATES CARRYING CONTINENTS

- If two converging plates carry continents, neither can sink into the mantle because of their low densities.
- In this case, the two continents collide and crumple against each other, forming a huge **mountain chain.**
- The Himalayas, the Alps, and the Appalachians all formed as results of continental collisions.

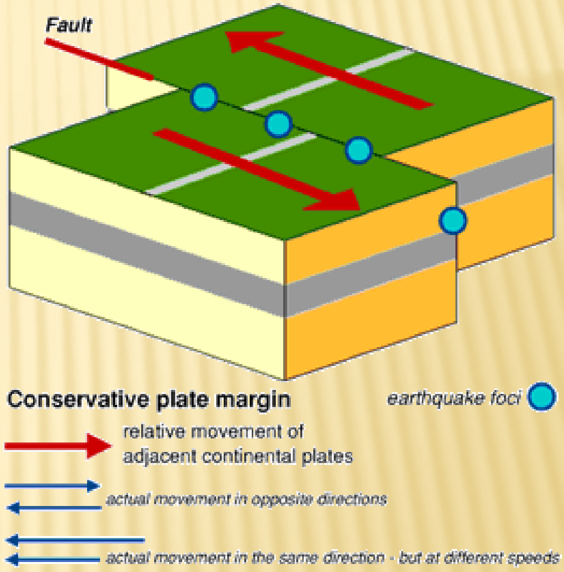


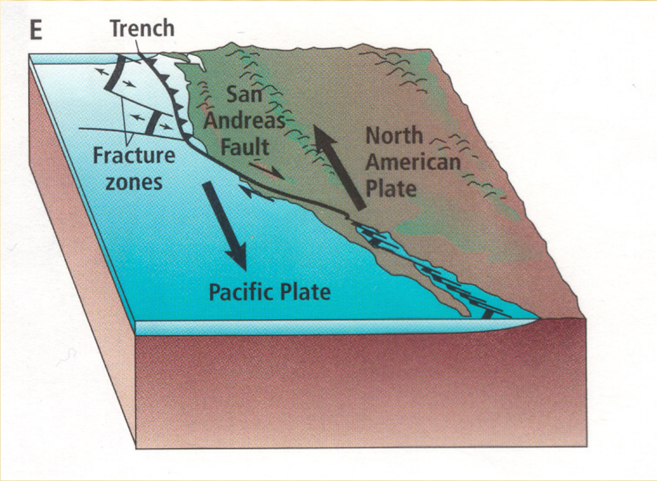
Continental-continental convergence



TRANSFORM PLATE BOUNDARIES

- A transform plate boundary forms where two plates slide horizontally past one another as they move in opposite directions.
- California's San Andreas fault is the transform boundary between the North American plate and the Pacific plate.
- This type of boundary can occur in both oceans and continents.





CHARACTERISTICS OF LITHOSPHERIC PLATES

- A plate is a segment of the lithosphere; thus, it includes the uppermost mantle and all of the overlying crust.
- A single plate can carry both oceanic and continental crust.
- A plate is composed of hard, mechanically strong rock.
- A plate floats on the underlying hot, plastic asthenosphere and glides horizontally over it.
- A plate behaves like a large slab of ice floating on a pond. In general, however, each plate moves as a large, intact sheet of rock.
- A plate margin is tectonically active. Earthquakes and volcanoes are common at plate boundaries. In contrast, the interior of a lithospheric plate is normally tectonically stable.
- Tectonic plates move at rates that vary from less than 1 to 16 centimeters per year.

CONSEQUENCES OF MOVING PLATES

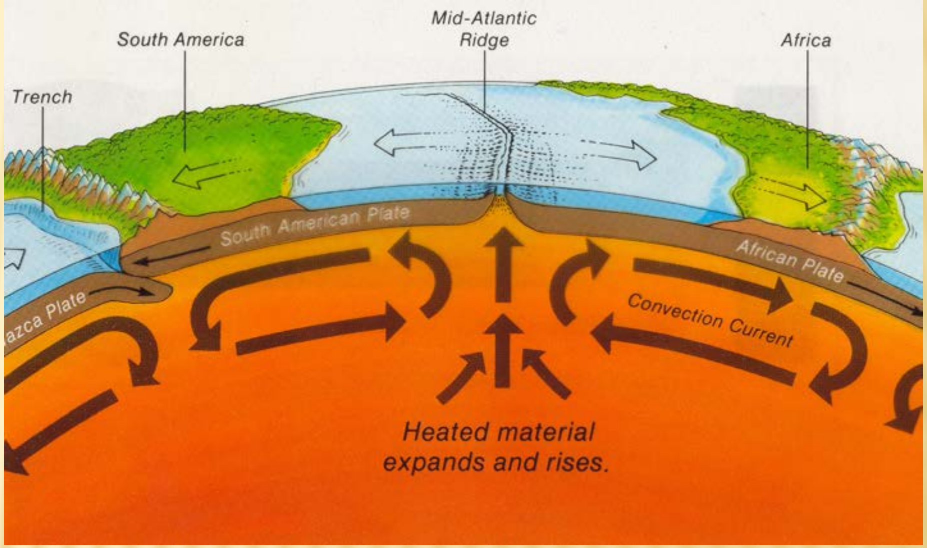
- Volcanoes
  - A volcanic eruption occurs where hot magma rises to the Earth’s surface.
  - Volcanic eruptions are common at both divergent and convergent plate boundaries.
- Earthquakes
  - Earthquakes are common at all three types of plate boundaries, but less common within the interior of a tectonic plate.
  - Quakes concentrate at plate boundaries simply because those boundaries are zones of deep fractures in the lithosphere where one plate slips past another.
- Mountain Building
  - Mountains can be formed both at divergent as well as convergent plate margins.
  - Several processes combine to build a mountain chain at a subduction zone.

CONSEQUENCES OF MOVING PLATES

- **Oceanic Trenches**
  - An oceanic trench is a long, narrow trough in the sea floor that develops where a subducting plate sinks into the mantle.
  - A trench can form wherever subduction occurs—where oceanic crust sinks beneath the edge of a continent, or where it sinks beneath another oceanic plate.
  - Trenches are the deepest parts of the ocean basins.
  - The deepest point on Earth is in the Mariana trench in the southwestern Pacific Ocean, where the sea floor is as much as 10.9 kilometers below sea level (compared with the average sea-floor depth of about 5 kilometers).
- **Migrating Continents and Oceans**
  - Continents migrate over the Earth's surface because they are integral parts of the moving lithospheric plates.
  - Measurements of these movements show that North America is now moving away from Europe at about 2.5 centimeters per year, as the mid-Atlantic ridge continues to separate.
  - South America is drawing away from Africa at a rate of about 3.5 centimeters per year.
  - As the Atlantic Ocean widens, the Pacific is shrinking at the same rate.
  - Thus, as continents move, ocean basins open and close over geologic time.

FORCE BEHIND PLATE TECTONICS

- Mantle convection may cause plate movement.
- Alternatively, a plate may move because it slides downhill from a spreading center, as its cold leading edge sinks into the mantle and drags the rest of the plate along.
- The concept that the lithosphere floats on the asthenosphere is called isostasy.
- When weight such as a glacier is added to or removed from the Earth's surface, the lithosphere sinks or rises.
- This vertical movement in response to changing burdens is called isostatic adjustment.



UNIT - 7

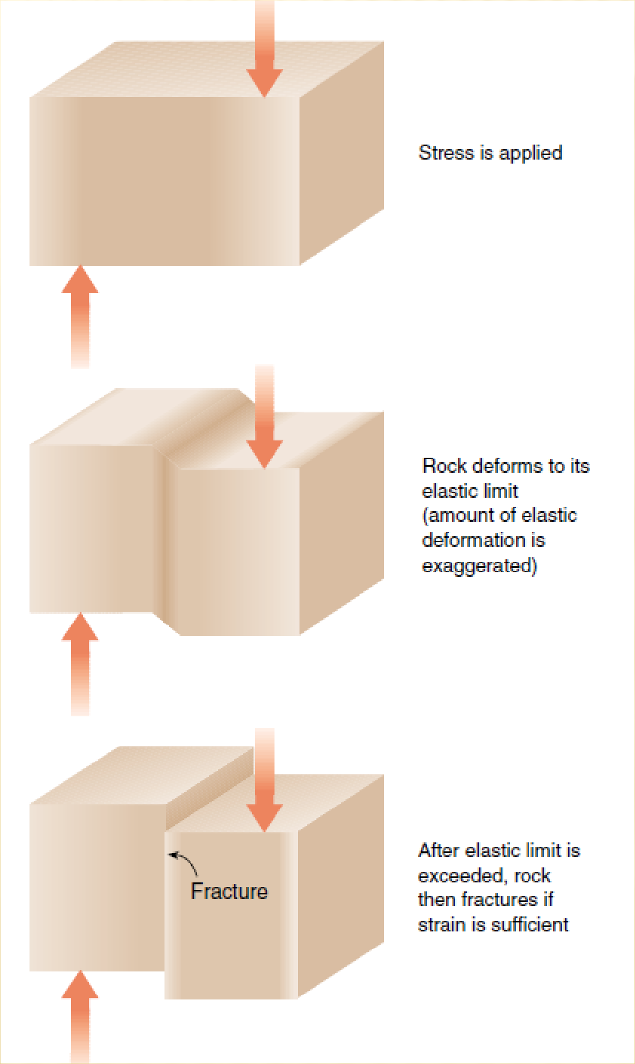
EARTHQUAKES

WHAT IS AN EARTHQUAKE

- An earthquake is a sudden motion or trembling of the Earth caused by the abrupt release of energy that is stored in rocks.
- Modern geologists know that most earthquakes occur along plate boundaries, where huge tectonic plates separate, converge, or slip past one another.
- Earthquakes also occur when rock slips along previously established faults.
- Tectonic plate boundaries are huge faults that have moved many times in the past and will move again in the future.

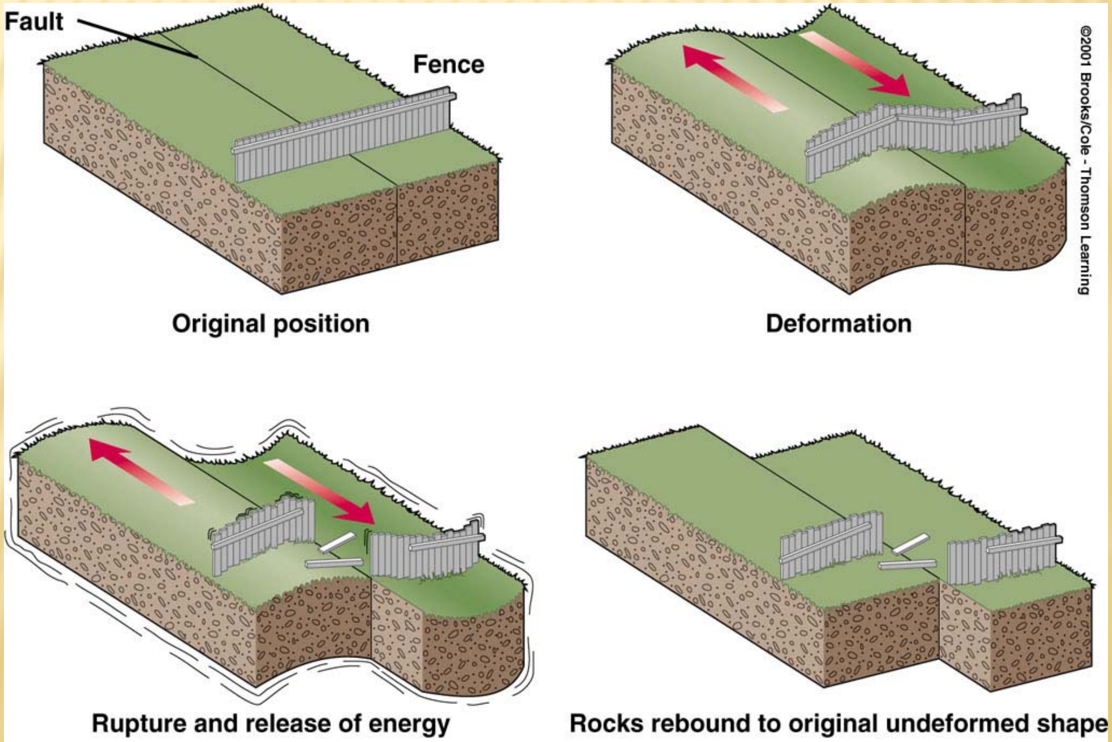
HOW EARTHQUAKE OCCURS

- Every rock has a limit beyond which it cannot deform elastically.
- Under certain conditions, when its elastic limit is exceeded, a rock continues to deform.
- This behavior is called plastic deformation.
- Earthquakes do not occur when rocks deform plastically.
- Under other conditions, an elastically stressed rock may rupture by brittle fracture.
- The fracture releases the elastic energy, and the surrounding rock **springs** back to its original shape.
- This rapid motion creates vibrations that travel through the Earth and are felt as an earthquake.



THE ELASTIC REBOUND THEORY

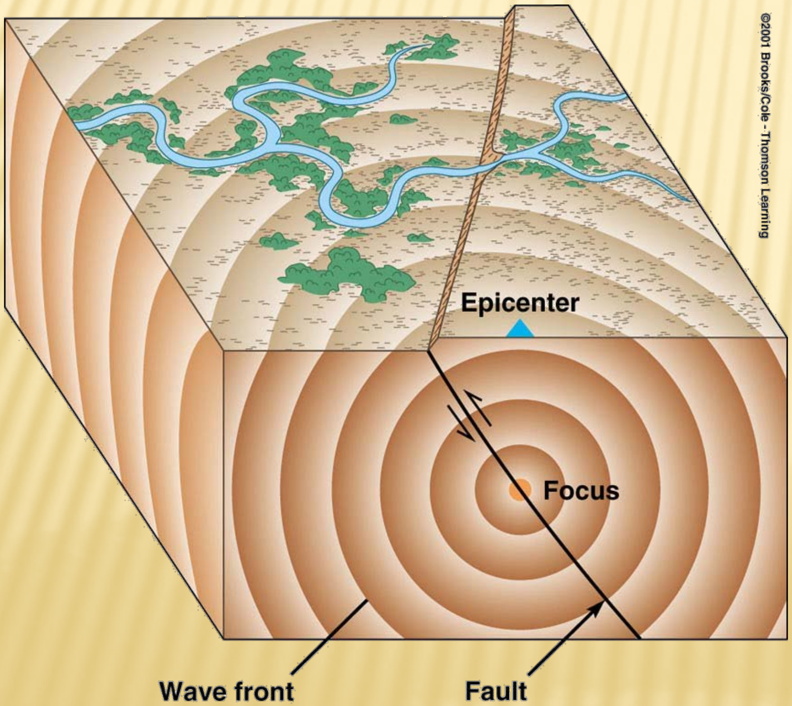
- The Elastic Rebound Theory explains how energy is stored in rocks
  - Rocks bend until the strength of the rock is exceeded
  - Rupture occurs and the rocks quickly rebound to an undeformed shape
  - Energy is released in waves that radiate outward from the fault

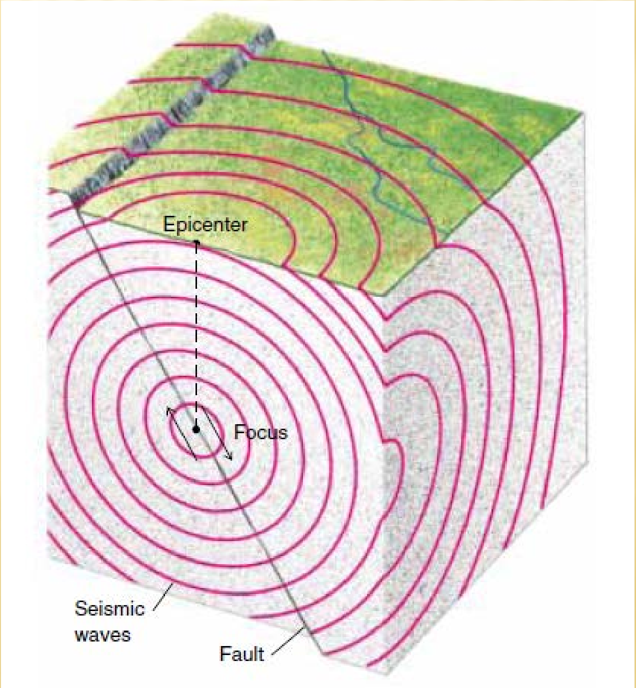


THE FOCUS AND EPICENTER OF AN EARTHQUAKE

- The point within Earth where faulting begins is the **focus**, or **hypocenter.**

- The point directly above the focus on the surface is the **epicenter**



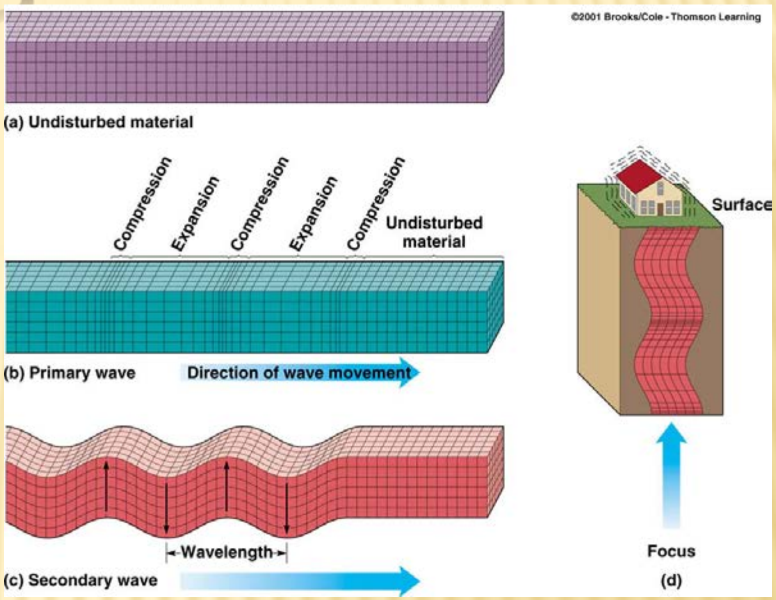


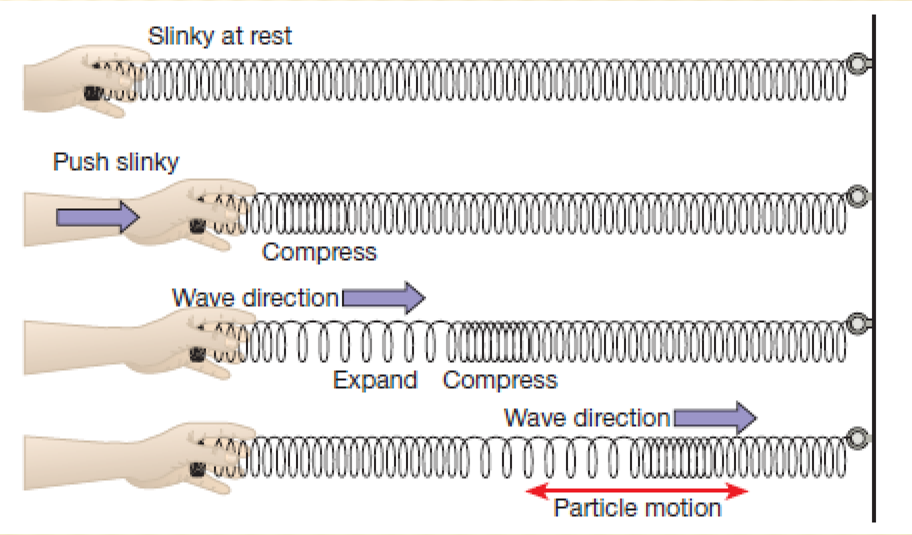
WHAT ARE SEISMIC WAVES

- Waves that travel through rock are called seismic waves.
- Earthquakes and explosions produce seismic waves.
- Seismology is the study of earthquakes and the nature of the Earth's interior based on evidence from seismic waves.
- An earthquake produces several different types of seismic waves.
- Two types of waves are produced during an Earthquake
  - Body waves
    - P and S
  - Surface waves
    - R and L

BODY WAVES: P WAVES

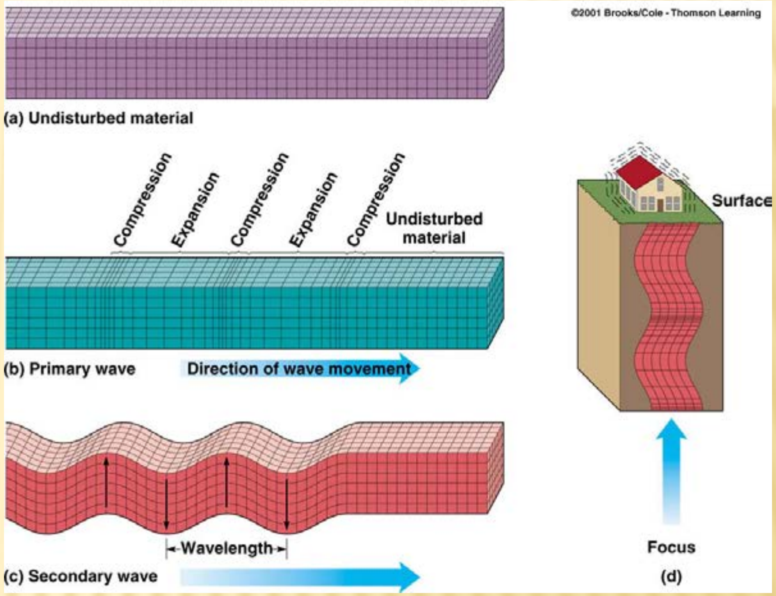
- Two main types of body waves travel through the Earth's interior.
- P wave (also called a compressional wave) is an elastic wave that causes alternate compression and expansion (rarefaction) of the rock.
- P waves travel through air, liquid, and solid material.
- P waves travel at speeds between 4 and 7 kilometers per second in the Earth's crust and at about 8 kilometers per second in the uppermost mantle.
- P waves are also known as Primary waves.

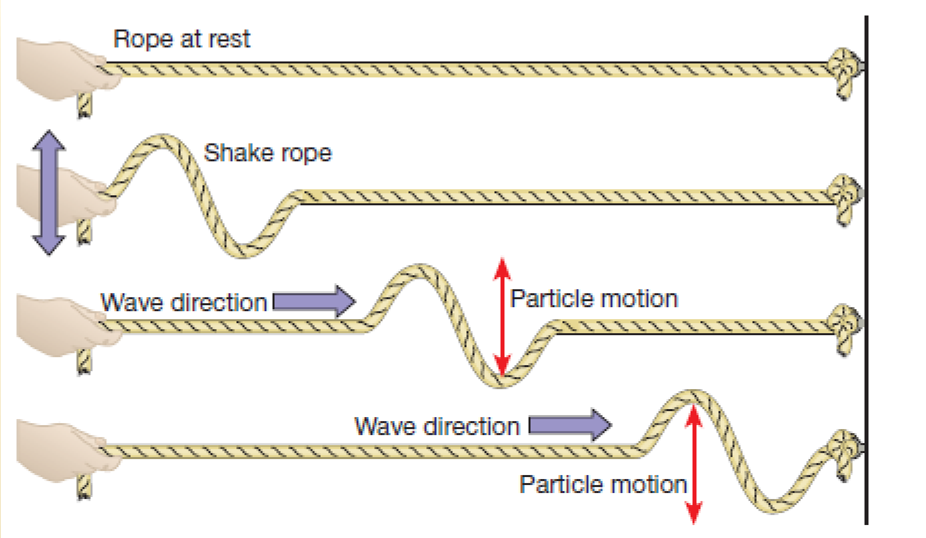




BODY WAVES: S WAVES

- A second type of body wave, called an S wave, is a shear wave.
- They are transverse waves meaning that wave particles travel perpendicular to the direction of the propagation of the wave.
- S waves are slower than P waves and travel at speeds between 3 and 4 kilometers per second in the crust.
- As a result, S waves arrive after P waves.
- The S waves are also known as Secondary waves.
- Unlike P waves, S waves move only through solids.

