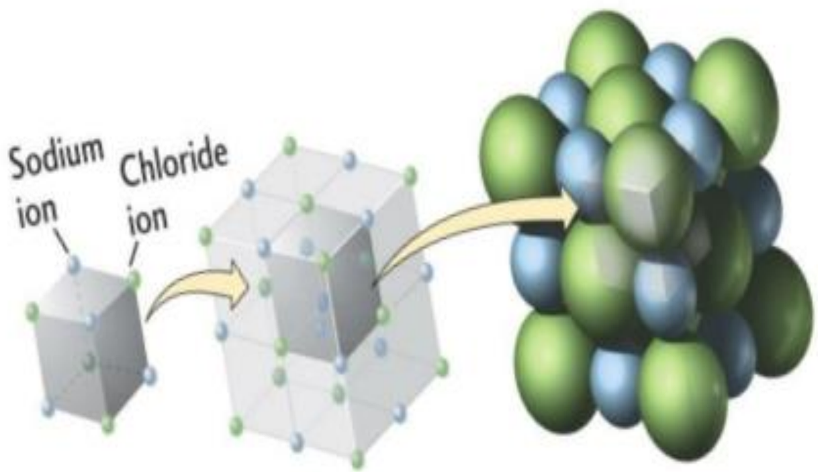
Chapter 2

Crystals and minerals

Outline:

- *Crystal definition*
- *crystal characteristics*
- *Atomic arrangement*
- *Mineral and rock*
- *Mineral classification*
- *Rock forming minerals*
- *physical properties of minerals*



What is crystal?

- A **crystal** is a solid state of matter containing an internal arrangement of atoms, molecules or ions that is **regular**, **repeated** and geometrical arranged.
- ✓ It is characterized by well developed faces.
- ✓ It is a 3D solid which is bounded by
- symmetrically arranged faces having a regular geometric shape an regular internal arrangement of atoms.
- It can originated from **melt** (olivine crystal),**solution** (halite crystal),or **vapour** (Sulphur)
- Crystals are made of 3-dimensional arrays of atoms which are called **lattice.**

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Characteristics of lattice

- A face more commonly developed in a crystal if it intersects a larger number of lattice points.
- Since all crystals of the same substance will have the same spacing between lattice points (they have the same crystal structure), the angles between corresponding faces of the same mineral will be the same. This is known as the ***Law of constancy of inter facial angles***.

why we study crystal?

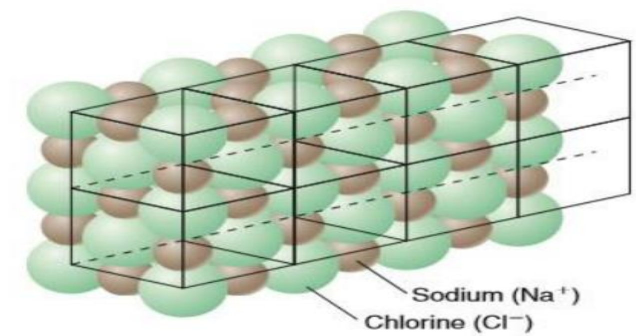
- Crystal structures determine the minerals properties like hardness**. e.g.** graphite and diamond. Graphite is soft but diamond is hardest due to the close packing of carbon atoms. in graphite the carbon atoms are bonded in sheets to make it weak.

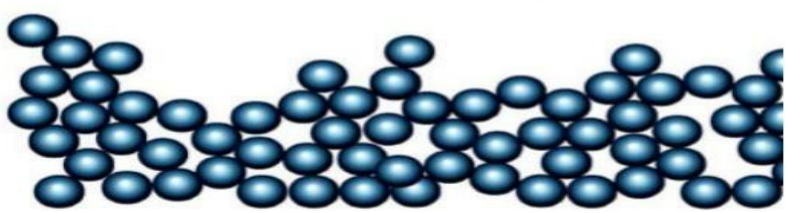
Atomic arrangement

- Solid can be crystalline or amorphous .