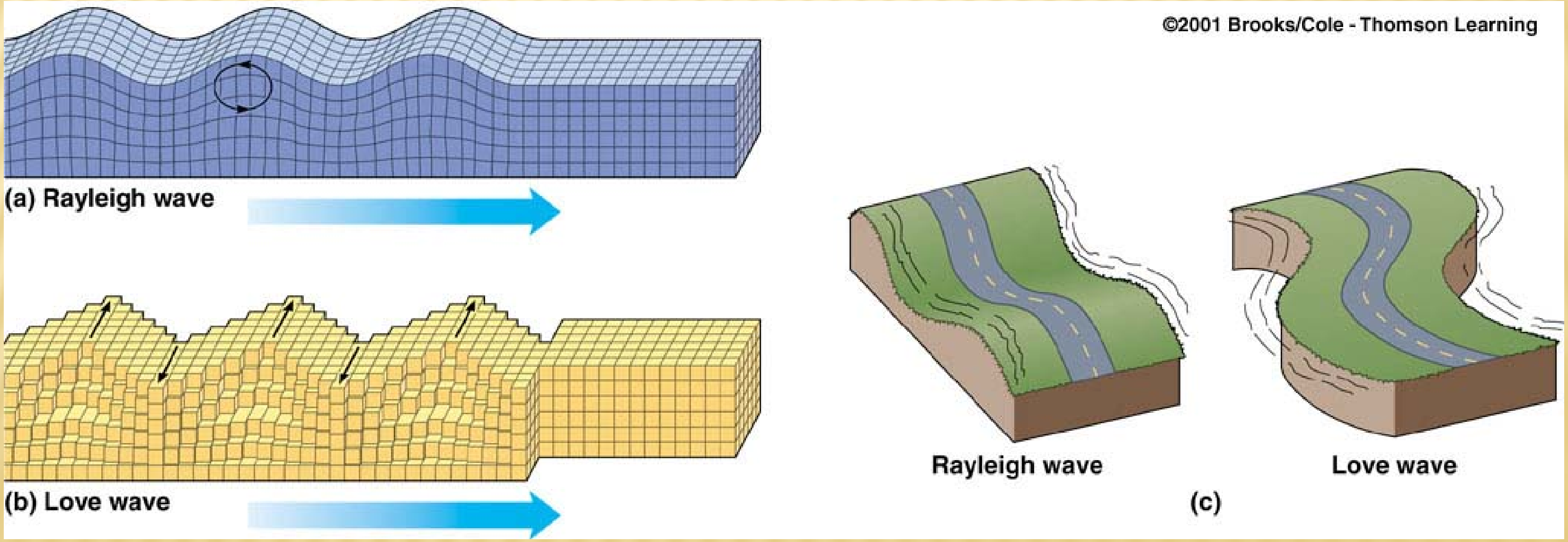




SURFACE WAVES

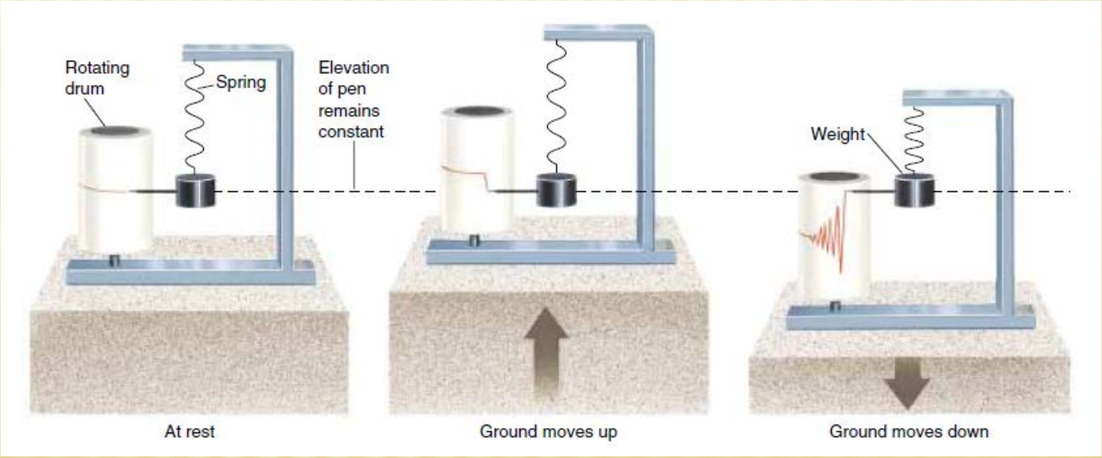
- Surface waves travel more slowly than body waves. Two types of surface waves occur simultaneously in the Earth.

- 1. Rayleigh wave moves with an up-and down rolling motion like an ocean wave.
- 2. Love waves produce a side-to-side vibration.



MEASUREMENT OF SEISMIC WAVES

- A seismograph is the device that scientists use to measure earthquakes.
- The goal of a seismograph is to accurately record the motion of the ground during a quake.
- A seismograph has a pen that is hanging in the air. The pen touches a roll of paper called a drum. When an earthquake happens, the roll of paper shakes. The pen does not. A weight holds the pen still.
- The marks on the paper show the size of the earthquake. A small motor rolls the drum of paper. This lets the seismograph record what happens as time passes.
- A seismogram is a graph output by a seismograph. It is a record of the ground motion at a measuring station as a function of time



MEASUREMENT OF EARTHQUAKE STRENGTH

- Earthquake intensity is a measure of the effects of an earthquake in a particular place.
- Modified Mercalli Scale is use for measuring the intensity of earthquakes, adapted from the original Mercalli scale.
- The Mercalli scale was devised in 1902 by Italian seismologist Giuseppe Mercalli.
- American seismologists Harry O. Wood and Frank Neumann created the Modified Mercalli scale in 1931 to measure the intensity of earthquakes that occur in California.
- The Modified Mercalli scale has 12 levels of intensity.
- Each level is defined by a group of observable earthquake effects, such as shaking of the ground and damage to structures such as buildings, roads, and bridges.
- The levels are designated by the Roman numerals I to XII.
- Levels I through VI are used to describe what people see and feel during a small to moderate earthquake.
- Levels VII through XII are used to describe damage to structures during a moderate to catastrophic earthquake.

MEASUREMENT OF EARTHQUAKE STRENGTH

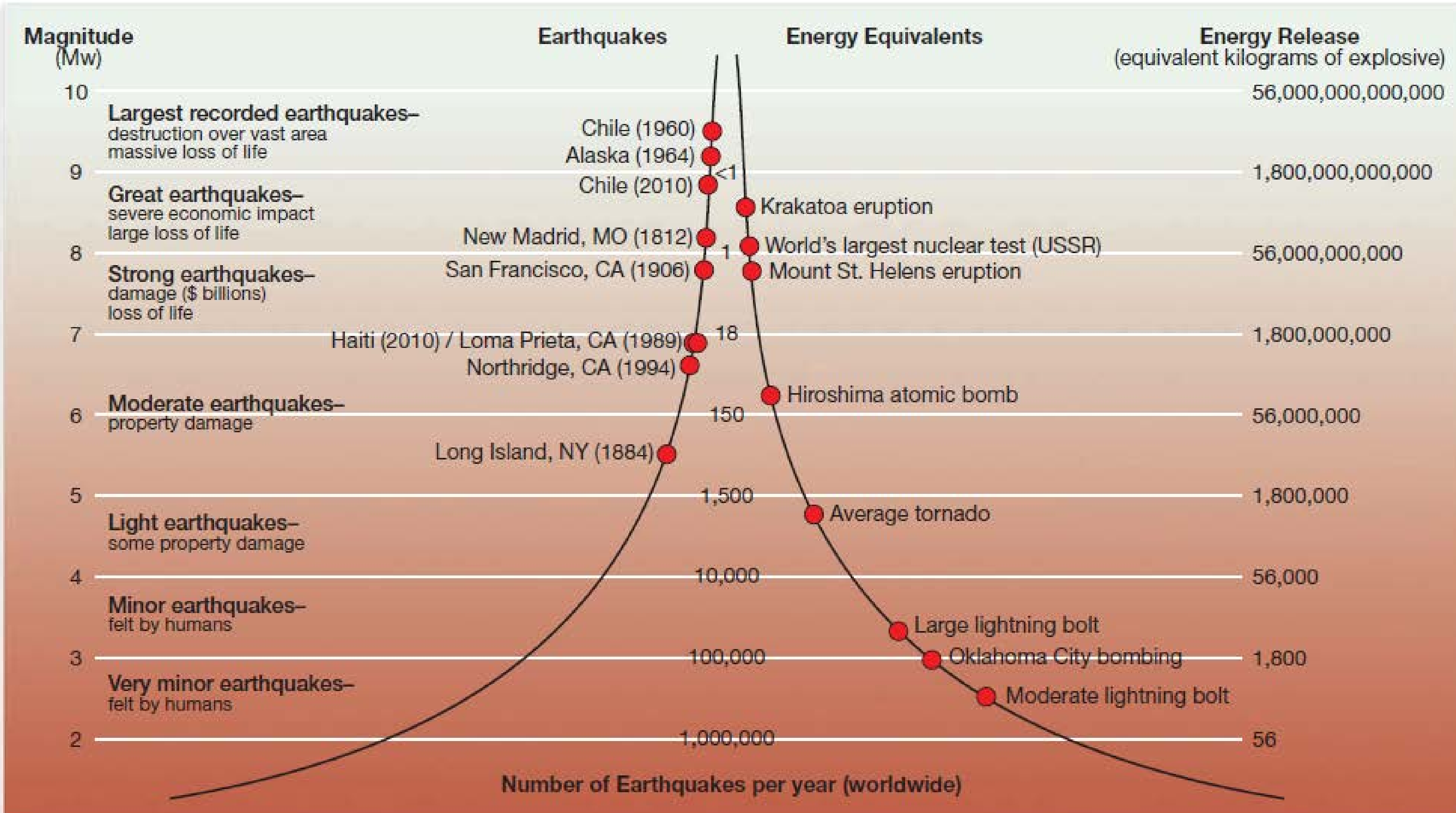
Modified Mercalli Scale	
I	Only felt by sensitive instruments
II	Felt by few persons at rest, especially on upper floors, delicate suspended objects may swing
III	Felt indoors, but may not be recognized as earthquake, vibrations like large passing truck
IV	Felt indoors by many, some outdoors, may awaken some sleeping persons; dishes, windows, doors may move, cars rock.
V	Felt by most; some windows, dishes break; tall objects may fall.
VI	Felt by by all, falling plaster and chimneys, light damage but some fear.
VII	Very noticeable, damage to weaker buildings on fill; driving automobiles notice.
VIII	Walls, monuments, chimneys, bookcases fall; liquifaction; driving is difficult
IX	Buildings shifted off foundations, cracked and twisted; ground is cracked and underground pipes are broken.
X	Most structures severely damaged to destroyed; ground is cracked, rails are bent, landslides on steep slopes
XI	Few structures standing; bridges and roads severely damaged or destroyed, large fissures in ground
XII	Total damage; can see the earthquake wave move through the ground; gravity overcome and objects thrown into the air

Richter Magnitude Scale
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0

MEASUREMENT OF EARTHQUAKE STRENGTH

- Earthquake Magnitude is a measure of the strength of an earthquake, or the amount of strain that rocks in Earth's crust release when an earthquake occurs.
- The Richter scale and the moment magnitude scale are used to measure the magnitude of earthquakes.
- Richter Scale, method of ranking the strength or size of an earthquake.
- The Richter scale, also known as the local magnitude scale, was devised in 1935 by the American seismologist Charles F. Richter to rank earthquakes occurring in California.
- Richter and his associates later modified it to apply to earthquakes anywhere in the world.
- The Richter scale ranks earthquakes based on how much the ground shakes 100 km (60 mi) from the earthquake's epicenter, the site on the earth's surface directly above the earthquake's origin.
- The Richter scale is a logarithmic scale—each increase of 1 on the Richter scale represents a tenfold increase in movement.
- Thus, an earthquake registering 7 on the scale is 10 times as strong as an earthquake registering 6, and the earth moves 10 times as far.

MEASUREMENT OF EARTHQUAKE STRENGTH



DAMAGE FROM EARTHQUAKES

- Large earthquakes can displace rock and alter the Earth's surface. Most earthquake fatalities and injuries occur when falling structures crush people. Structural damage, injury, and death depend on the magnitude of the quake, its proximity to population centers, rock and soil types, topography, and the quality of construction in the region.

- CONSTRUCTION DESIGN AND EARTHQUAKE DAMAGE

- A magnitude 6.4 earthquake struck central India in 1993, killing 30,000 people. In contrast, the 1994 magnitude 6.6 quake in Northridge (near Los Angeles) killed only 55. The tremendous mortality in India occurred because buildings were not engineered to withstand earthquakes.

- Some common framing materials used in buildings, such as wood and steel, bend and sway during an earthquake but resist failure. However, brick, stone, concrete, adobe (dried mud), and other masonry products are brittle and likely to fail during an earthquake.

DAMAGE FROM EARTHQUAKES

- FIRE

  Earthquakes commonly rupture buried gas pipes and electrical wires, leading to fire, explosions, and electrocutions. Water pipes may also break, so fire fighters cannot fight the blazes effectively.

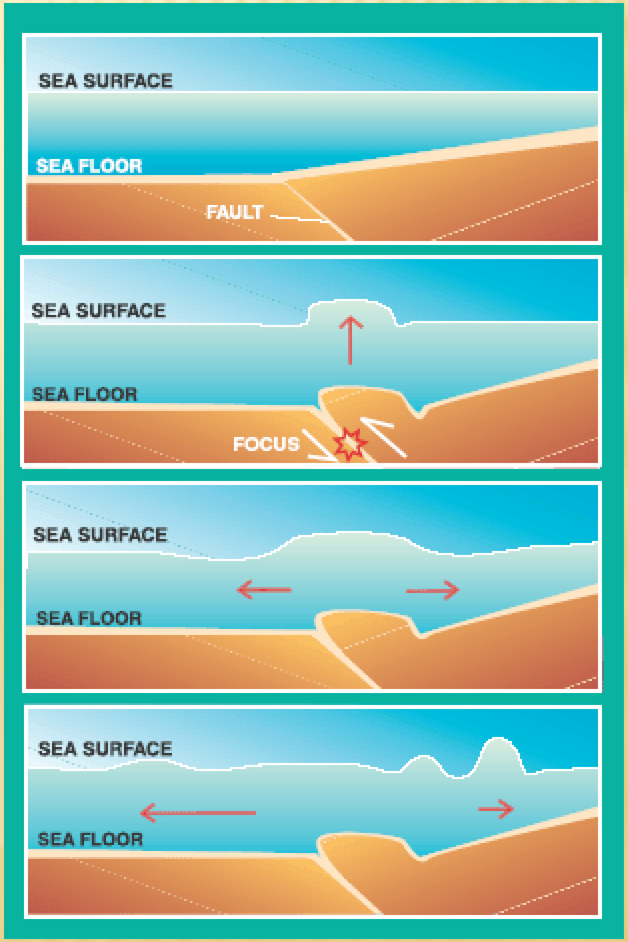
- LANDSLIDES

  Landslides are common when the Earth trembles. They occur mostly when earthquake occurs in a hilly region.

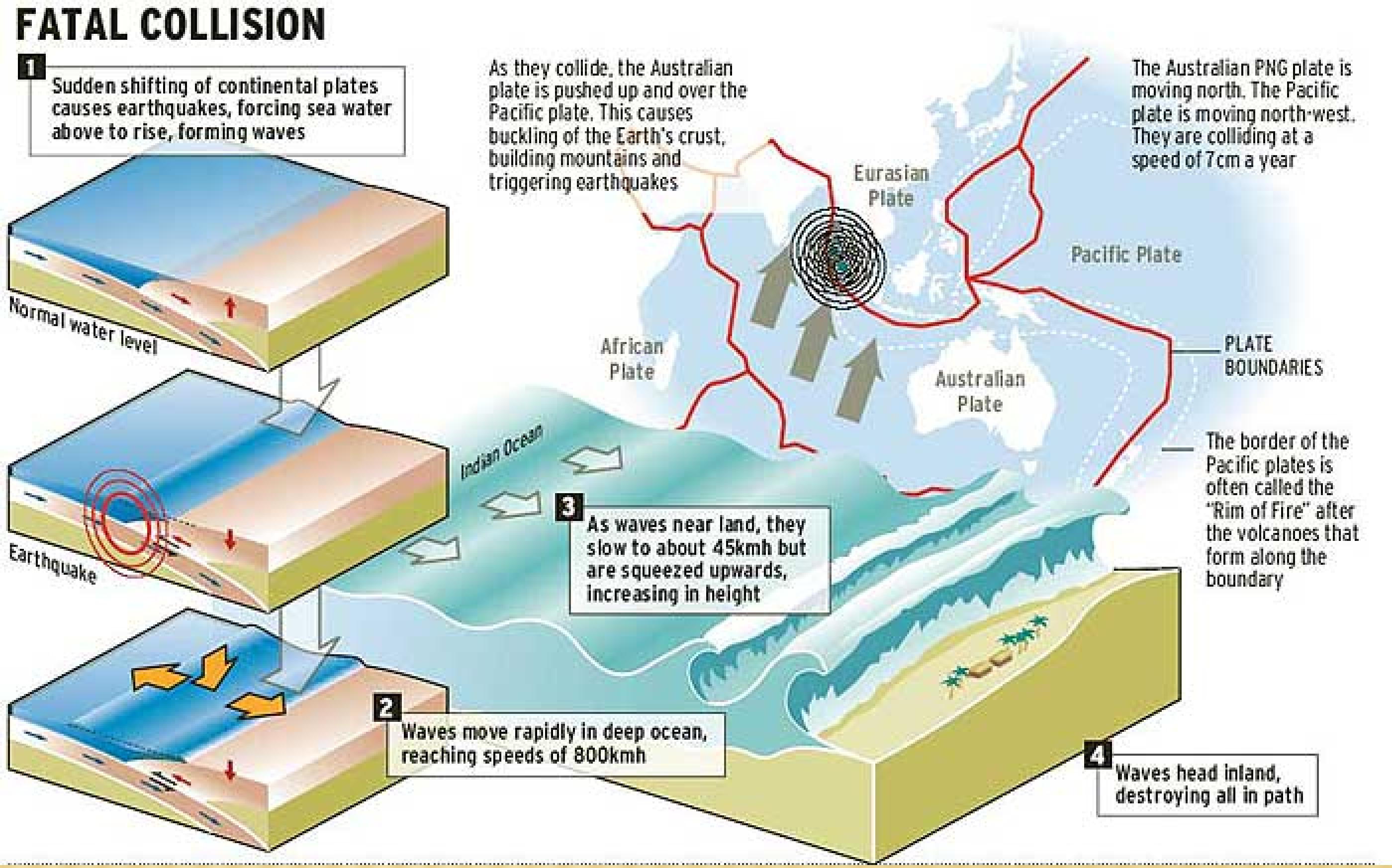
DAMAGE FROM EARTHQUAKES

TSUNAMIS

- When an earthquake occurs beneath the sea, part of the sea floor rises or falls and water is displaced in response to the rock movement, forming a wave.
- Sea waves produced by an earthquake are often called tidal waves, but they have nothing to do with tides.
- Therefore, geologists call them by their Japanese name, tsunami.
- In the open sea, a tsunami is so flat that it is barely detectable. Typically, the crest may be only 1 to 3 meters high, and successive crests may be more than 100 to 150 kilometers apart.
- However, a tsunami may travel at 750 kilometers per hour.
- When the wave approaches the shallow water near shore, the base of the wave drags against the bottom and the water stacks up, increasing the height of the wave. The rising wall of water then flows inland.

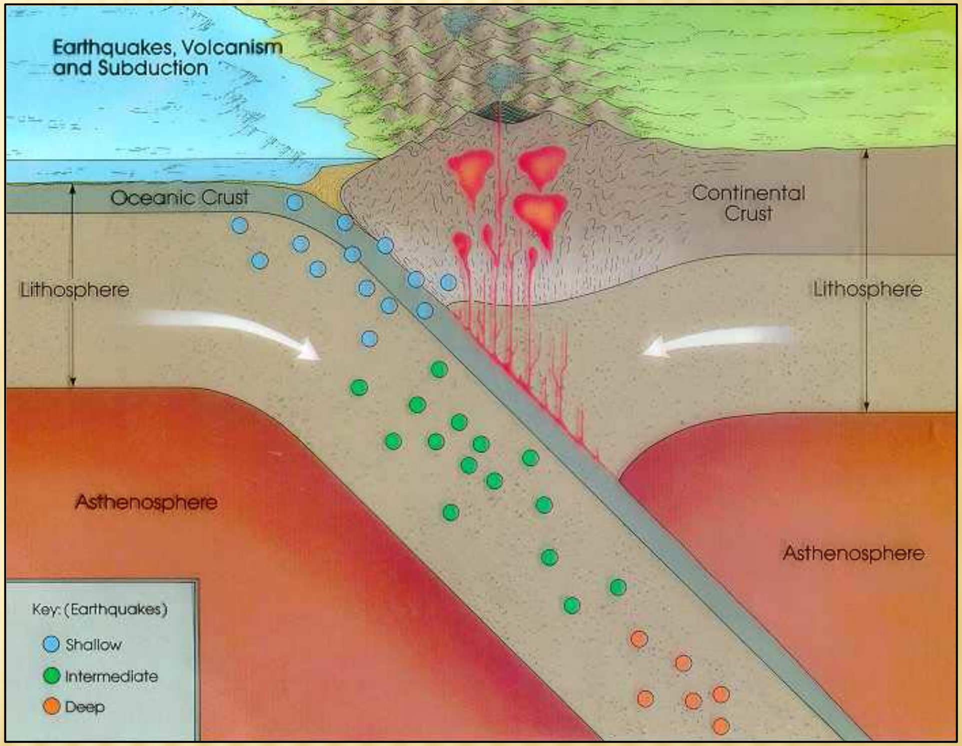


FORMATION OF A TSUNAMIS



DEPTH OF EARTHQUAKES

- Earthquakes can occur anywhere between the Earth's surface and about 700 kilometers below the surface. For scientific purposes, this earthquake depth range of 0 - 700 km is divided into three zones: shallow, intermediate, and deep.
- Shallow earthquakes are between 0 and 70 km deep;
- Intermediate earthquakes: 70 - 300 km deep; and
- Deep earthquakes:300 - 700 km deep.
- In general, the term "deep-focus earthquakes" is applied to earthquakes deeper than 70 km.
- All earthquakes deeper than 70 km are localized within great slabs of shallow lithosphere that are sinking into the Earth's mantle.



EARTHQUAKE AND TECTONIC PLATE BOUNDARIES

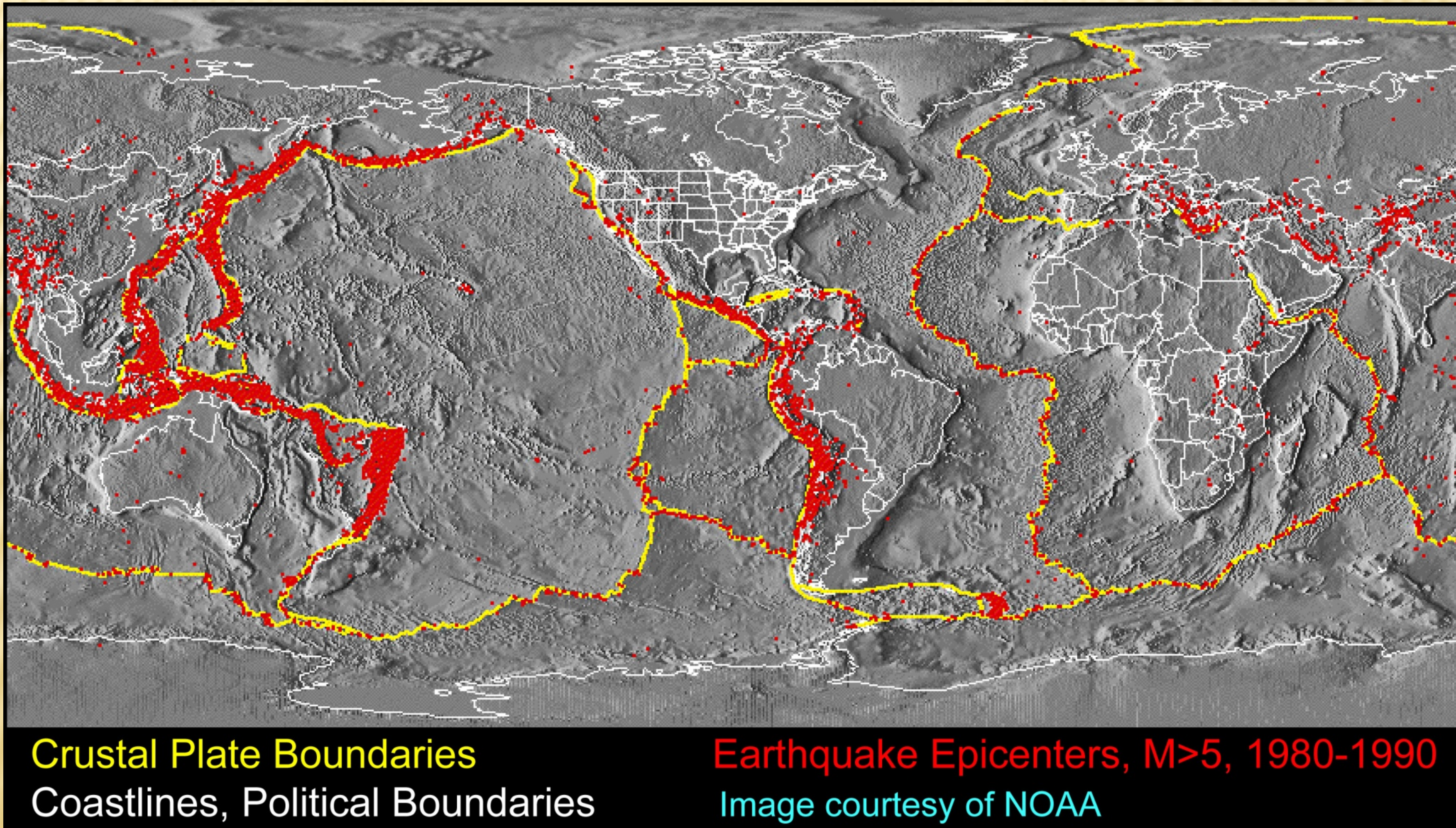
- Although many faults are located within tectonic plates, the largest and most active faults are the boundaries between tectonic plates.

- Therefore, earthquakes occur most frequently along plate boundaries.

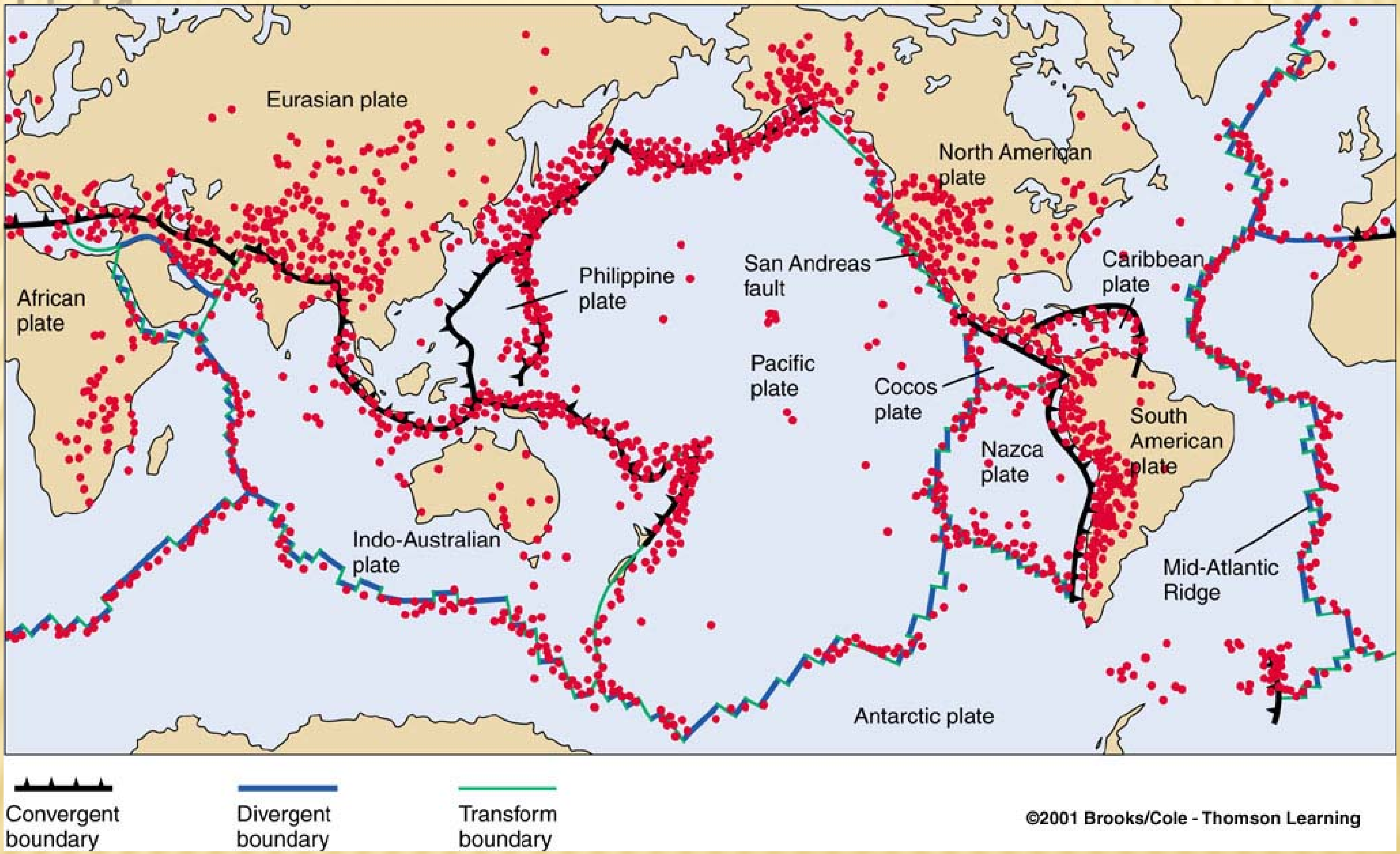
- Earthquake occurs at all the three type of plate boundaries that is the divergent plate boundaries, convergent plate boundaries and transform plate boundaries.

- However only shallow earthquakes occur along the mid-oceanic ridge (divergent plate boundary)because here the asthenosphere rises to within 20 to 30 kilometers of the Earth's surface and is too hot and plastic to fracture.

EARTHQUAKE AND TECTONIC PLATE BOUNDARIES



WHERE DO EARTHQUAKES OCCUR AND HOW OFTEN



80% of all earthquakes occur in the circum-Pacific belt. Most of these result from convergent margin activity~15% occur in the Mediterranean-Asiatic belt.

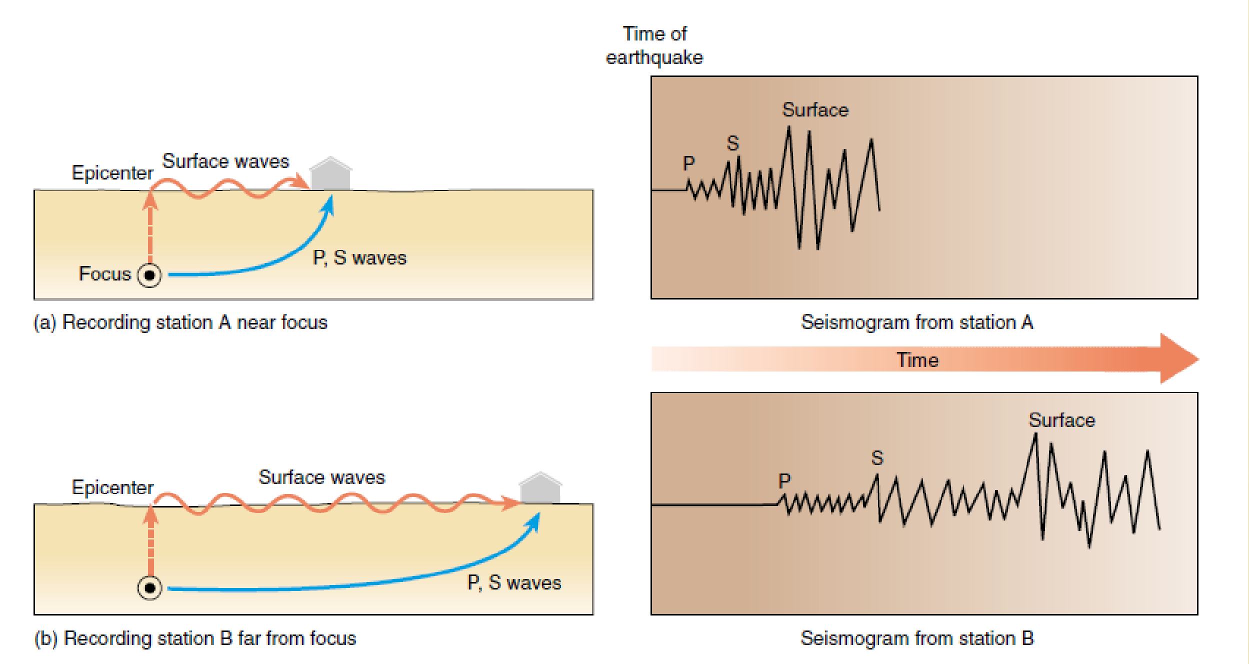
Remaining 5% occur in the interiors of plates and on spreading ridge centers. More than 150,000 quakes strong enough to be felt are recorded each year

EARTHQUAKE PREDICTION

- **Long term prediction**: Earthquakes occur over and over in the same places because it is easier for rocks to move along an old fracture than for a new fault to form in solid rock.
- Many of these faults lie along tectonic plate boundaries.
- Therefore, long-term earthquake prediction recognizes that earthquakes have recurred many times in a specific place and will probably occur there again.
- **Short-term prediction** is based on occurrences of foreshocks, release of radon gas, changes in the land surface, the water table, electrical conductivity, and erratic animal behavior.

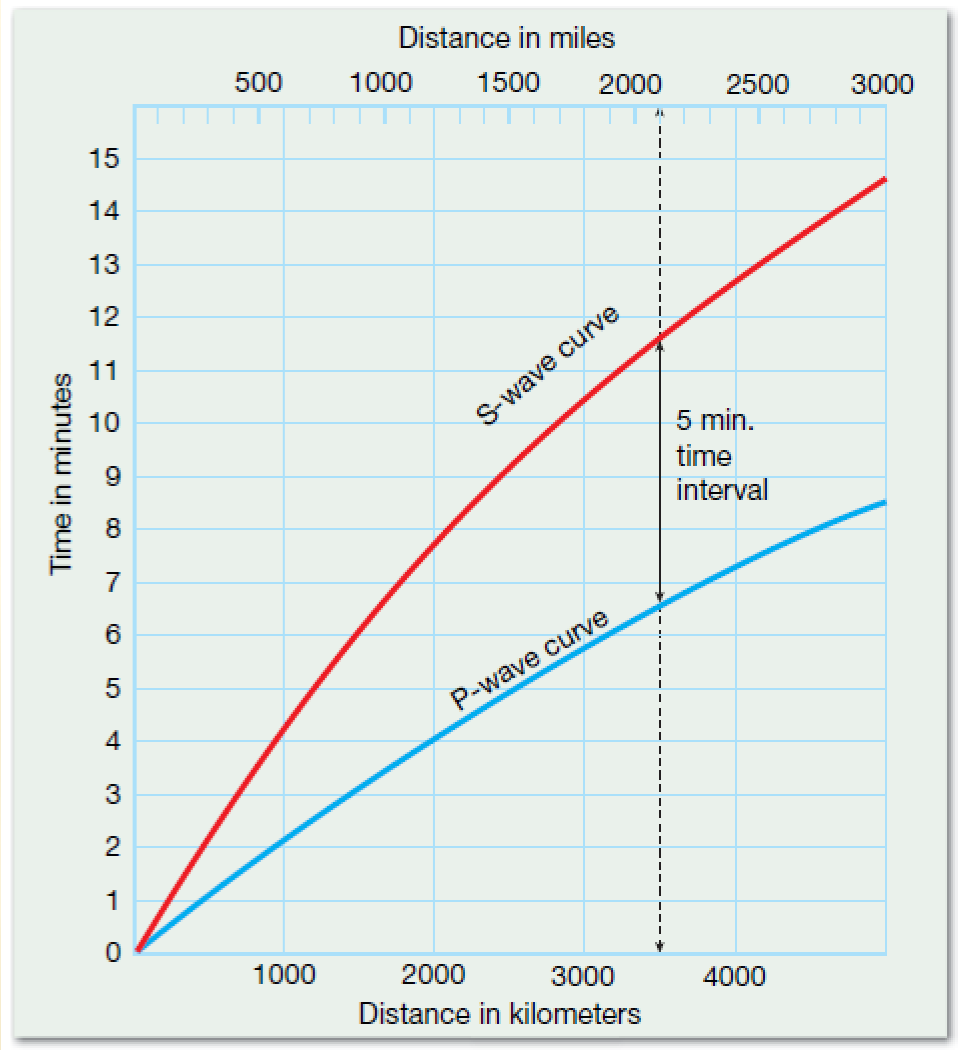
LOCATING THE SOURCE OF AN EARTHQUAKE

- P waves travel faster then the S waves and the surface waves are the slowest.
- If a seismograph is located close to an earthquake epicenter, the different waves will arrive in rapid succession.
- On the other hand, if a seismograph is located far from the epicenter, the S waves arrive at correspondingly later times after the P waves arrive, and the surface waves are even farther behind.



LOCATING THE SOURCE OF AN EARTHQUAKE

- Geologists use a time-travel curve to calculate the distance between an earthquake epicenter and a seismograph.
- To make a time-travel curve, a number of seismic stations at different locations record the times of arrival of seismic waves from an earthquake with a known epicenter and occurrence time. Then a graph is drawn.
- The figure on the right shows us that if the first P wave arrives 5 minutes before the first S wave, the recording station is about 3400 kilometers from the epicenter.



LOCATING THE SOURCE OF AN EARTHQUAKE

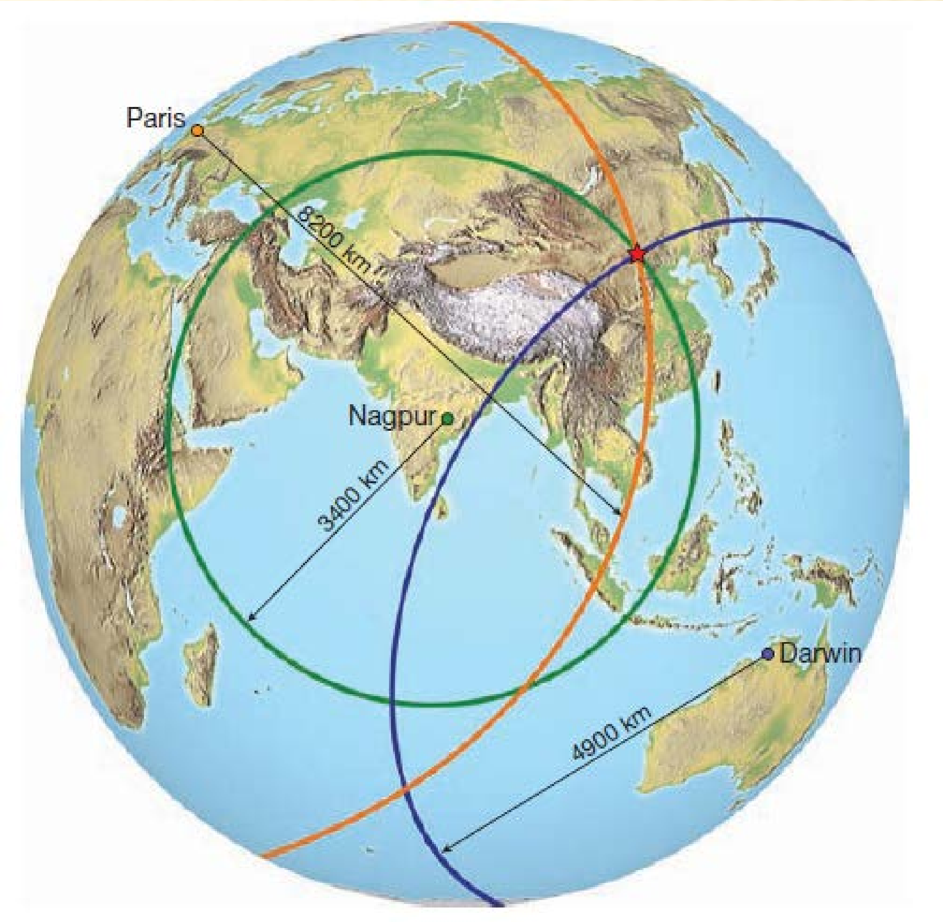
- But this distance does not indicate whether the earthquake originated to the north, south, east, or west.

- To pinpoint the location of an earthquake, geologists compare data from three or more recording stations.

- If a seismic station in Darwin records an earthquake with an epicenter 4900 kilometers away, geologists know that the epicenter lies somewhere on a circle 4900 kilometers from Darwin.

- The same epicenter is reported to be 8200 kilometers from a seismic station in Paris and 3400 kilometers from one in Nagpur, India.

- If one circle is drawn for each recording station, the arcs intersect at the epicenter of the quake.



UNIT - 8

VOLCANOES

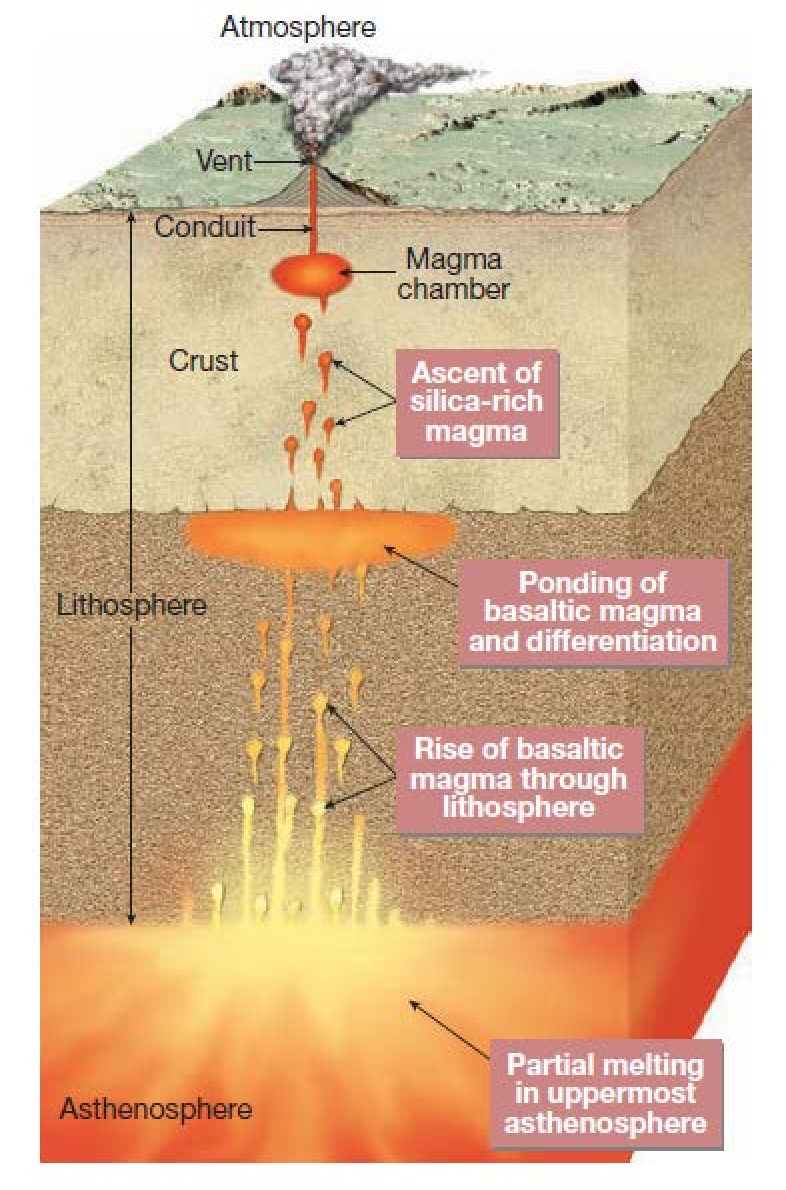
WHAT IS A MAGMA

- Magma is a mixture of molten rock, volatiles and solids that is found beneath the surface of the Earth.

- In some instances, it solidifies within the crust to form plutonic rocks. In others, it erupts onto the Earth's surface to form volcanic rocks

MAGMA BEHAVIOUR

- The magma cools as it enters shallower and cooler levels of the Earth.
- Second, pressure drops because the weight of overlying rock decreases.
- Cooling tends to solidify the magma, but decreasing pressure tends to keep it liquid.



TYPES OF MAGMA

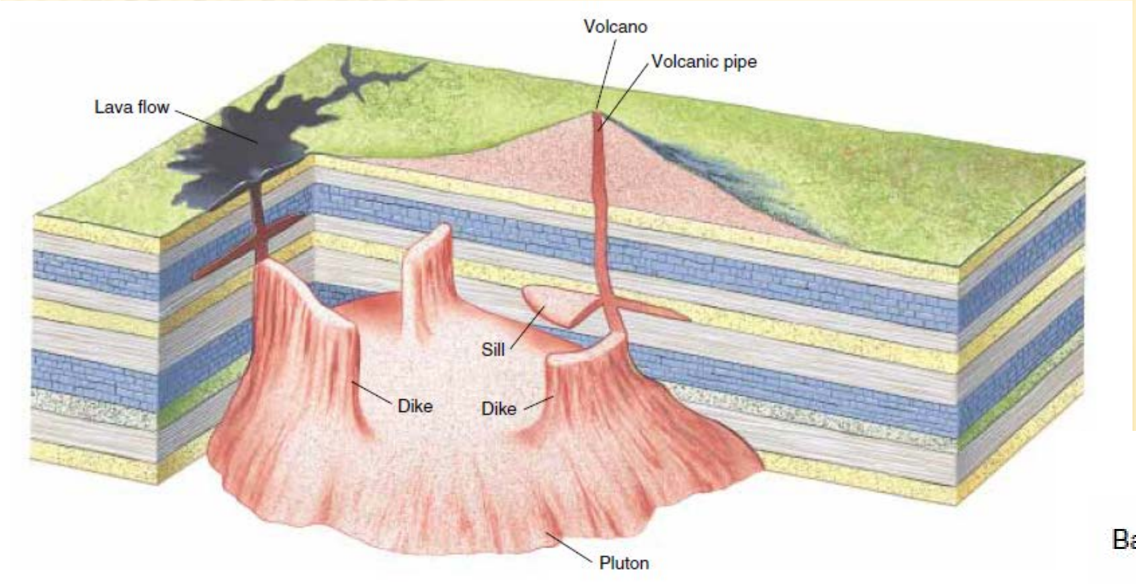
Magma Type	Solidified Rock	Chemical Composition	Temperature	Viscosity	Gas Content
Basaltic	Basalt	45-55 SiO_2 %, high in Fe, Mg, Ca, low in K, Na	1000 - 1200°C	Low	Low
Andesitic	Andesite	55-65 SiO_2 %, intermediate in Fe, Mg, Ca, Na, K	800 - 1000°C	Intermediate	Intermediate
Rhyolitic/ Granitic	Rhyolite	65-75 Sio_2 %, low in Fe, Mg, Ca, high in K, Na.	650 - 800°C	High	High

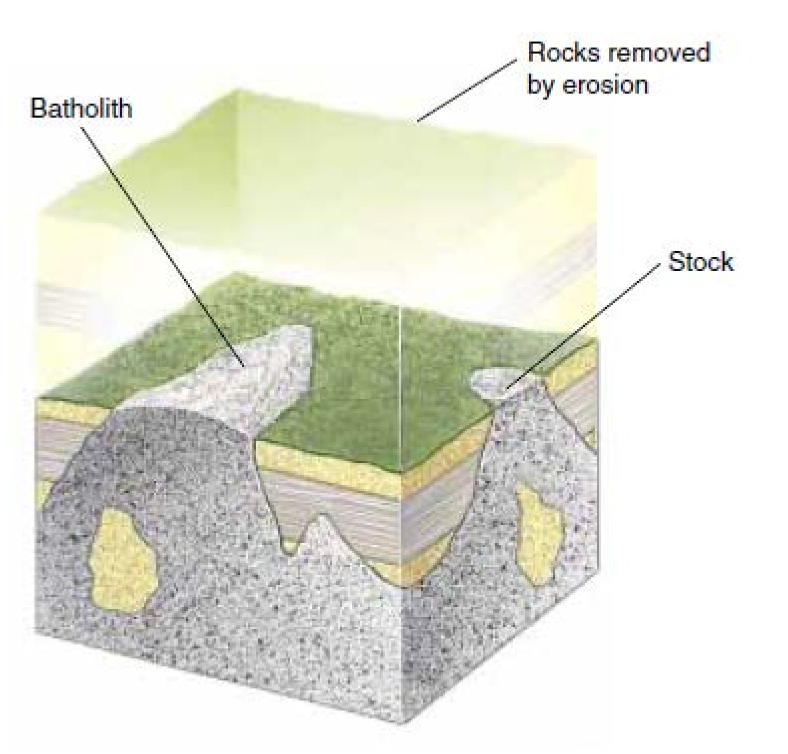
- Higher SiO_2 (silica) content magmas have higher viscosity than lower SiO_2 content magmas (viscosity increases with increasing SiO_2 concentration in the magma).
- Lower temperature magmas have higher viscosity than higher temperature magmas (viscosity decreases with increasing temperature of the magma).

PLUTONS

- In most cases, granitic magma solidifies within the Earth’s crust to form a pluton.
- A batholith is a pluton exposed over more than 100 square kilometers of the Earth’s surface.
- A stock is similar to a batholith but is exposed over less than 100 square kilometers.