- **Crystalline-**regular arrangement of atoms: definite repetitive pattern. The periodicity of atoms in crystalline solids can be described by a network of atoms in space called lattice. it is an arrangement of points.
- **Amorphous-**random arrangement of atoms. **e.g.**; Random arrangement in glass

Fig. lattice arrangement in halite





Mineral

- **A mineral** is defined to be a naturally occurring, crystalline, inorganic, homogeneous solid with a chemical composition that is either fixed or varies within certain fixed limits, and a characteristic internal structure manifested in its exterior form and physical properties.

- A substance is said to be a **mineral** if:
  - it is natural
  - it is inorganic
  - it is solid .
  - It has a well defined regular internal arrangement of its constituent atoms and ions.
  - It has definite chemical composition which can be expressed by a chemical formula.
  - It has a definite set of physical properties that are fixed with in certain limits. **e.g.** hardness, density, color, etc

- **Rocks** are collections of one or more minerals. In order to understand how rocks vary in composition and properties, it is necessary to know the variety of minerals that commonly occur in them, and to identify a rock it is necessary to know which minerals are present in it.
- **Two techniques are employed to identify minerals:**

(a) the study of a hand specimen of the mineral, or the rock in which it occurs, using a hand lens (×8 or ×10) and observing diagnostic features; and

(b) the examination of a thin slice of the mineral, ground down to a thickness of 0.03 mm, using a microscope, the rock slice being mounted in transparent resin on a glass slide.

- The former method is by far the most useful to an engineer, since proficiency in the use of a microscope requires an amount of study out of proportion to its future benefit, except for the specialist engineering geologist.

Mineral groups

- ❖ Minerals are commonly grouped based on their chemical compositions.

The most important groups of minerals include:

1) **Native elements** - gold, silver, copper, iron, platinum, sulfur etc
2) **Sulphates** - gypsum ($CaSO_4.2H_2O$), barite ($BaSO_4$)
3) **Oxides** - magnetite(Fe_3O_4), hematite(Fe_2O_3), corundum (Al_2O_3)
4) **Carbonates** - calcite ($CaCO_3$), dolomite ($(Ca, Mg)CO_3$), magnesite ($MgCO_3$)
5) **Halides** - halite (NaCl), fluorite (CaF_2), sylvite (KCl)
6) **Sulphides** - pyrite (FeS_2), galena (PbS), Sphalerite (ZnS)
7) **Phosphates -** apatite ($Ca_5(PO_4)_3(F,OH, Cl)$)
8) **Silicates** olivine ($(Mg, Fe)_2SiO_4$), pyroxene ($MgSiO_3$), amphibole $Mg_7Si_8O_{22}(OH)_2$)

Rock forming minerals

- ❑ The most common rock forming minerals are:

 Silicates - Sulfides Oxides - Sulfates Carbonates

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Physical properties commonly used are:

1. Hardness: it is the measure of the ease with which the surface of a mineral can be scratched. Hardness is measured on a relative scale called the Mohs' scale of hardness, which consists of ten common minerals arranged in order of their increasing hardness.

2. **Crystal Form/**: the geometric form of a crystal . external shape depends on the temperature, pressure and unrestricted environment (it develope) during their formation.

3. **Color**: color of a mineral is determined by examining a fresh surface in reflected light. The color or lack of color may be diagnostic in some minerals, but in others the color varies due either to a slight difference in chemical composition or to small amounts of impurities within the mineral.

4. **Streak**: streak is the color of the mineral in powdered form and is usually a better diagnostic tool than the color. Hematite of (Fe_2O_3) can have various colors, but its streak is always red-brown.

5. **Fracture**: is the tendency of the crystal to break along irregular surface other than cleavage planes.

6. **Lustre;** ways of reflection of Light from the surface of a mineral. the amount of light depending on physical qualities of the surface (such as its smoothness and transparency).

7. **Cleavage**: The tendency of a crystalline substance to split or break along smooth planes parallel to zone of weak bonding in crystal structure. **e.g**. **Mica** -single perfect cleavage, **Halite**- three cleavage directions at right angles to each other.