PLUTONS





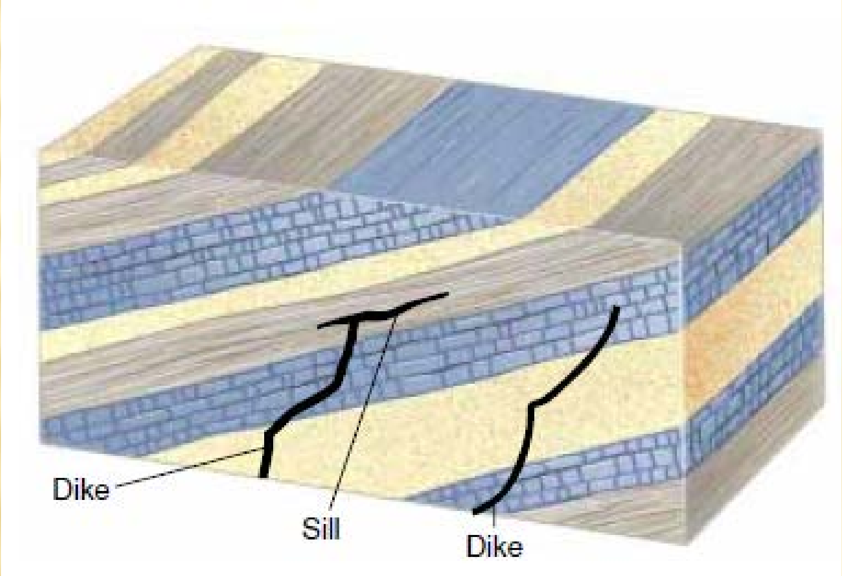
BATHOLITH AND STOCK

PLUTONS

- A dike is a tabular, or sheet like, intrusive rock that forms when magma oozes into a fracture Dikes cut across sedimentary layers or other features in country rock and range from less than a centimeter to more than a kilometer thick.

- Magma that oozes between layers of country rock forms a sheet like rock parallel to the layering, called a sill.

PLUTONS



DIKE

SILL

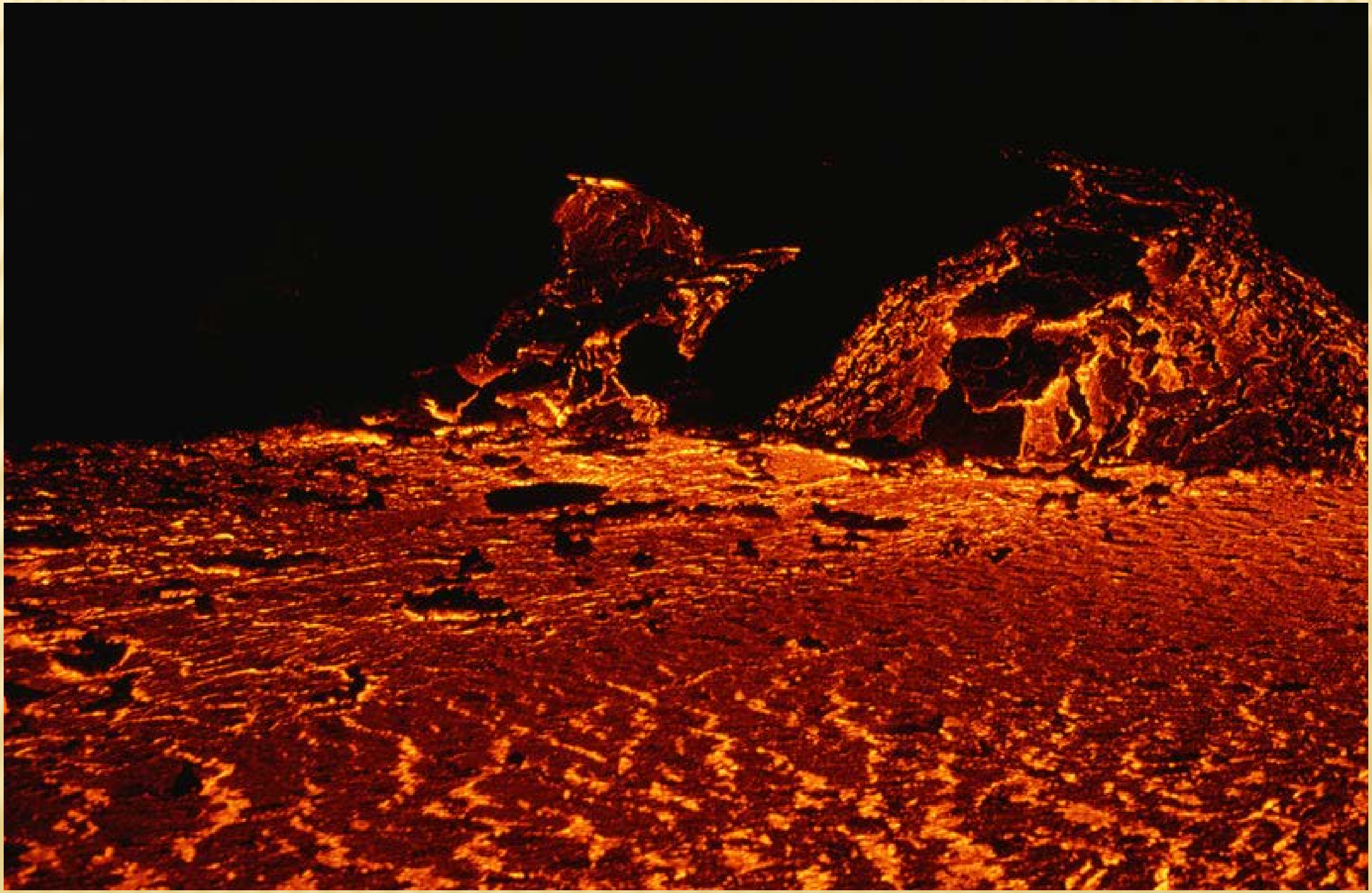
VOLCANIC ROCKS AND VOLCANOES

- The material erupted from volcanoes creates a wide variety of rocks and landforms, including lava plateaus and several types of volcanoes.

- Lava is fluid magma that flows onto the Earth's surface. Lava generally comes on to the earth's surface through volcanoes.

- A volcano is an opening, or rupture, in a planet's surface or crust, which allows hot magma, volcanic ash and gases to escape from below the surface

VOLCANIC ROCKS AND VOLCANOES



LAVA

VOLCANIC ROCKS AND VOLCANOES

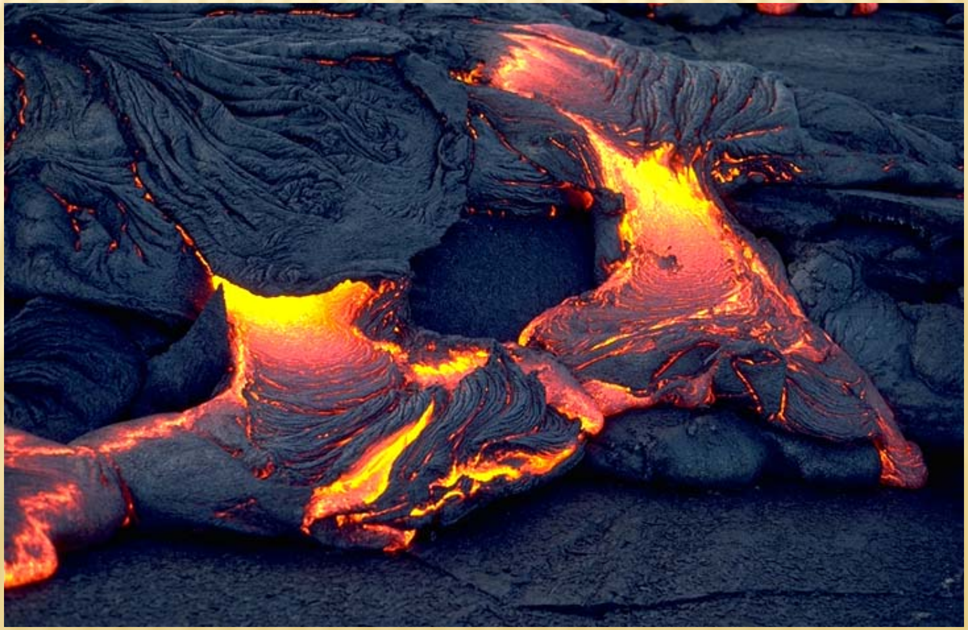
VOLCANO

TYPES OF LAVA

- A'a: Pronounced "ah-ah", this is a basaltic lava that doesn't flow very quickly. These types of lava erupt at temperatures above 1000 to 1100 degrees C

TYPES OF LAVA

- Pahoehoe: Pronounced “pa-ho-ho”, this type of lava is much thinner and less viscous than a’a. It can flow down the slopes of a volcano in vast rivers. Pahoehoe erupts at temperatures of 1100 to 1200 degree C

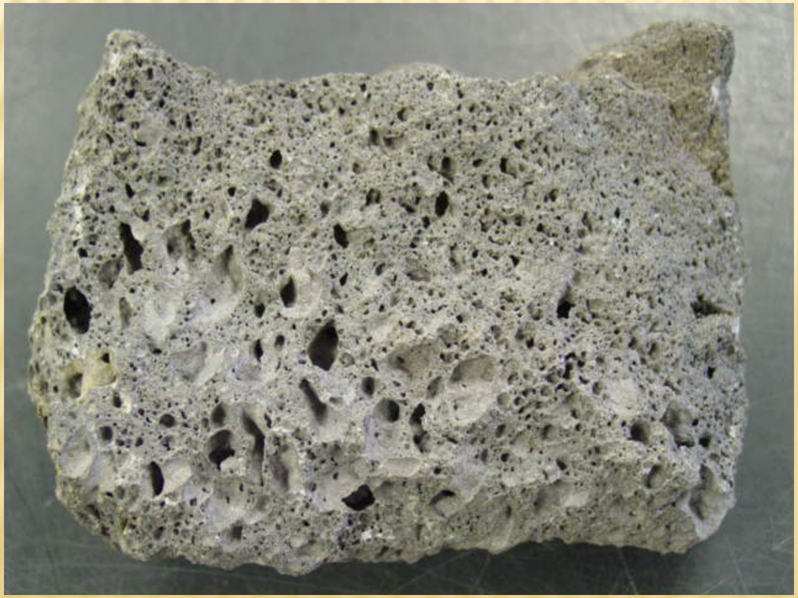


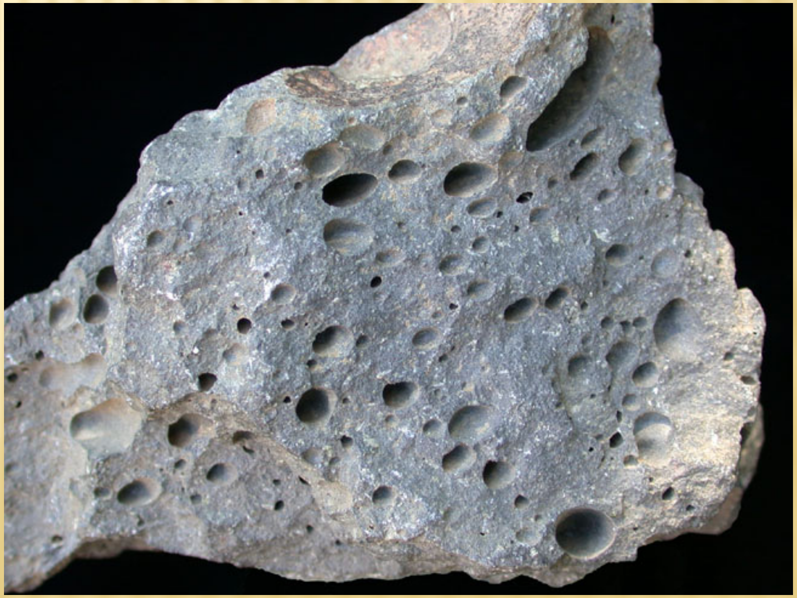
TYPES OF LAVA

- Pillow Lava: Pillow lava is typically found erupting from underwater volcano vents.

STRUCTURES IN VOLCANIC ROCKS

- When lava cools, escaping gases such as water and carbon dioxide form bubbles in the lava.
- If the lava solidifies before the gas escapes, the bubbles are preserved as holes called vesicles





STRUCTURES IN VOLCANIC ROCKS

- Hot lava shrinks as it cools and solidifies. The shrinkage pulls the rock apart, forming cracks that grow as the rock continues to cool. Such cracks, called columnar joints

PYROCLASTIC ROCKS

- If a volcano erupts explosively, it may eject both liquid magma and solid rock fragments. A rock formed from particles of magma that were hurled into the air from a volcano is called a pyroclastic rock
- The smallest particles is called volcanic ash

PYROCLASTIC ROCKS

- Cinders vary in size from 2 to 64 millimeters

PYROCLASTIC ROCKS

- Particles greater than 64 mm in diameter are called volcanic bombs

FISSURE ERUPTIONS AND LAVA PLATEAUS

- The gentlest type of volcanic eruption occurs when magma comes out from the cracks in the land surface called fissures and flows over the land like water.

- Basaltic magma commonly erupts in this manner because of its low viscosity

FISSURE ERUPTIONS AND LAVA PLATEAUS

- Some times fissures extend for tens or hundreds of kilometers and pour thousands of cubic kilometers of lava onto the Earth's surface.
- A fissure eruption of this type creates a flood basalt, which covers the landscape like a flood

FISSURE ERUPTIONS AND LAVA PLATEAUS

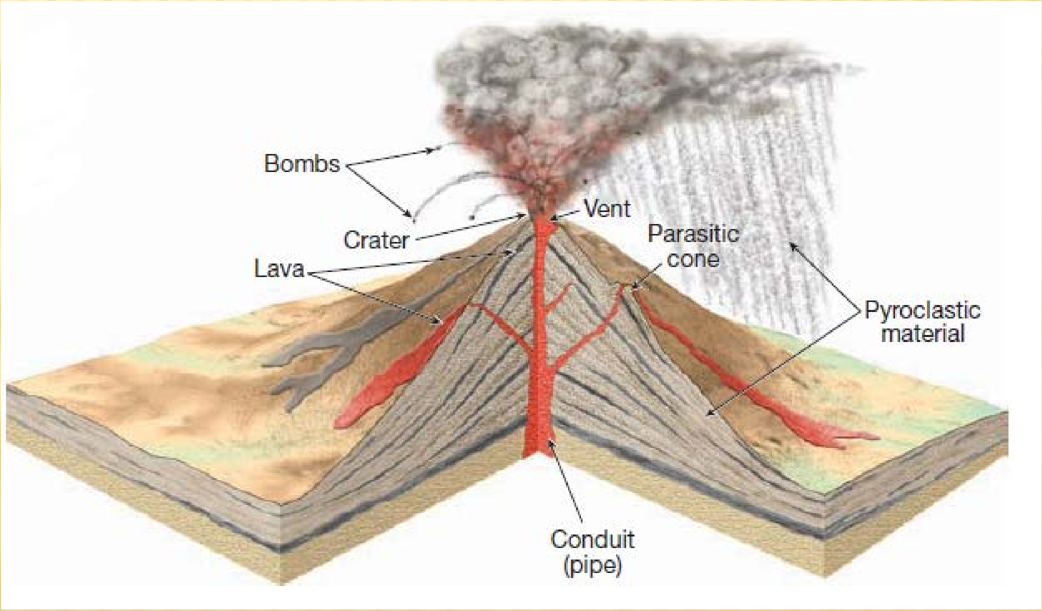
- Many such eruptions may occur in rapid succession and to create a lava plateau covering thousands of square kilometers

VOLCANOES

- If lava is too viscous to spread out as a flood, it builds a hill or mountain called a volcano.

VOLCANOES

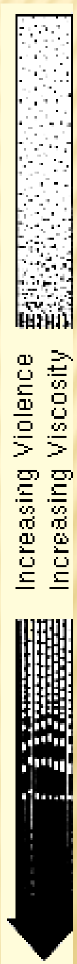
- Volcanoes differ widely in shape, structure, and size.
- Lava and rock fragments commonly erupt from an opening called a vent.
- The vent joins the crater which is a bowl shaped depression present at the top of the volcano.



VOLCANO TYPES BASED ON ACTIVITY

- An active volcano is one that is erupting or is expected to erupt
- A dormant volcano is one that is not now erupting but has erupted in the past and will probably do so again
- An extinct volcano is one that is expected never to erupt again

TYPES OF VOLCANOES



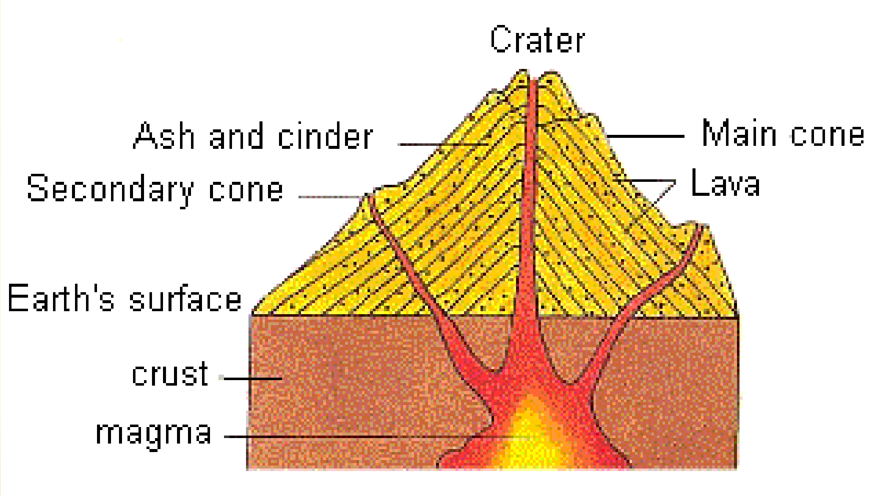
TYPE OF VOLCANO	FORM OF VOLCANO	SIZE	TYPE OF MAGMA	STYLE OF ACTIVITY	EXAMPLES
Basalt plateau	Flat to gentle slope	100,000 to 1,000,000 km^2 in area; 1 to 3 km thick	Basalt	Gentle eruption from long fissures	Columbia River Plateau
Shield volcano	Slightly sloped, 6° to 12°	Up to 9000 m high	Basalt	Gentle, some fire fountains	Hawaii
Cinder cone	Moderate slope	100 to 400 m high	Basalt or andesite	Ejections of pyroclastic material	Paricutín, Mexico
Composite volcano	Alternate layers of flows and pyroclastics	100 to 3500 m high	Variety of types of magmas and ash	Often violent	Vesuvius, Mount St. Helens, Aconcagua
Caldera	Cataclysmic explosion leaving a circular depression called a caldera	Less than 40 km in diameter	Granite	Very violent	Yellowstone, San Juan Mountains

TYPES OF VOLCANOES

BASLAT PLATEAU

SHIELD VOLCANO

TYPES OF VOLCANOES



COMPOSITE VOLCANO

CINDER CONE

CALDERA

DISTRIBUTION OF WORLD VOLCANOES

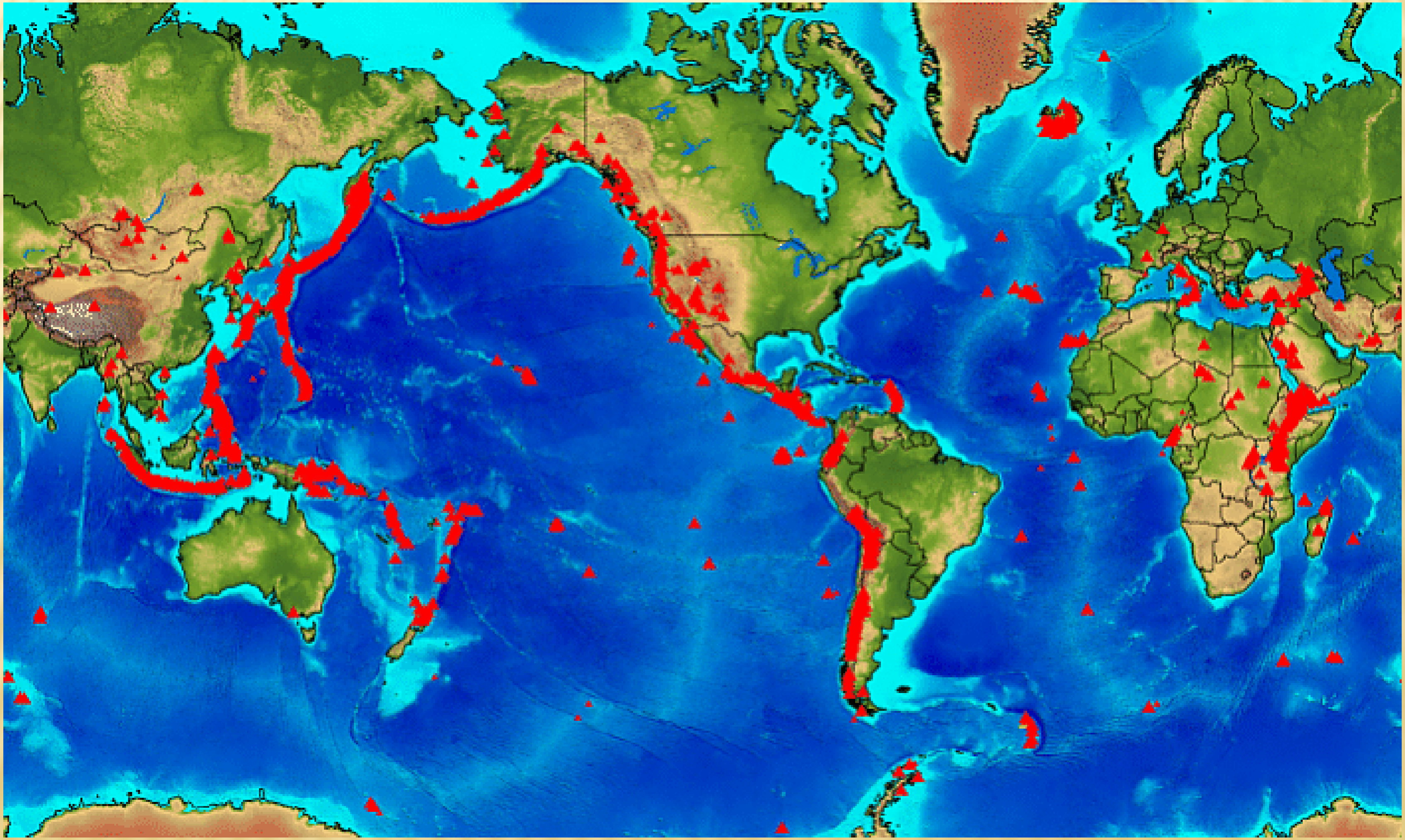


PLATE TECTONICS AND VOLCANIC ACTIVITY

- Most active volcanoes are associated with plate boundaries.
- Active areas of volcanism are found along mid-ocean ridges where seafloor spreading is occurring (divergent plate boundaries),
- in the vicinity of ocean trenches where one plate is being subducted beneath another (convergent plate boundaries), and
- In the interiors of plates themselves (intraplate volcanism). Rising plumes of hot mantle rock are the source of most intraplate volcanism.

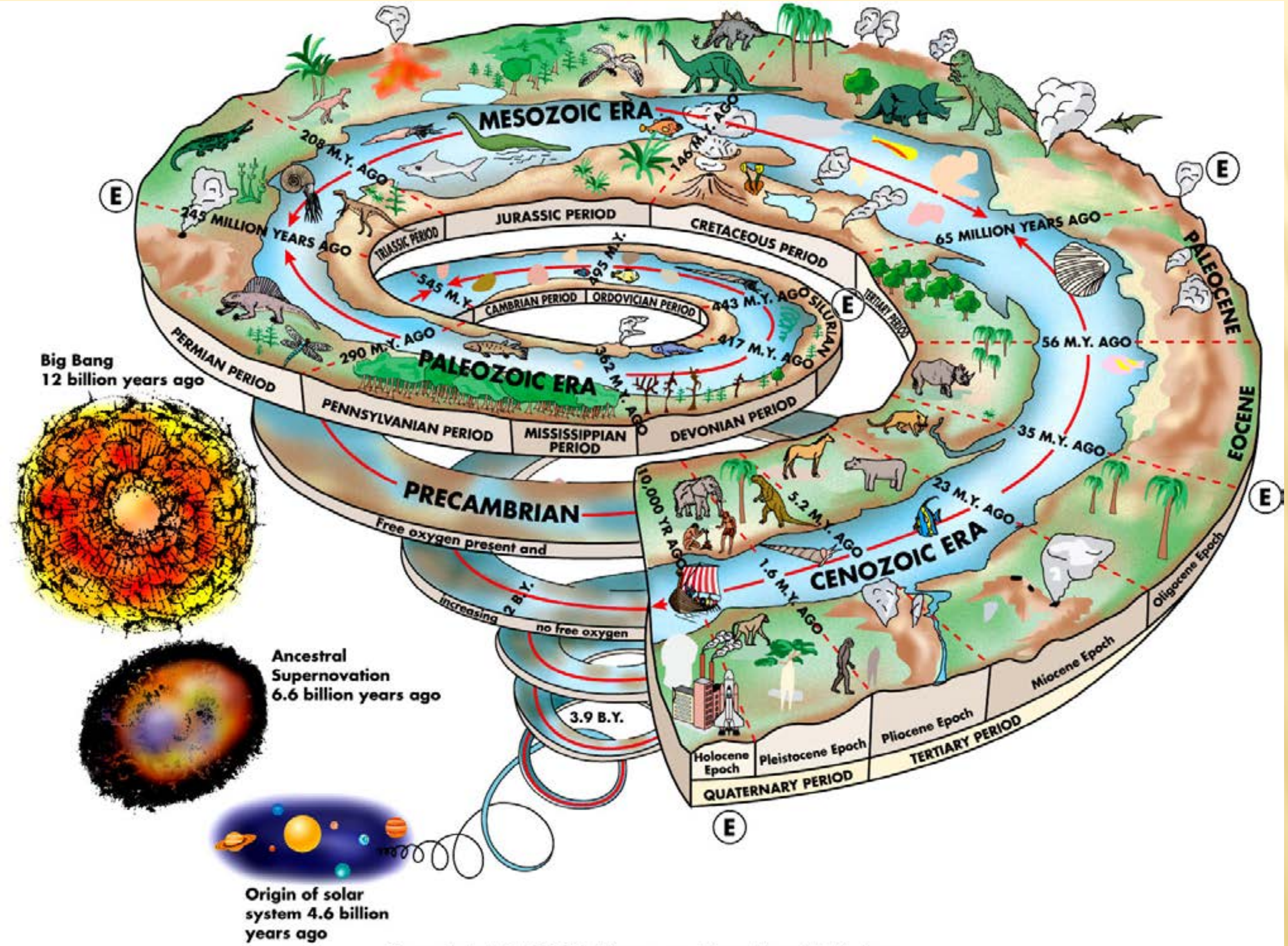
OCCURRENCE AND PREDICTION OF VOLCANOES

- Volcanic eruptions are common near a subduction zone, near a spreading center, and at a hot spot over a mantle plume but are rare in other tectonic environments.

- Eruptions on a continent are often violent, whereas those in oceanic crust are gentle. Such observations form the basis of regional predictions of volcanic hazards.

- Short-term predictions are made on the basis of earthquakes caused by magma movements, swelling of a volcano, increased emissions of gas and ash from a vent, and other signs that magma is approaching the surface

UNIT - 9



GEOLOGIC TIME

GEOLOGIC TIME

- Normally we think of time in terms of days or years but geologists commonly refer to events that happened millions or billions of years ago

- For example earth is approximately 4.6 billion years old

GEOLOGIC TIME

- Geologists measure geologic time in two different ways

- Relative Age and Absolute Age

GEOLOGIC TIME

RELATIVE AGE

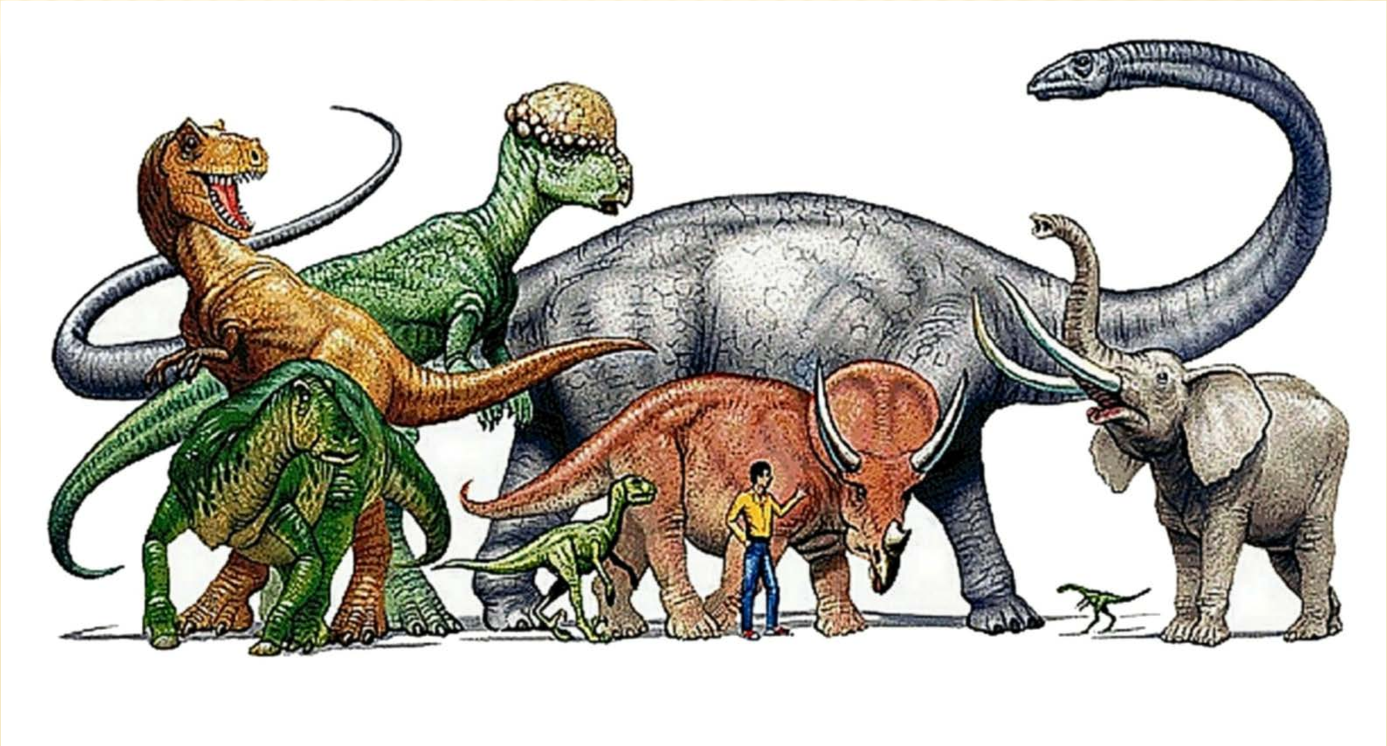
- Determination of relative age is based on a simple principle:
- In order for an event to affect a rock, the rock must exist first. Thus, the rock must be older than the event.

FOLDED ROCKS

GEOLOGIC TIME

ABSOLUTE AGE

- Absolute age is age in years
- Dinosaurs became extinct 65 million years ago



RELATIVE GEOLOGIC TIME

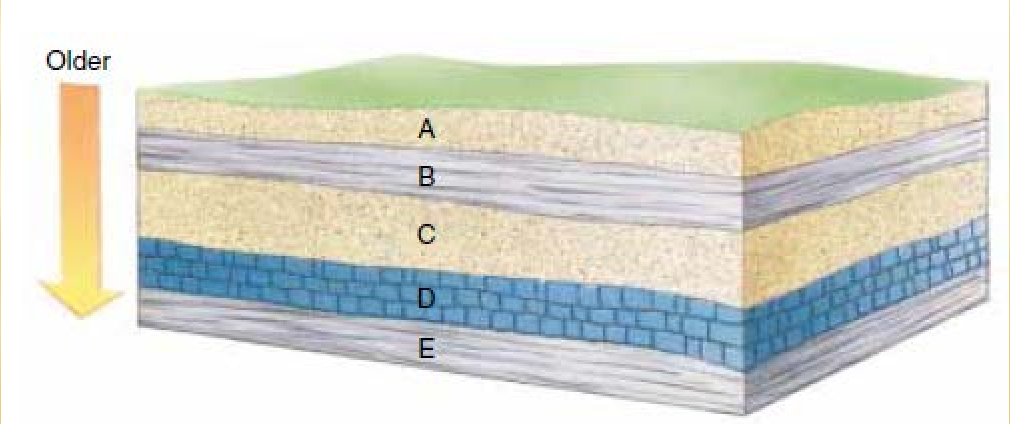
The principle of original horizontality

- It is based on the fact that sediment usually accumulates in horizontal layers.
- If sedimentary rocks lie at an angle, we can infer that tectonic forces tilted them after they formed

RELATIVE GEOLOGIC TIME

The principle of superposition

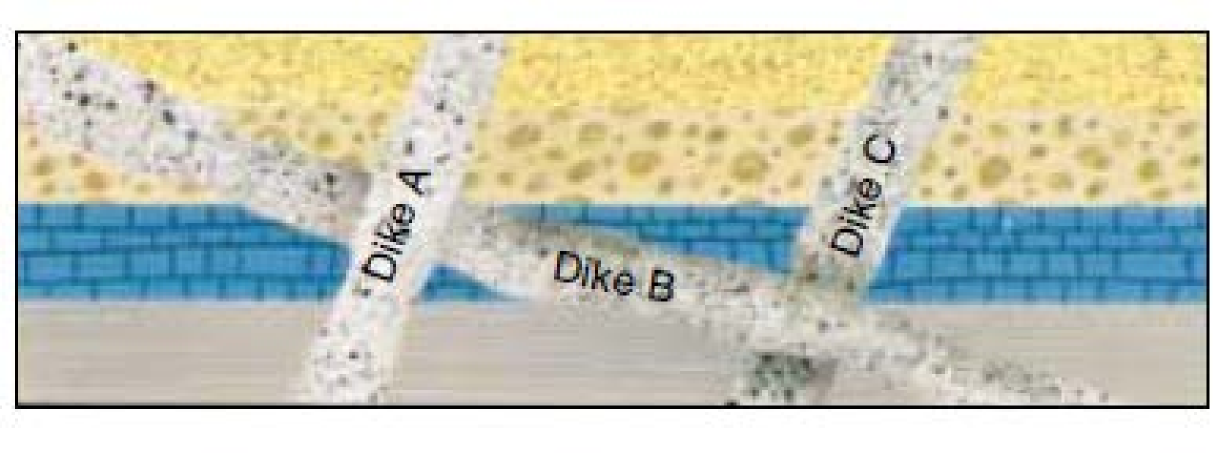
- It states that sedimentary rocks become younger from bottom to top (as long as tectonic forces have not turned them upside down).
- This is because younger layers of sediment always accumulate on top of older layers. In the figure below the sedimentary layers become progressively younger in the order E, D, C, B, and A.



RELATIVE GEOLOGIC TIME

The principle of cross-cutting relationships

- It states that a rock must first exist before anything can happen to it.
- The figure below shows sedimentary rocks intruded by three granite dikes.
- Dike B cuts dike C, and dike A cuts dike B, so dike C is older than B, and dike A is the youngest. The sedimentary rocks must be older than all of the dikes.



RELATIVE GEOLOGIC TIME

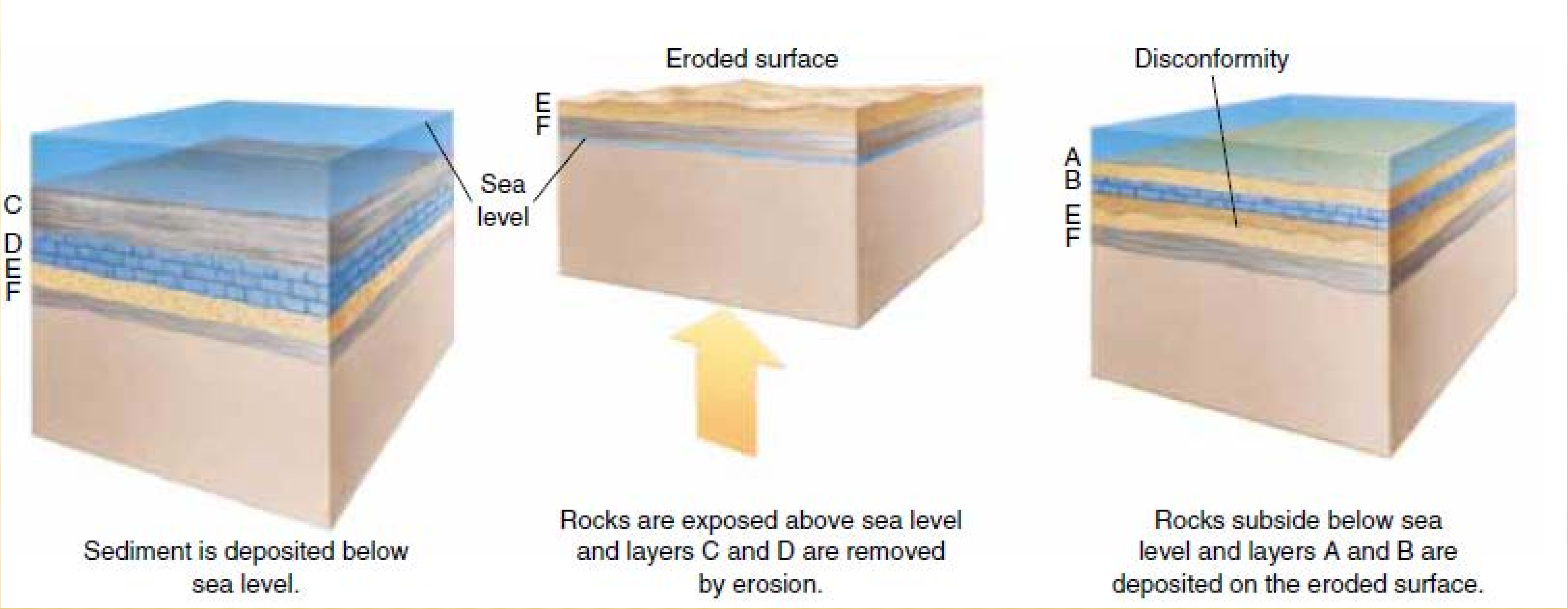
The principle of unconformities

- Layers of sedimentary rocks are conformable if they were deposited without interruption. An unconformity represents an interruption in deposition, usually of long duration.
- During the interval when no sediment was deposited, some rock layers may have been eroded
- Thus, an unconformity represents a long time interval for which no geologic record exists in that place. The lost record may involve hundreds of millions of years
- There are several types of unconformities

UNCONFORMITIES

Disconformity

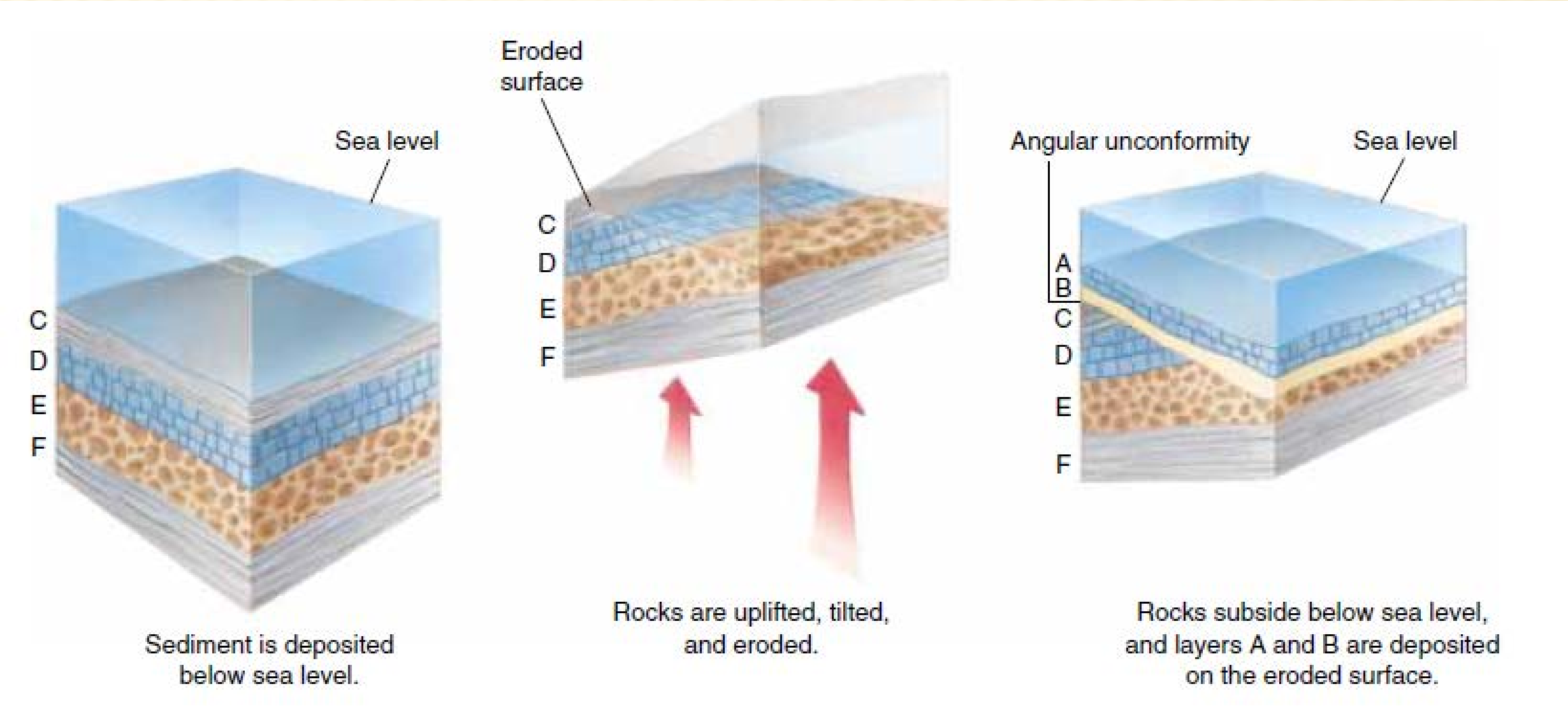
- In this case the sedimentary layers above and below the unconformity are parallel.
- Geologists identify disconformities by determining the ages of rocks using methods based on fossils and absolute dating



UNCONFORMITIES

Angular unconformity

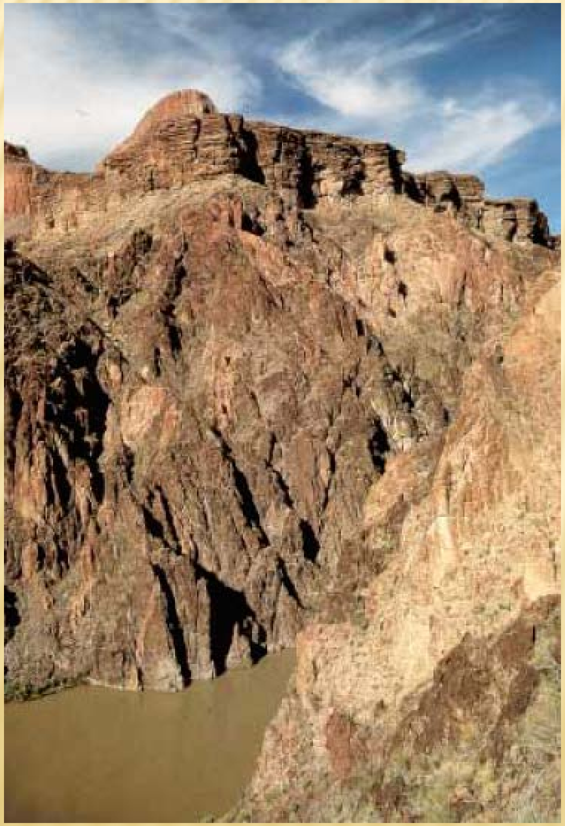
- In this case tectonic activity tilted older sedimentary rock layers before younger sediment accumulated

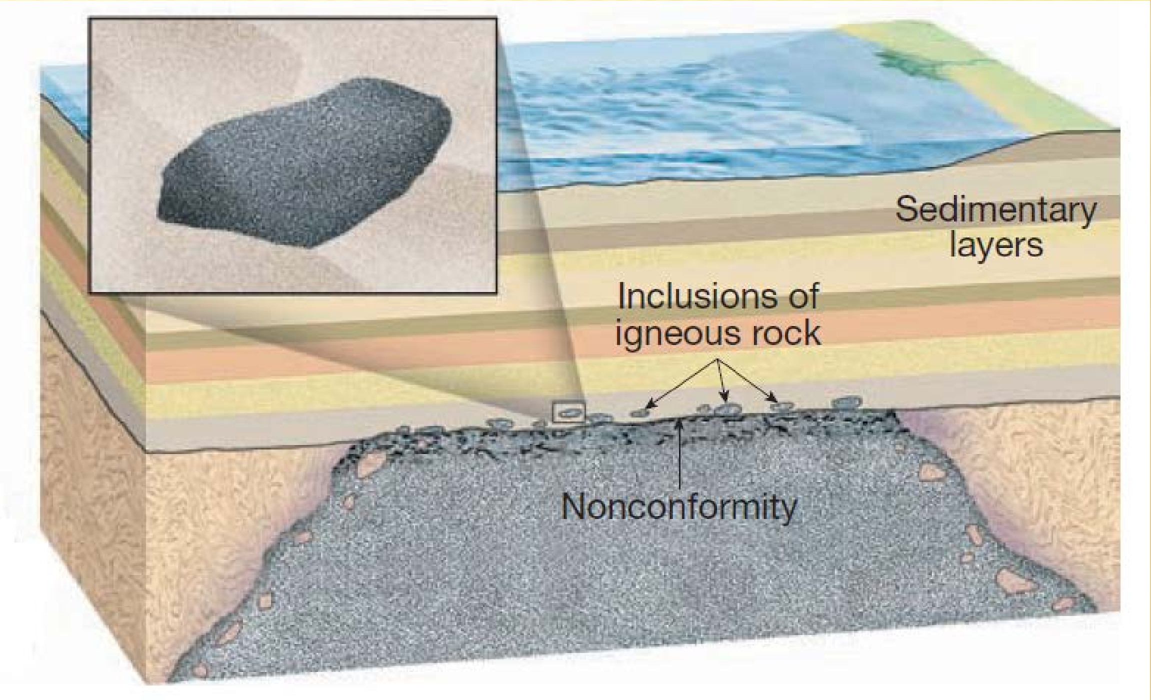


UNCONFORMITIES

Nonconformity

- In this case sedimentary rocks lie on igneous or metamorphic rocks

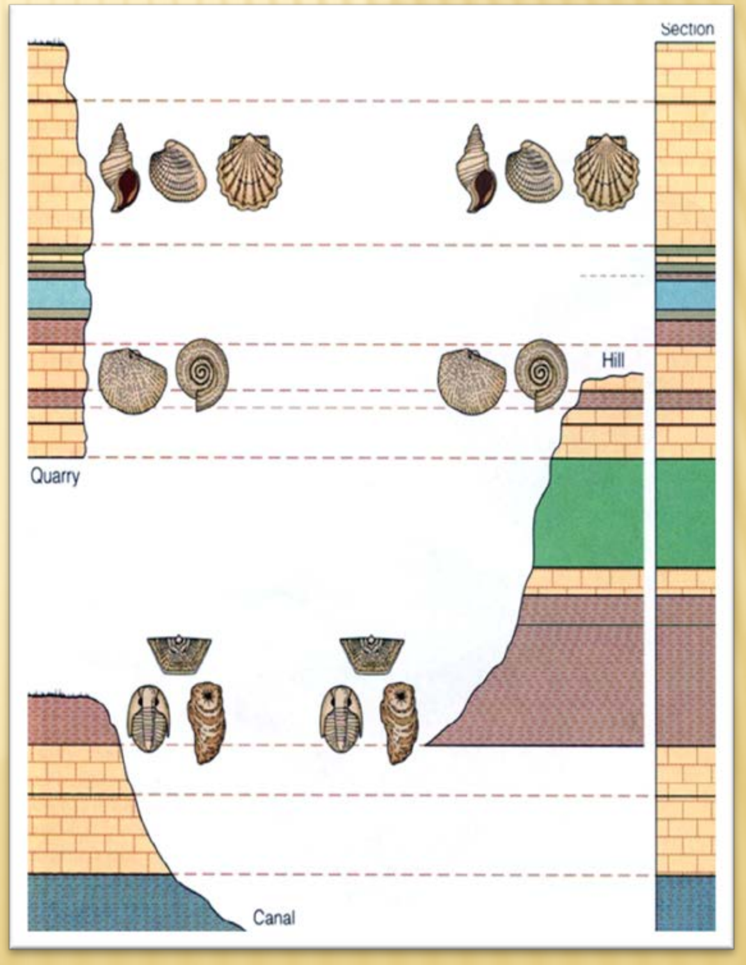




RELATIVE GEOLOGIC TIME

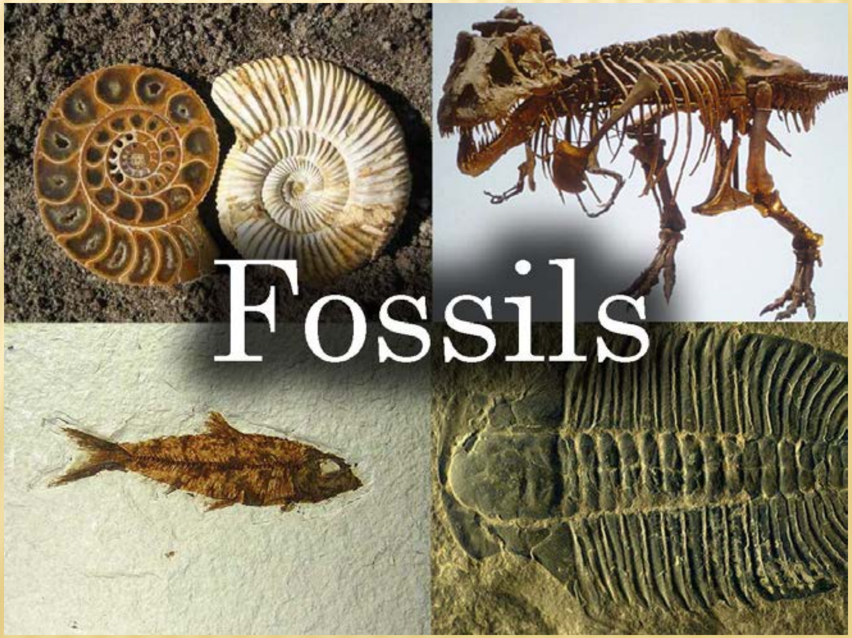
The principle of faunal succession

It states that fossil organisms succeeded one another through time in a definite and recognizable order and that the relative ages of rocks can therefore be recognized from their fossils



RELATIVE GEOLOGIC TIME

- Paleontologists study fossils, the remains and other traces of prehistoric life, to understand the history of life and evolution.
- Fossils also provide information about the ages of sedimentary rocks and their depositional environments



FOSSILS AND FAUNAL SUCCESSION

- The theory of evolution states that life forms have changed throughout geologic time.
- Fossils are useful in determining relative ages of rocks because different animals and plants lived at different times in the Earth's history.
- For example, trilobites lived from 535 million to 245 million years ago, and the first dinosaurs appeared about 220 million years ago.

CORRELATION

- To assemble a complete and continuous a record, geologists combine evidence from many localities. To do this, rocks of the same age from different localities must be matched in a process called correlation

- There are two kinds of correlation
  - Time correlation and
  - Lithologic correlation

CORRELATION

- Time correlation: matching of rocks deposited at the same time (e.g. Mesozoic sedimentary rocks in the U.S. with Mesozoic sedimentary rocks in Mexico)

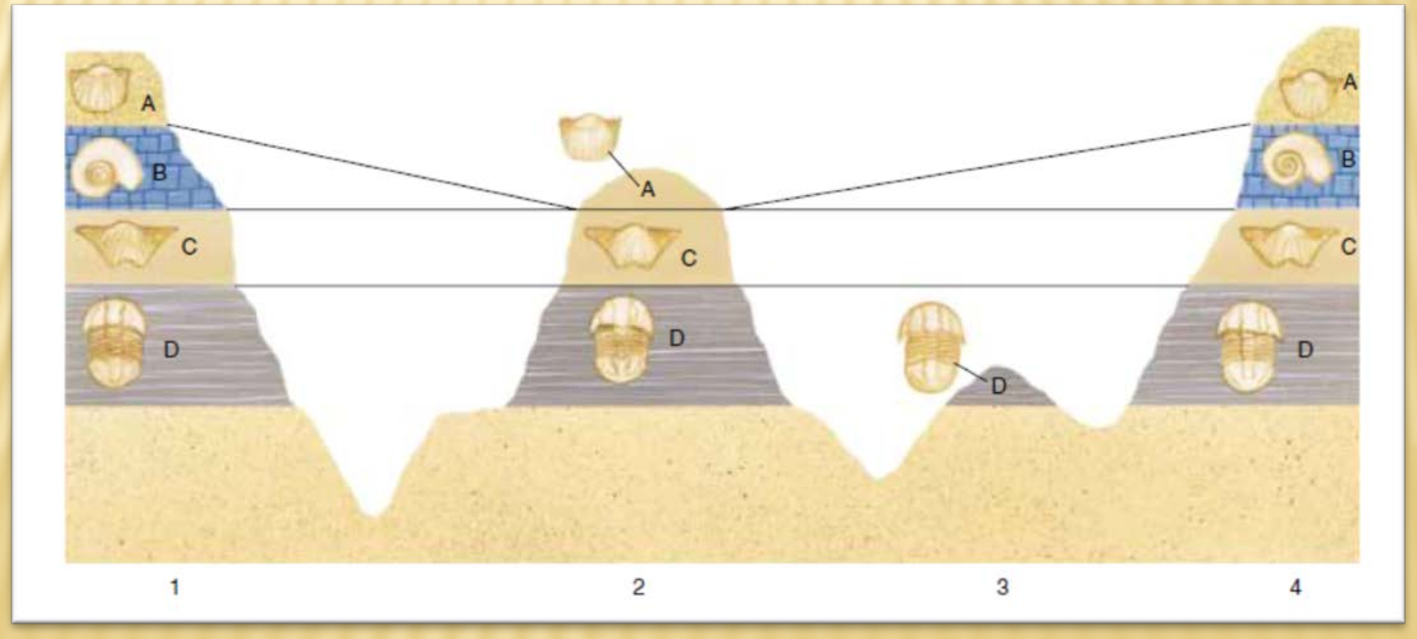
- Time correlation requires the use of index fossils to demonstrate rocks were deposited at the same time

CORRELATION

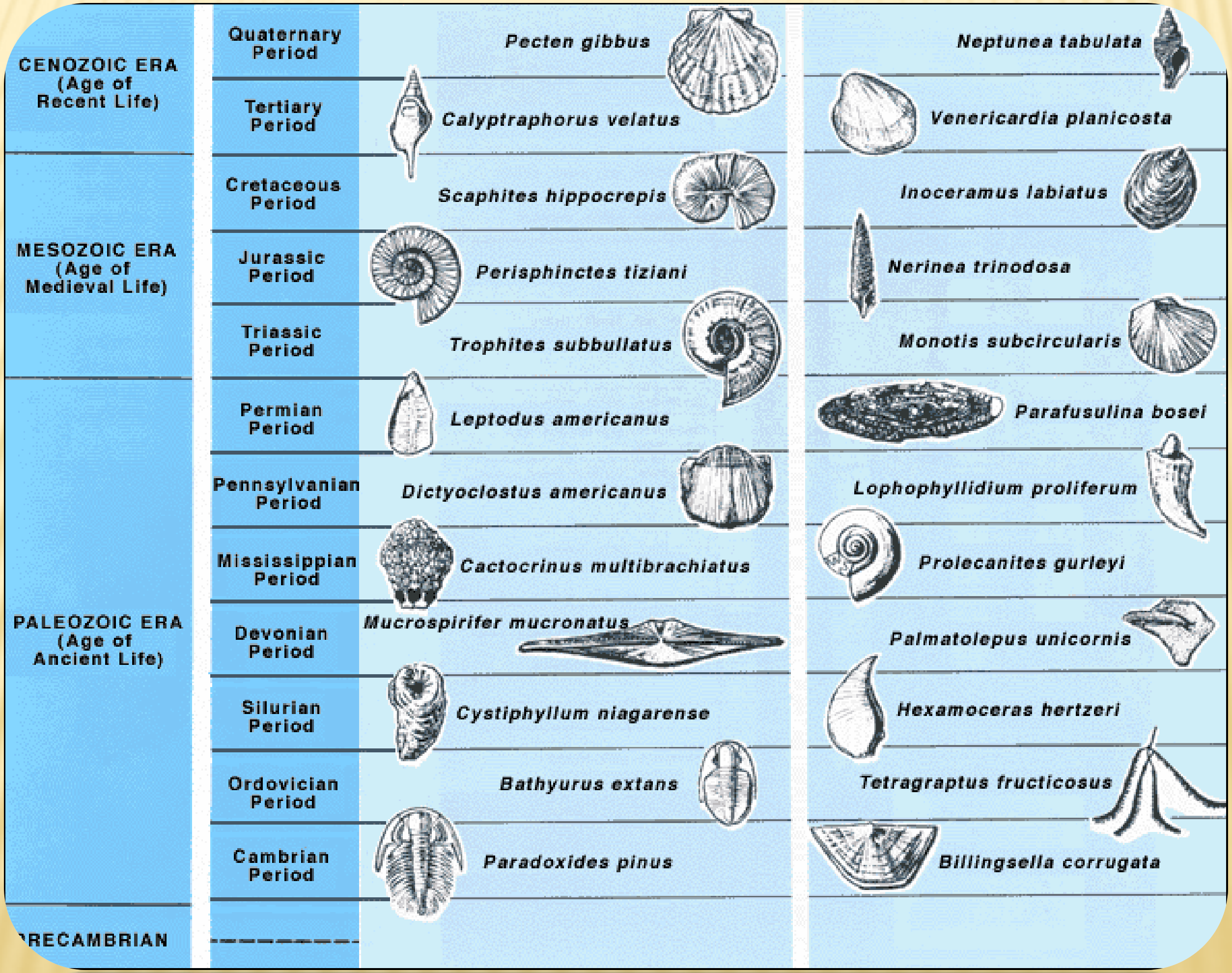
- Index fossils are fossils used to define and identify geologic periods.
- They work on the premise that, although different sediments may look different depending on the conditions under which they were laid down, they may include the remains of the same species of fossil.

CORRELATION

- To be useful, an index fossil is produced by an organism that
- **is abundantly preserved in rocks,**
- **was geographically widespread,**
- **existed as a species or genus for only a relatively short time**, and
- **is easily identified in the field.**



EXAMPLES OF INDEX FOSSILS



CORRELATION

- Lithologic correlation: matching rocks of the same character from one place to another. Usually it is not as accurate as time correlation, but easier
- This doesn't require index fossils, but lithologic correlation may not correlate rocks deposited at the same time.
- Lithologic correlation requires the use of key beds/marker beds

CORRELATION

- A key bed/marker bed is a thin, widespread sedimentary layer that was deposited rapidly and synchronously over a wide area and is easily recognized

- Examples are the ash deposits from volcanic eruptions

CORRELATION

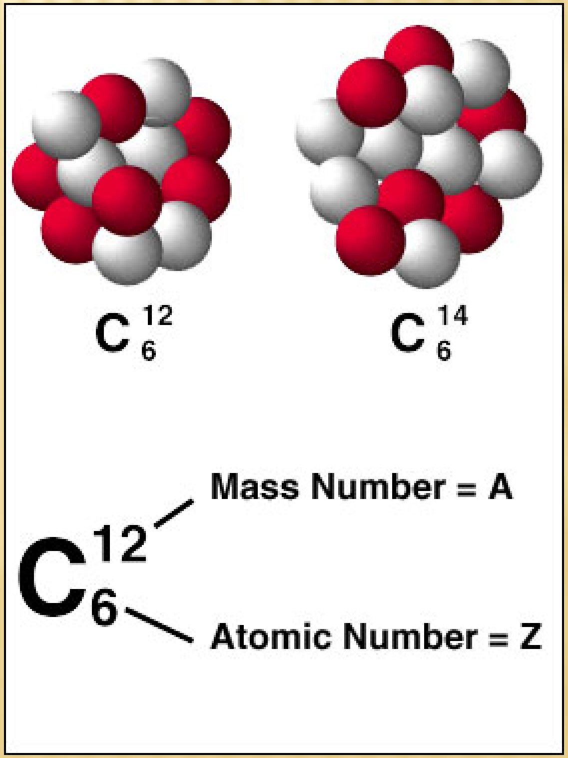
The K-T boundary layer which is marker bed found almost all over the world.The layer shows high concentration of the element iridium. iridium does not occur naturally on Earth in high concentrations, but it does occur in higher concentrations in certain types of meteorites. It points to a metorite impact 65 million years ago which was responsible for the extiction of the dinosaurs

ABSOLUTE GEOLOGIC TIME

- Natural Radioactivity of the elements present in rocks provides a way for measuring the absolute geologic time

•Elements having the same atomic number but different atomic mass are known as Isotopes

•The difference in mass is due to the difference in the number of neutrons

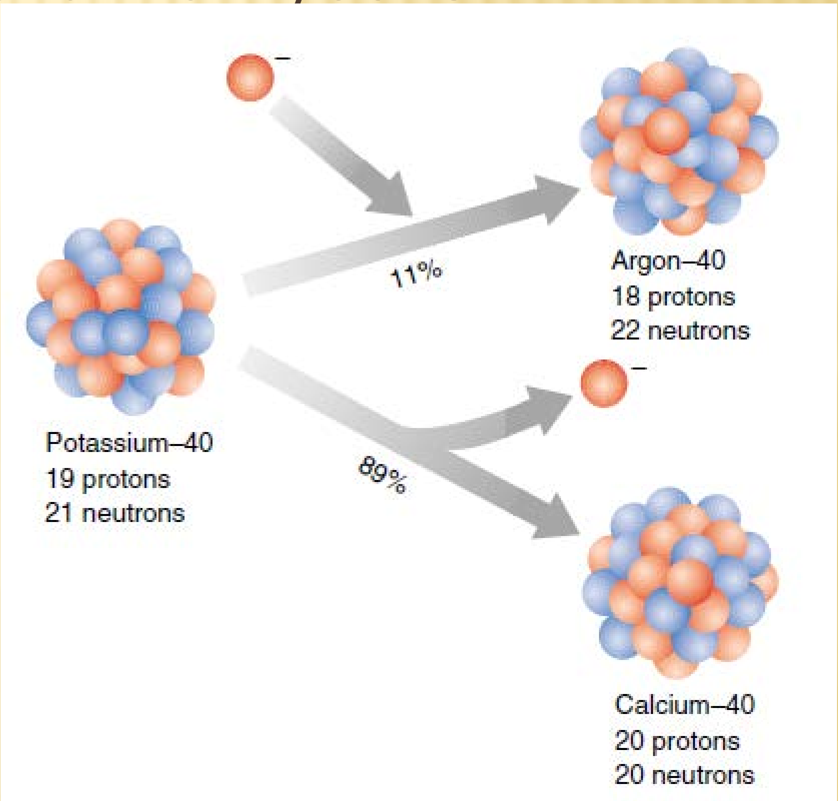


ABSOLUTE GEOLOGIC TIME

- Many isotopes are stable and do not change with time. For example potassium-39 remains unchanged even after 10 billion years

•Other isotopes are **unstable** or **radioactive**. Given time, their nuclei spontaneously break apart

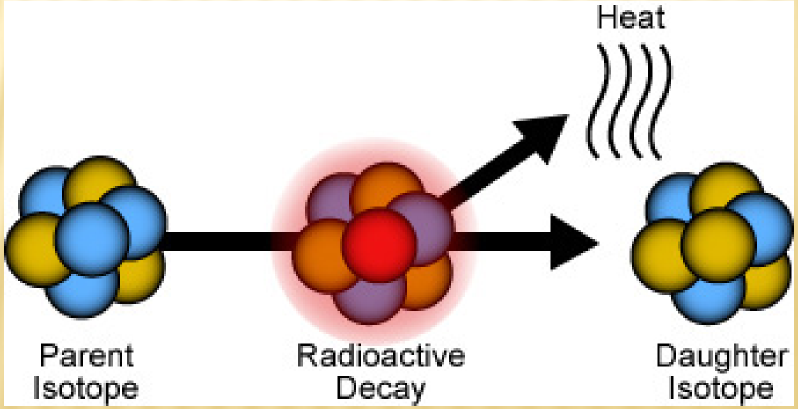
•Potassium-40 decomposes naturally to form two other isotopes, argon-40 and calcium-40



ABSOLUTE GEOLOGIC TIME

- A radioactive isotope such as potassium-40 is known as a parent isotope.

- An isotope created by radioactivity, such as argon-40 or calcium-40, is called a daughter isotope.

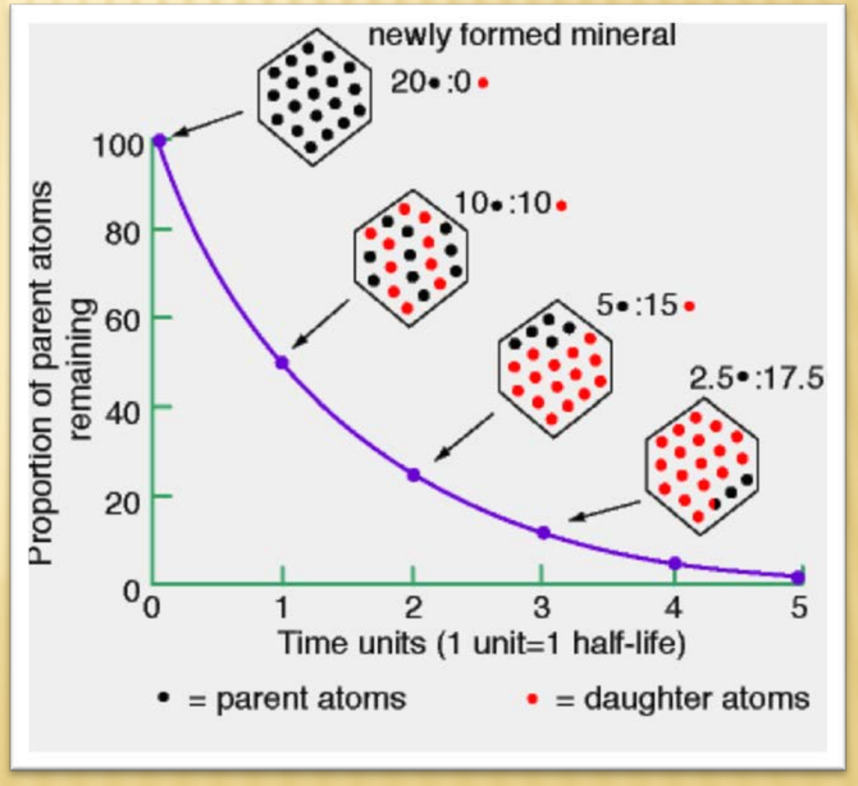


ABSOLUTE GEOLOGIC TIME

- The half-life is the time it takes for half of the atoms in a sample to decompose.

•The half-life of potassium- 40 is 1.3 billion years. Therefore, if 1 gram of potassium-40 were placed in a container, 0.5 gram would remain after 1.3 billion years, 0.25 gram after 2.6 billion years, and so on.

Each radioactive isotope has its own half-life; some half-lives are fractions of a second and others are measured in billions of years.



ABSOLUTE GEOLOGIC TIME

- Two aspects of radioactivity are essential to the calendars in rocks
- First, the half-life of a radioactive isotope is constant. It is easily measured in the laboratory and is unaffected by geologic processes. So radioactive decay occurs at a known, constant rate
- Secondly as a parent isotope decays, its daughter accumulates in the rock. The longer the rock exists, the more daughter isotope accumulates. The accumulation of a daughter isotope is similar to marking off days on a calendar

ABSOLUTE GEOLOGIC TIME

ISOTOPES		HALF-LIFE OF PARENT (YEARS)	EFFECTIVE DATING RANGE (YEARS)	MINERALS AND OTHER MATERIALS THAT CAN BE DATED
Parent	Daughter			
Carbon-14	Nitrogen-14	5730 ± 30	100–70,000	Anything that was once alive: wood, other plant matter, bone, flesh, or shells; also, carbon in carbon dioxide dissolved in ground water, deep layers of the ocean, or glacier ice
Potassium-40	Argon-40 Calcium-40	1.3 billion	50,000–4.6 billion	Muscovite Biotite Hornblende Whole volcanic rock
Uranium-238	Lead-206	4.5 billion	10 million–4.6 billion	Zircon Uraninite and pitchblende
Uranium-235	Lead-207	710 million		
Thorium-232	Lead-208	14 billion		
Rubidium-87	Strontium-87	47 billion	10 million–4.6 billion	Muscovite Biotite Potassium feldspar Whole metamorphic or igneous rock

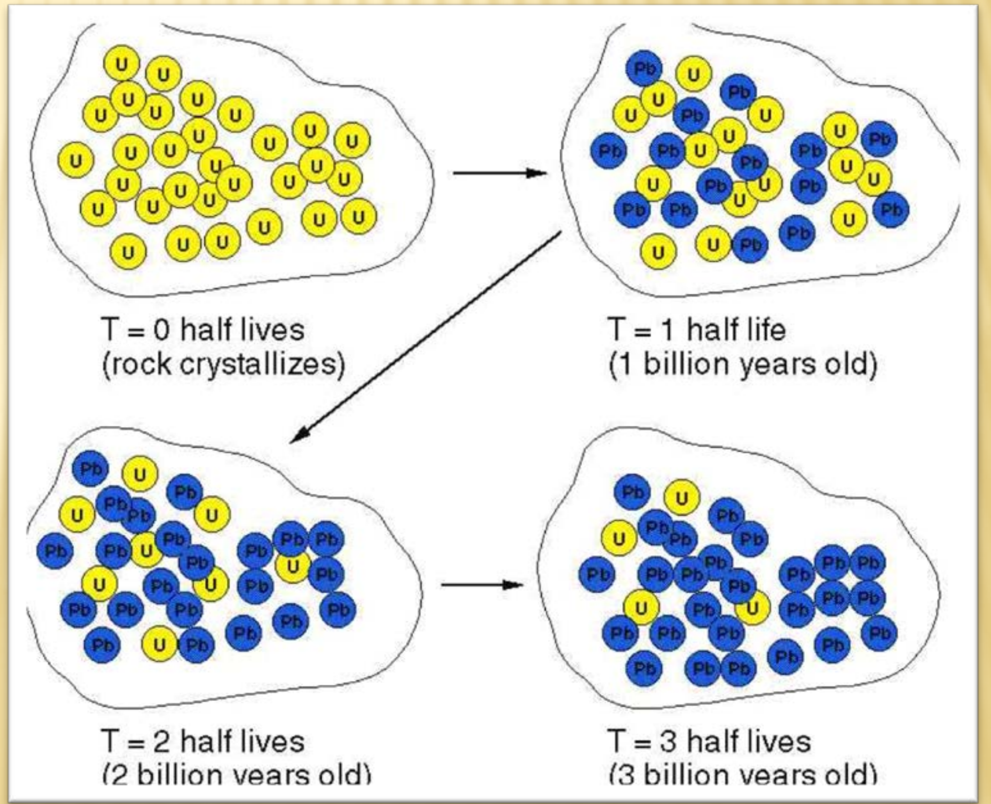
ABSOLUTE GEOLOGIC TIME

- **Radiometric dating** is the process of determining the ages of rocks, minerals, and fossils by measuring their parent and daughter isotopes

•At the end of one half-life, 50 percent of the parent atoms have decayed to daughter.

•At the end of two half-lives, the mixture is 25 percent parent and 75 percent daughter.

•To determine the age of a rock, a geologist measures the proportions of parent and daughter isotopes in a sample and compares the ratio.



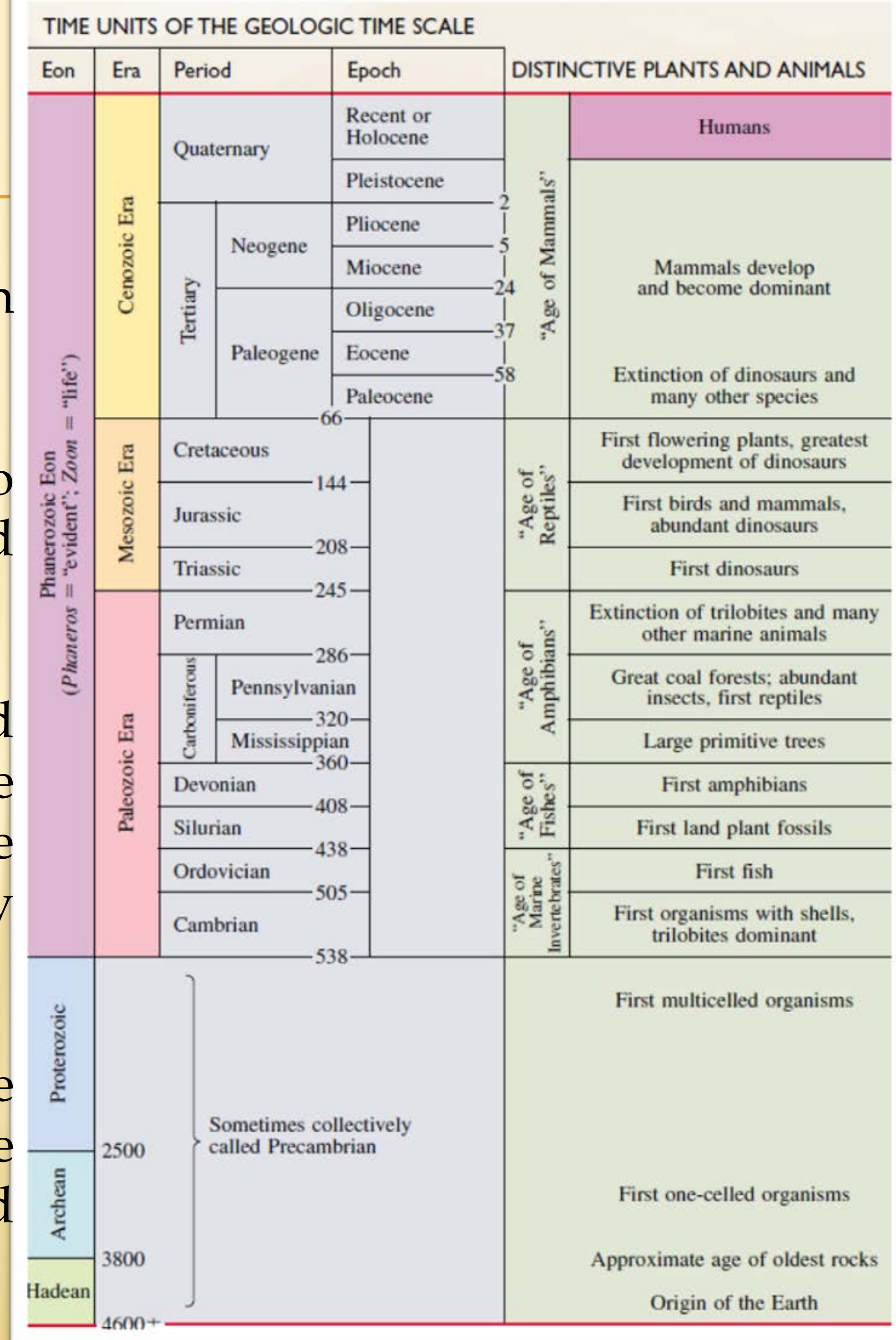
THE GEOLOGICAL COLUMN AND TIME SCALE

•The largest time units are **eons**, which are divided into **eras**.

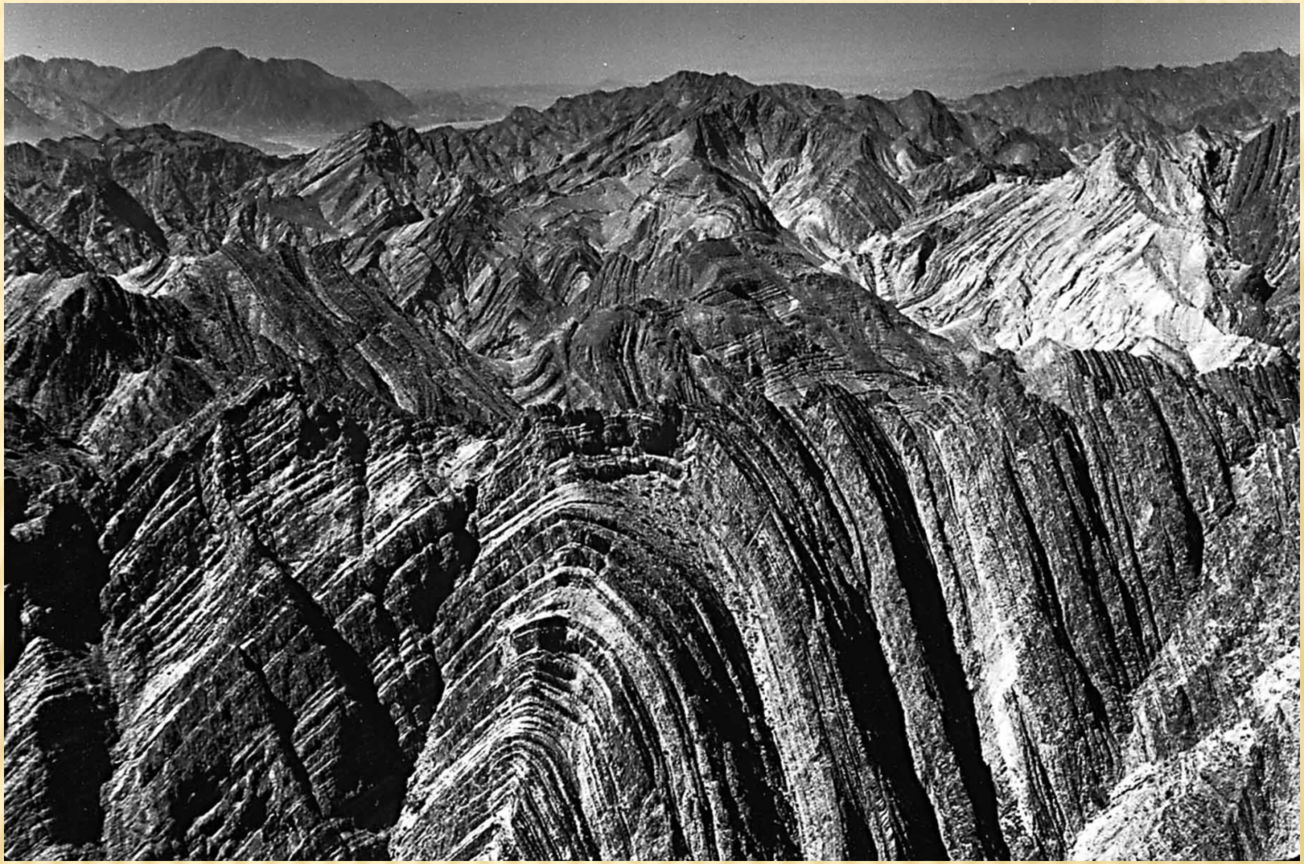
•Eras are subdivided, in turn, into **periods**, which are further subdivided into **epochs**

•The **Phanerozoic Eon** is finely and accurately subdivided because sedimentary rocks deposited at this time are often well preserved and they contain abundant well-preserved fossils

•In contrast, Precambrian rocks and time are only coarsely subdivided because fossils are scarce and poorly preserved and the rocks are often altered.



UNIT 10



MOUNTAIN BUILDING AND EVOLUTION OF CONTINENTS

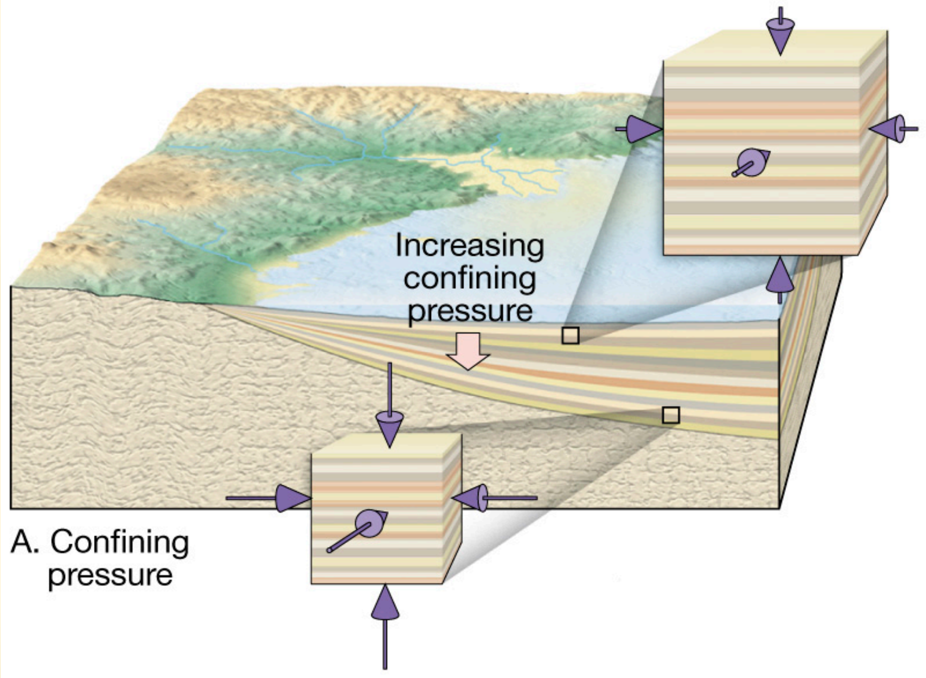
ROCK DEFORMATION

STRESS

- Tectonic forces exert different types of stress on rocks in different geologic environments.

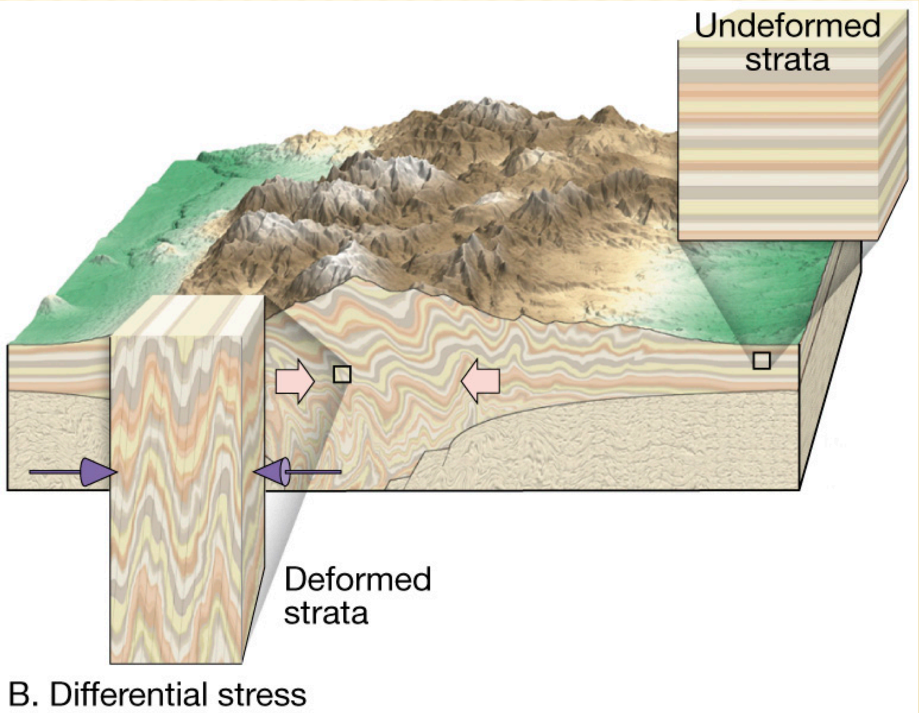
- The first, called confining stress or confining pressure, occurs when rock or sediment is buried.

- Confining pressure merely compresses rocks but does not distort them, because the compressive force acts equally in all directions



ROCK DEFORMATION

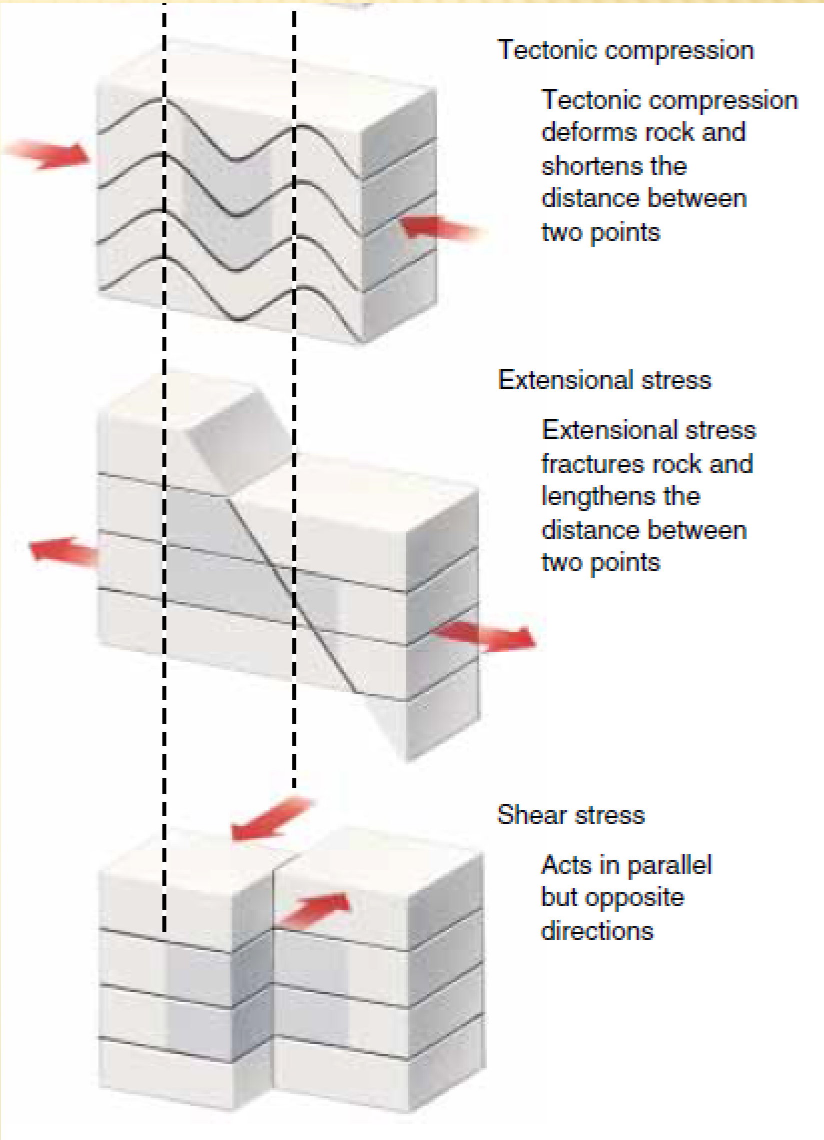
- STRESS
- In contrast <u>directed stress or directed pressure</u>, acts only in one direction.
- Tectonic processes create three types of directed stress.



ROCK DEFORMATION

DIRECTED PRESSURE

- **Compressive stress** is common in **convergent** plate boundaries,where two plates converge and the rock.
- **Extensional stress** (often called tensional stress) pulls rock apart and is the opposite of **tectonic** compression Rocks at a divergent plate boundary stretch and pull apart because they are subject to extensional stress.
- **Shear stress** **acts in parallel but** opposite directions. Shearing deforms rock by causing one part of a rock mass to slide past the other part, as in a transform fault or a transform plate boundary.



ROCK DEFORMATION

STRAIN

- Strain is the deformation produced by stress.
- Deformation can be of two types

1. Elastic deformation: An elastically deformed rock springs back to its original size and shape when the stress is removed.
2. Plastic deformation :During plastic deformation, a rock deforms like putty and retains its new shape.

- Once the substance/rock has reached the limit of plastic deformation, it breaks or ruptures. This is known as the brittle deformation.

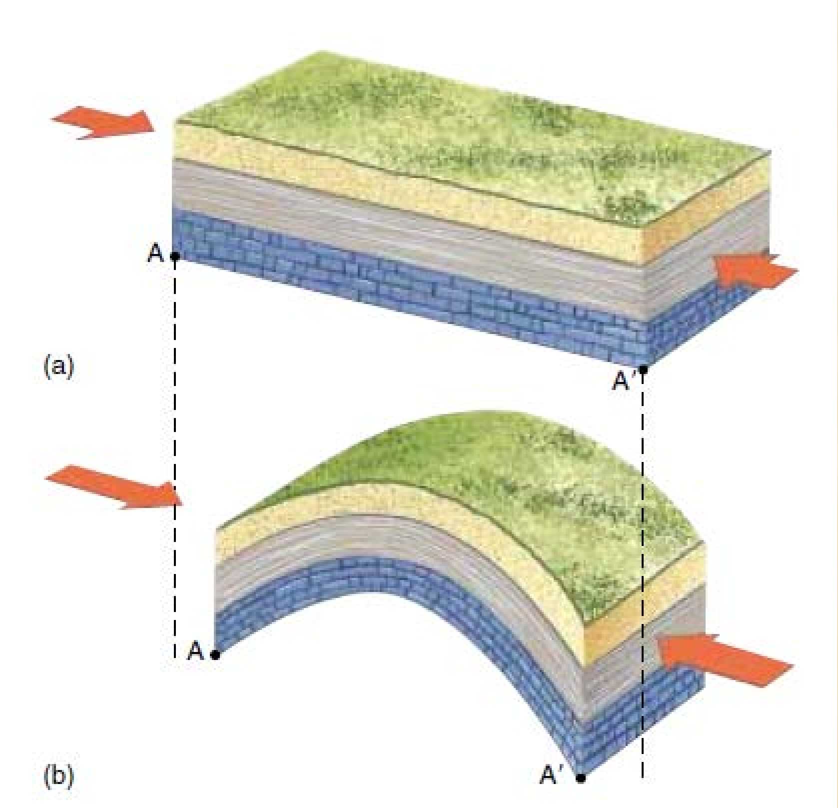
GEOLOGICAL STRUCTURES

- A geologic structure is any feature produced by rock deformation.
- Tectonic forces create three types of geologic structures: folds, faults, and joint.
- A fold is a bend in rock. Some folded rocks display little or no fracturing, indicating that the rocks deformed in a plastic manner. In other cases, folding occurs by a combination of plastic deformation and brittle fracture. Folds formed in this manner exhibit many tiny fractures

GEOLOGICAL STRUCTURES

FOLDS

- Folding usually results from compressive stress. For example, tightly folded rocks in the Himalayas indicate that the region was subjected to compressive stress.

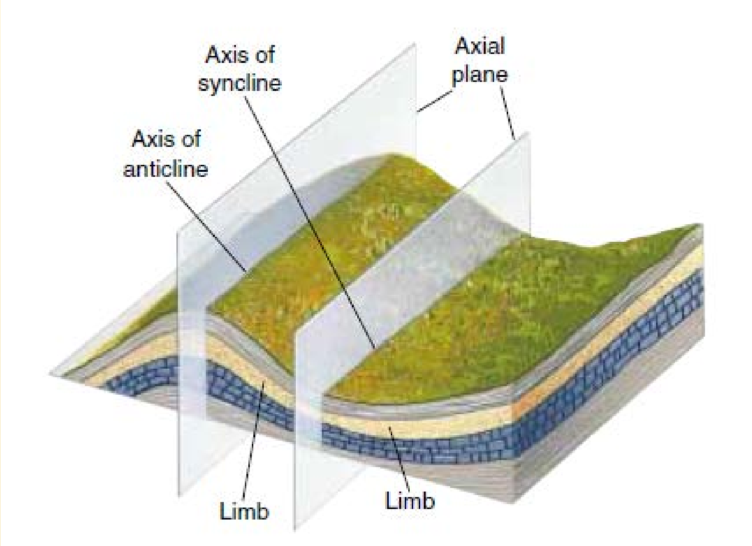


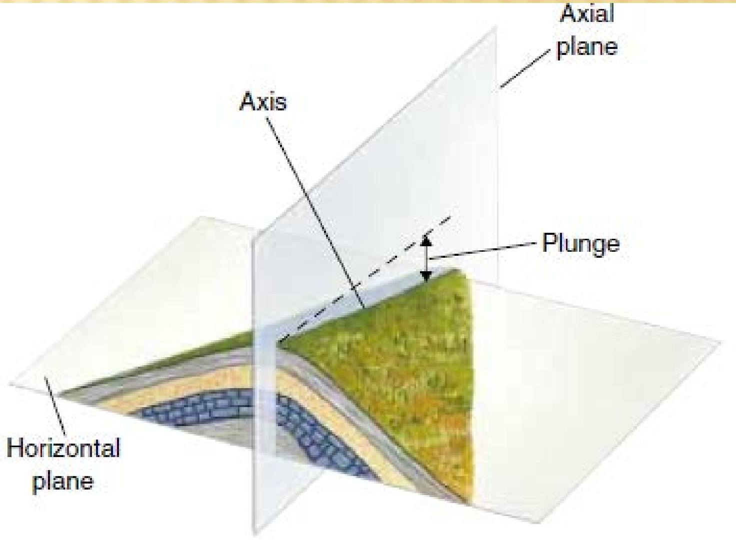
- Folding always shortens the horizontal distances in rock.

GEOLOGICAL STRUCTURES

PARTS OF A FOLD

- The sides of a fold are called the limbs.
- A line dividing the two limbs of a fold and running along the crest of an anticline or the trough of a syncline is the fold axis.
- The axial plane is an imaginary plane that runs through the axis and divides a fold as symmetrically as possible into two halves.

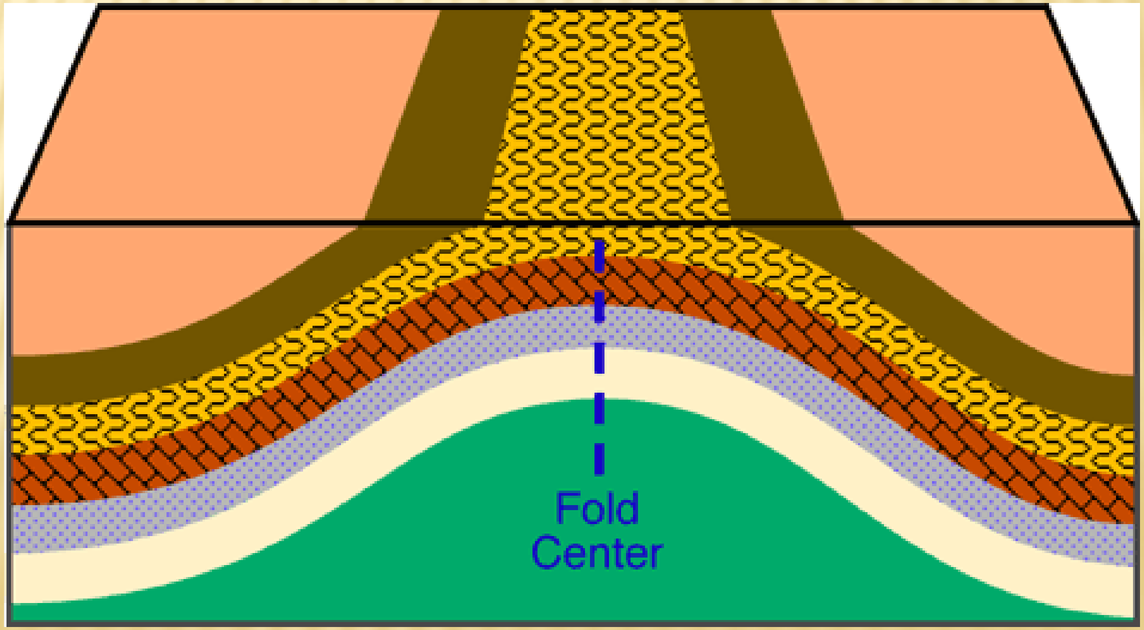




GEOLOGICAL STRUCTURES

TYPES OF FOLDS

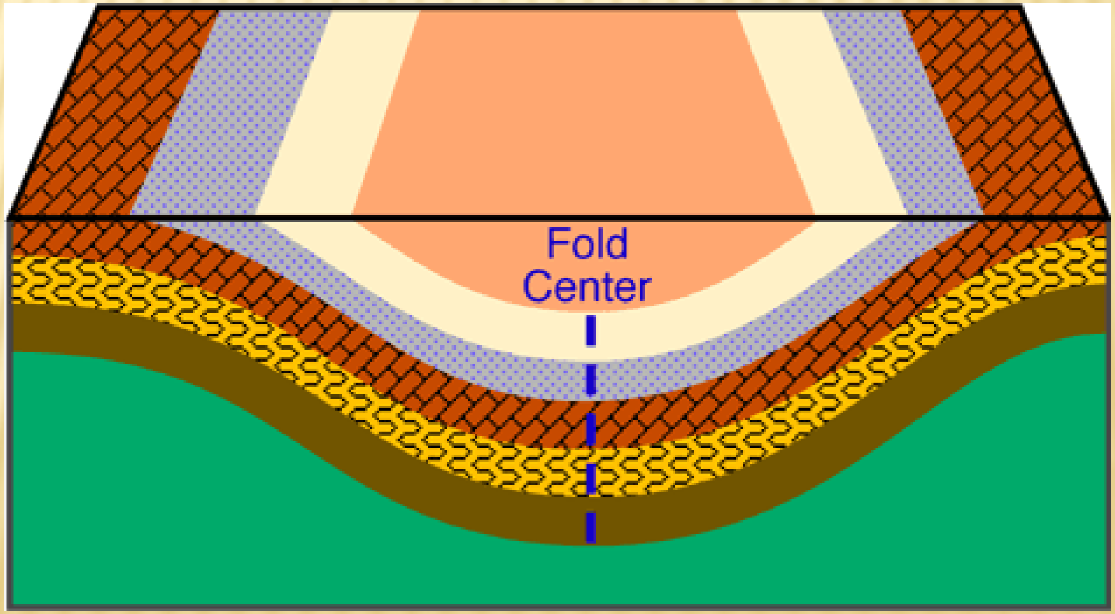
- An **anticline** is a convex up fold in which the limbs of the fold dip away from each other. The oldest rocks lie in the center of the fold



GEOLOGICAL STRUCTURES

TYPES OF FOLDS

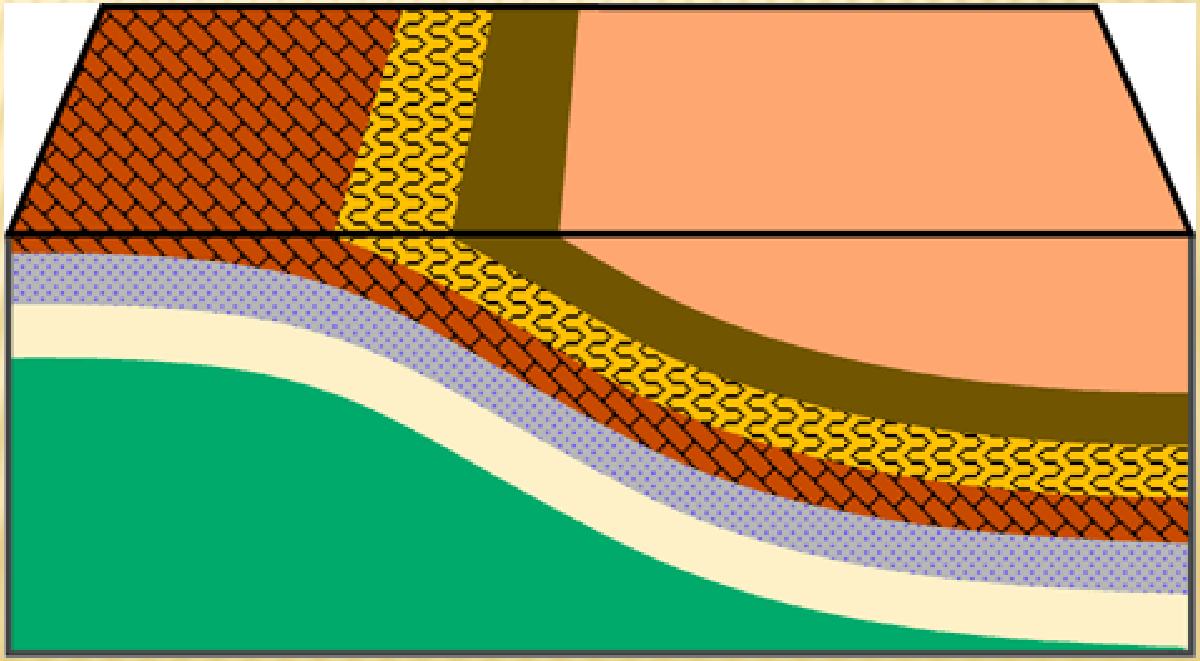
- In a <u>syncline</u> the limbs of the fold dip towards each other. The youngest beds are in the center of the fold



GEOLOGICAL STRUCTURES

TYPES OF FOLDS

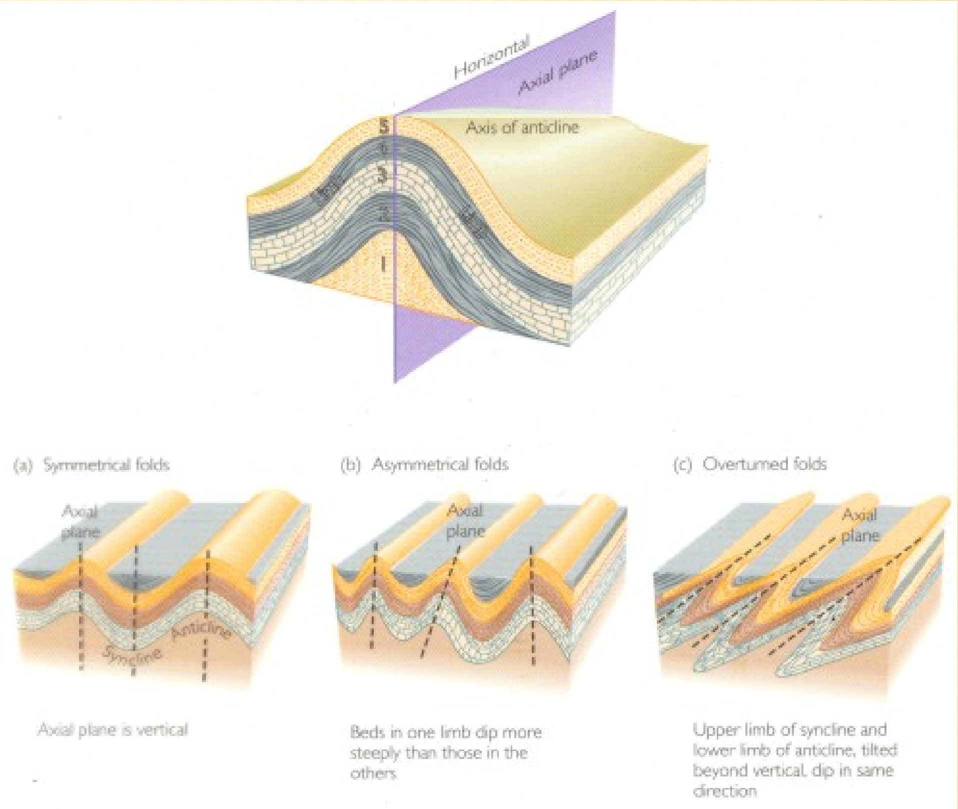
- A special type of fold with only one limb is a **monocline.**



GEOLOGICAL STRUCTURES

TYPES OF FOLDS

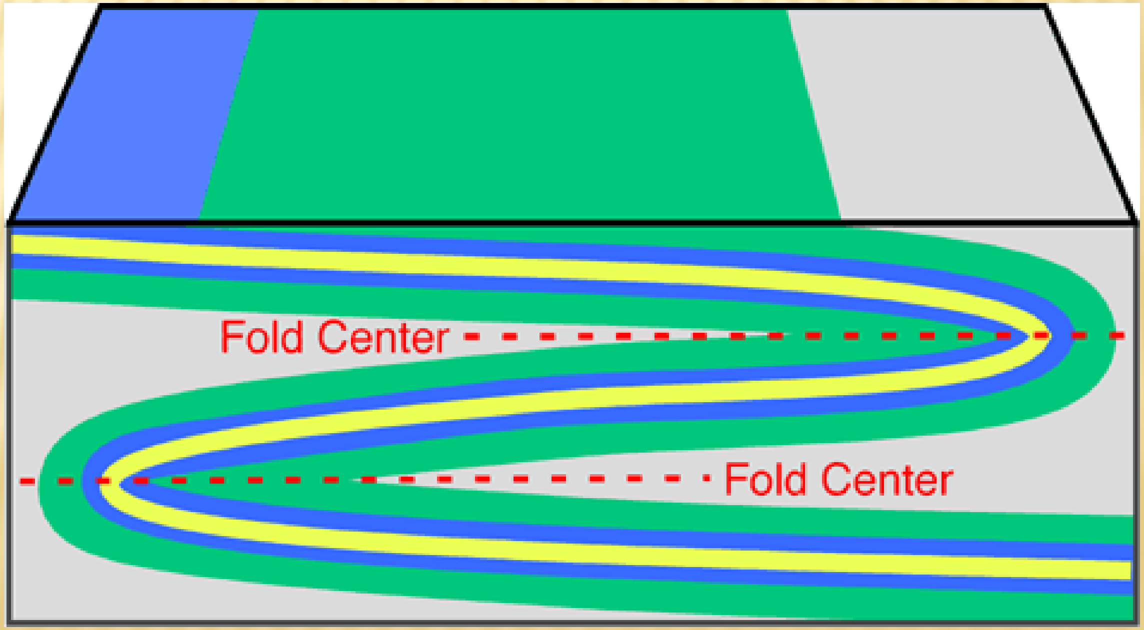
- A symmetrical fold is one in which the axial plane is vertical.
- An asymmetrical fold is one in which the axial plane is inclined.
- In an overturned fold, the beds dip in the same direction on both sides of the axial plane.



GEOLOGICAL STRUCTURES

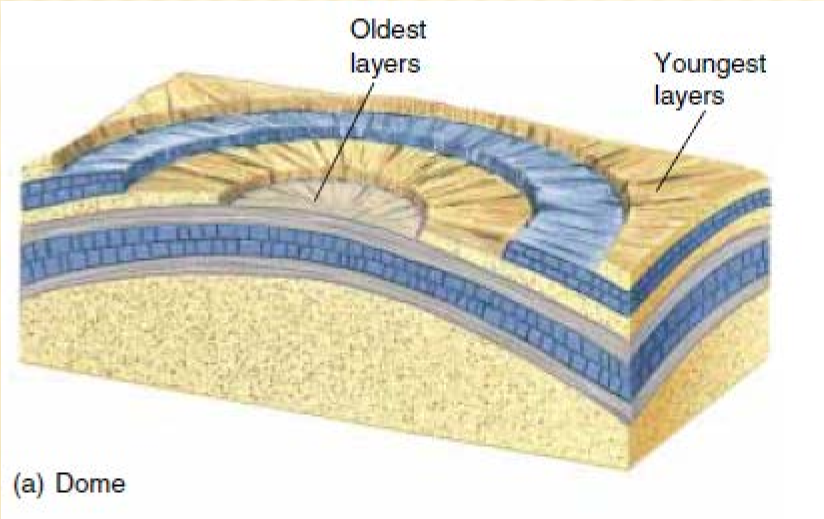
TYPES OF FOLDS

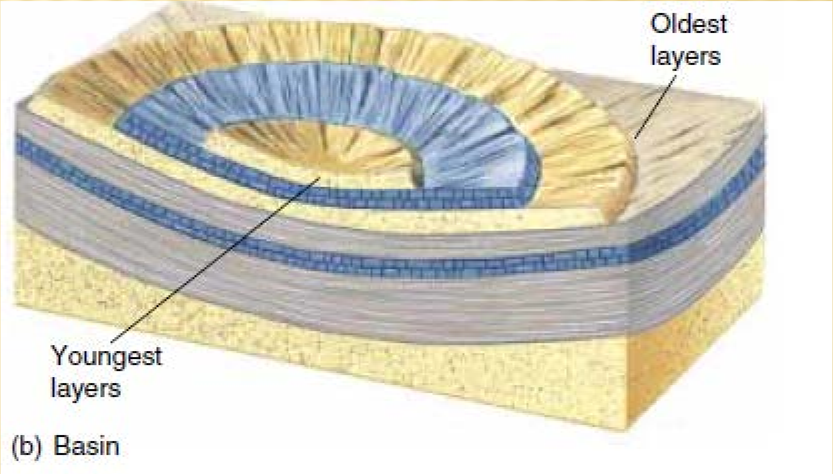
- In a **recumbent fold** the axial plane is horizontal and the limbs of the fold are parallel to each other.



GEOLOGICAL STRUCTURES

- A circular or elliptical anticlinal structure is called a **dome**. The layer dips away from the center of a dome in all directions.
- A circular or elliptical synclinal structure is called a **basin**. The layer dips towards the center of the basin in all directions.

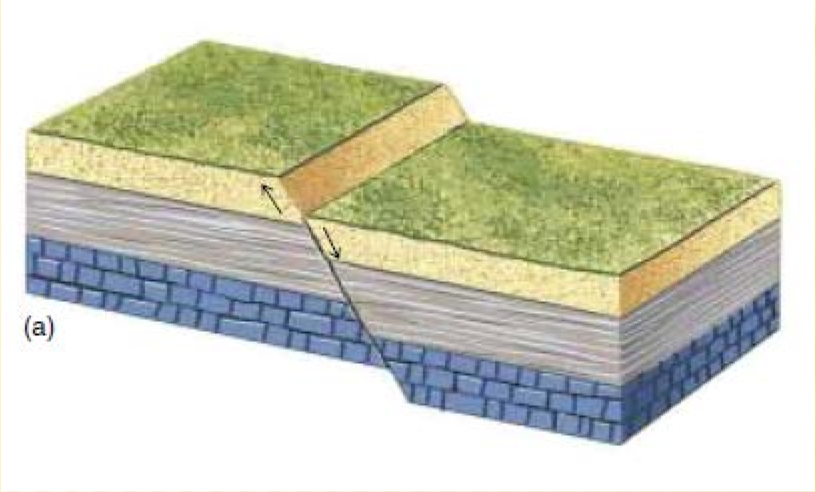


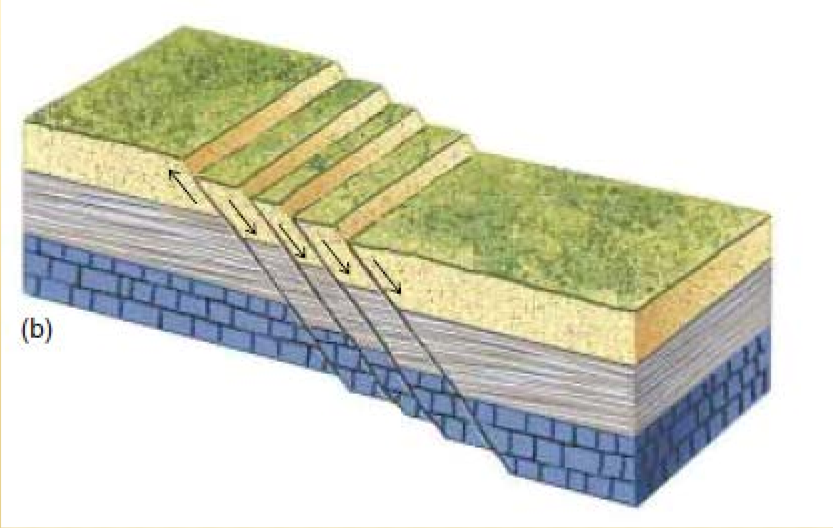


GEOLOGICAL STRUCTURES

FAULTS

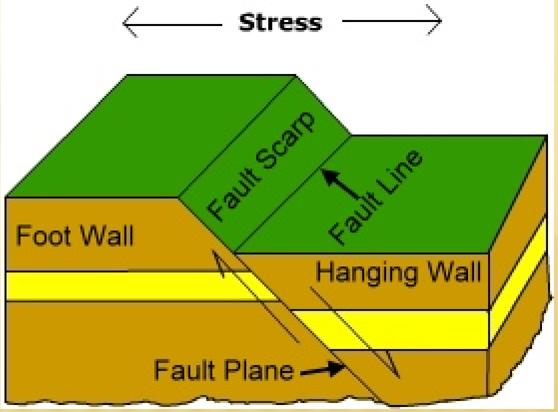
- A fault is a fracture along which rock on one side has moved relative to rock on the other side.
- Slip is the distance that rocks on opposite sides of a fault have moved.
- Some faults are a single fracture in rock; others consist of numerous closely spaced fractures called a fault zone.





GEOLOGICAL STRUCTURES

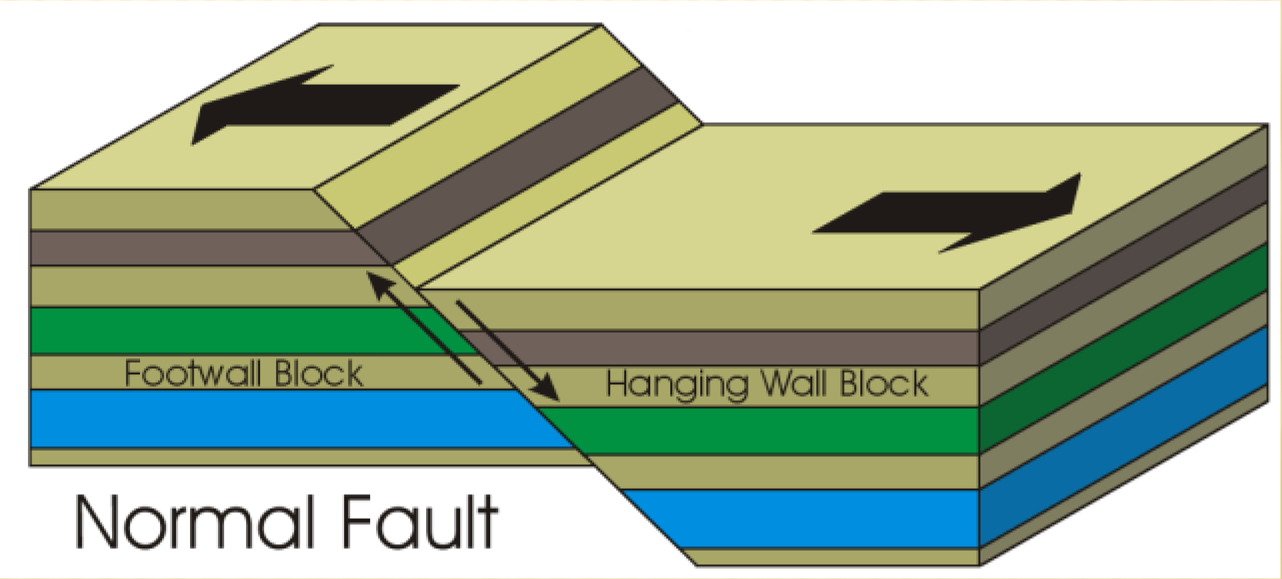
- The two sides of a non-vertical fault are known as the hanging wall and footwall.
- By definition, the hanging wall occurs above the fault and the footwall occurs below the fault.
- Fault Plane is the plane along which the rock or crustal material has fractured.



GEOLOGICAL STRUCTURES

Normal Fault

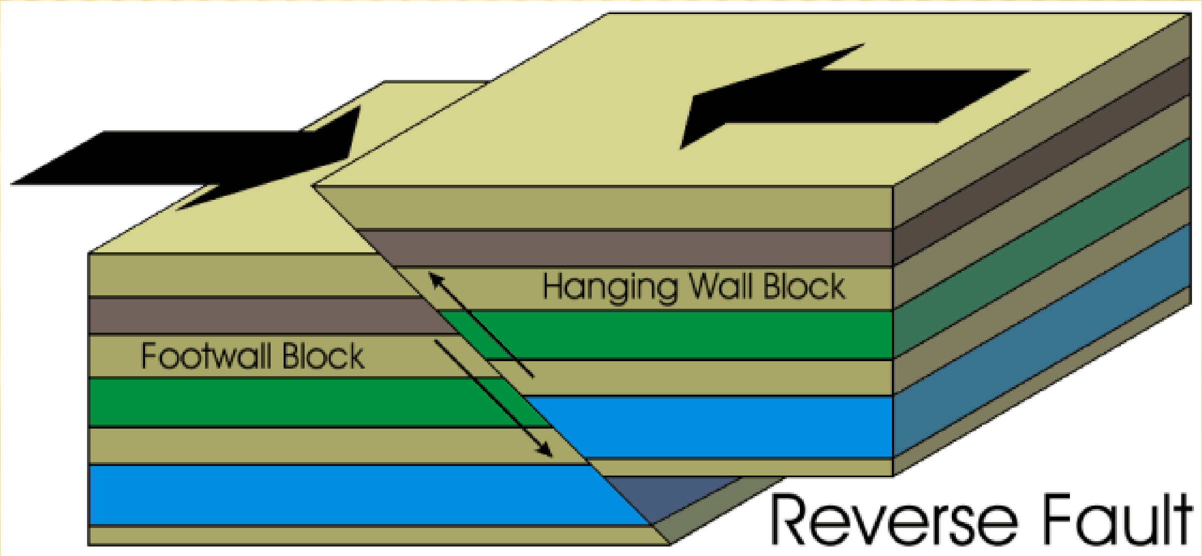
- Hanging wall moves down relative to footwall.
- Caused by horizontal tension stress.
- Results in extension.



GEOLOGICAL STRUCTURES

Reverse Fault

- Hanging wall moves up relative to footwall.
- Caused by compressive stress.
- Results in shortening.
- Fault plane is oriented between 30 and 90 degrees (measured from horizontal).

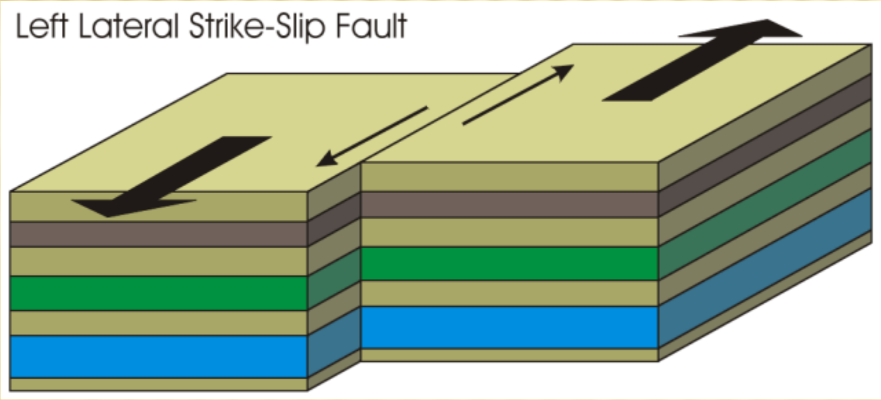


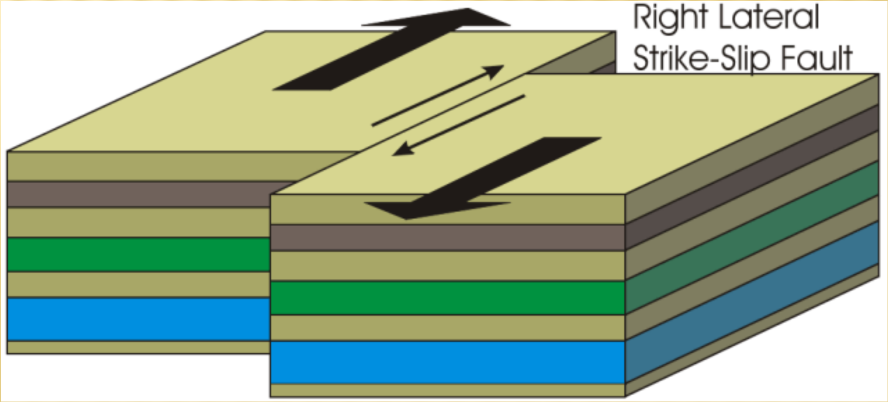
GEOLOGICAL STRUCTURES

Strike-Slip Faults

- A strike–slip fault is one in which the fracture is vertical, or nearly so, and rocks on opposite sides of the fracture move horizontally past each other.

- A transform plate boundary is a strike–slip fault

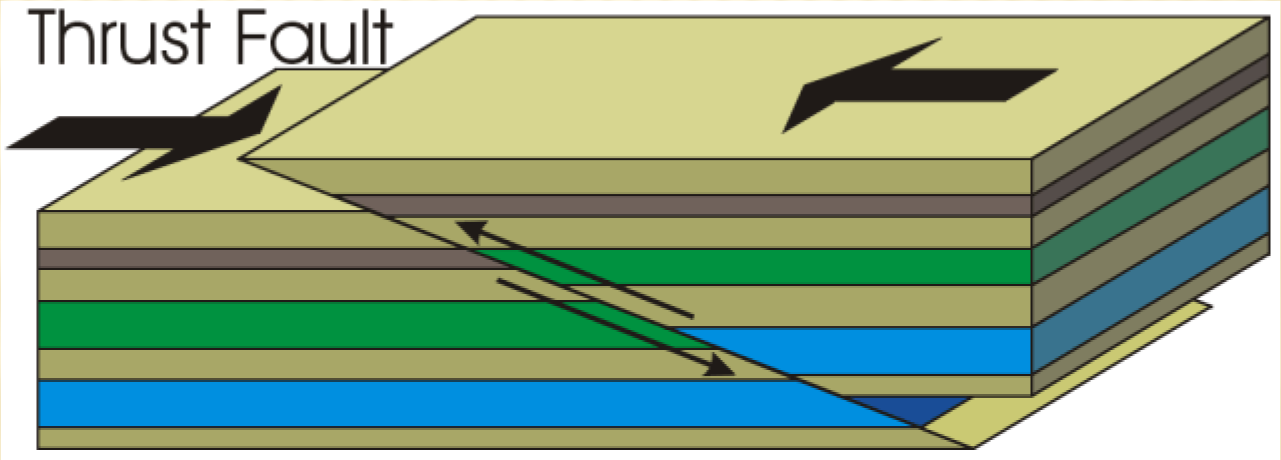




GEOLOGICAL STRUCTURES

Thrust Fault

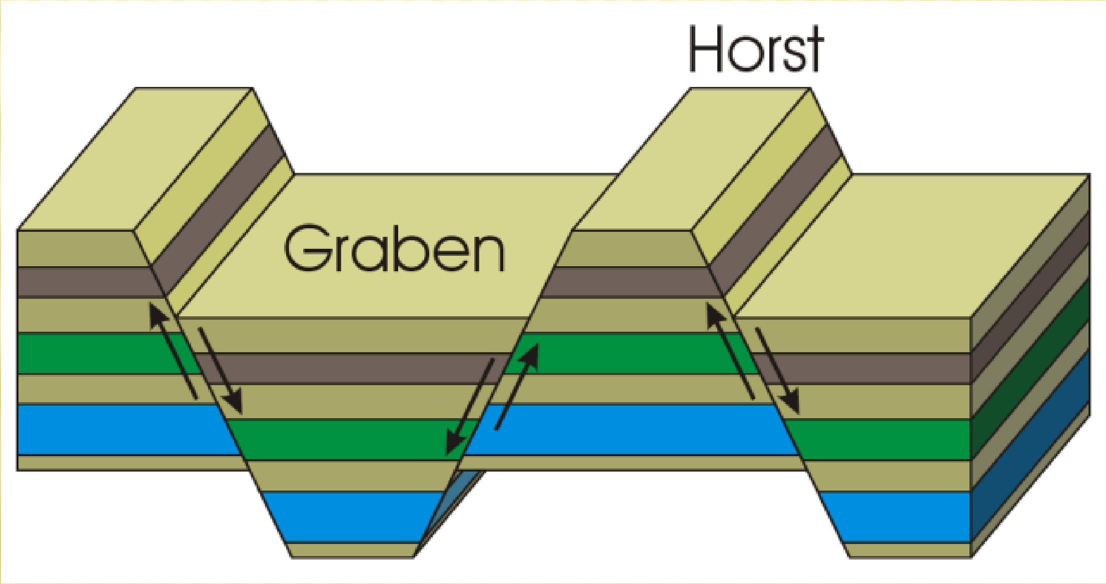
- A thrust fault is a special type of reverse fault that is nearly horizontal
- Fault plane is at less than 30 degrees



GEOLOGICAL STRUCTURES

Horsts and Grabens

- Horsts are up thrown blocks bounded on either side by non-parallel normal faults.
- Grabens are downthrown blocks bounded on either side by non-parallel normal faults.



GEOLOGICAL STRUCTURES

JOINTS

- A joint is a fracture in rock and is therefore similar to a fault except that in a joint rocks on either side of the fracture have not moved