Rock types

- **Rock** is an aggregate of a single or poly minerals.
- Based on origins, rock is classified as igneous, sedimentary ,and metamorphic rocks.
- ✓ **Igneous rocks** formed by the cooling and crystallization of molten material within or at the surface of the earth;
- ✓ **Igneous rocks** are aggregates of minerals that crystallize from a molten material that is generated deep within the earth's mantle. The molten material **magma**, is a complex solution of **silicates** plus **water** and **various gases**.
- Some of this magma may **reach the surface** of the earth where it is **extruded as lava**, but other magmas solidify before they reach the surface.
- ✓ **Sedimentary rocks** formed from lithification of sediments derive from pre-existing rocks, by precipitation from solution, or by the accumulation of organic materials;
- ✓ **Metamorphic rocks** resulting from the change of pre-existing rocks into new rocks with different textures and mineralogy as a result of the effects of heat, pressure, chemical action, or combinations of these.

- ***What is magma?*** It is a mass of molten mineral matter capable of yielding the silicate rock forming minerals,which is composed of early-formed solid crystals and gases.

- ✓ Greater than 90% of the gases in magma are carbon dioxide (CO_2) and water (H_2O) vapor.
- ✓ Silicate magma is generally simple in its chemical composition, for about 99% of the magma material is composed of only eight elements (expressed in terms of their respective oxides: Si-oxide, Al-oxide, Fe-oxide, Mg-oxide, Ca-oxide, Na-oxide and K-oxide) that can form their own minerals. .
- ✓ Crystallization is a process of change from liquid state to solid state.
- ✓ Magma is a solution of minerals but it doesn't crystallize in the same way as ordinary solutions do. If crystallization of magma were similar, it would always yield a rock of the same composition.
- ✓ But, magma is unique solution in this respect, for magma of a given composition is able to crystallize in to a number of solid rocks having different composition.

Classification of Igneous Rocks

- **Classification of igneous rocks is basedon:Mode of Occurrence,Texture,and Composition.**

I. Mode of Occurrence: Refers to the place where igneous rocks are formed not to the place where they are found today.

- Igneous rocks are classified into two based on their mode of occurrence.

 Intrusive (plutonic) Rocks:

- ✔ Rocks formed when magma cools and crystallizes below Earth's surface.
- ✔ Crystals of intrusive rocks are generally large enough to see without magnification.
- ✔ Magma cools so slowly that there is enough time for the formation of coarse grained crystals and corresponding coarse grained rocks *e.g.*, granite, gabbro etc.

 Extrusive (volcanic) Rocks: formed on the surface of earth.

- ✔ The lava cools so instantly that there is no enough time for the formation of crystals of large size & corresponding fine-grained rocks are formed. e.g. Basalt, rhyolite etc.

 Hypabyssal rocks: which are formed beneath, but very near to the surface of the earth and they are usually medium grained. E.g. Dolerite

II. Texture

- ***The texture of igneous rocks refers to***:
  - ✔ The size of the minerals with in the rock
  - ✔ The nature of the minerals(whether they are crystalline or not)
  - ✔ The way in which the mineral grains are arranged (orientation).

- ***Texture of rocks depends on***; The physical conditions under which the rock is formed, and the rate of cooling of the magma.

- **Textures of igneous rocks are described as:**

1. PHANERITIC: Coarse grained granular rocks which are formed by slow cooling of magma beneath the surface of the earth.

The crystals are so big that the individual crystals can be observed

Most intrusive rocks exhibit such a texture where the crystals are usually interlocked. **e.g**. Granite, and Gabbro.

Granite,

Gabbro

2. APHANETIC ; Fine grained granular rocks which are formed by rapid cooling of lava at the surface of the earth. Most extrusive rocks exhibit such a texture (grain size). **e.g**. Rhyolite, basalt

Rhyolite **Basalt**

3. GLASSY: Massive, non-granular rocks which are formed by very rapid

- (instant chilling) of magma

  The condition doesn't allow the formation of crystals.

- Glassy rocks show a shiny or glassy surface with out any crystalline grains. e.g. obsidian.

4. PORPHYRITIC**;** Rocks w/c composed of large (coarse) crystals set in fine ground mass.

- The coarse crystals are known as the PHENOCRYSTS and the fine grained mass are GROUND MASS or MATRIX**.**

  ……..Such a texture results due to multistage cooling of magma at different physical locations.

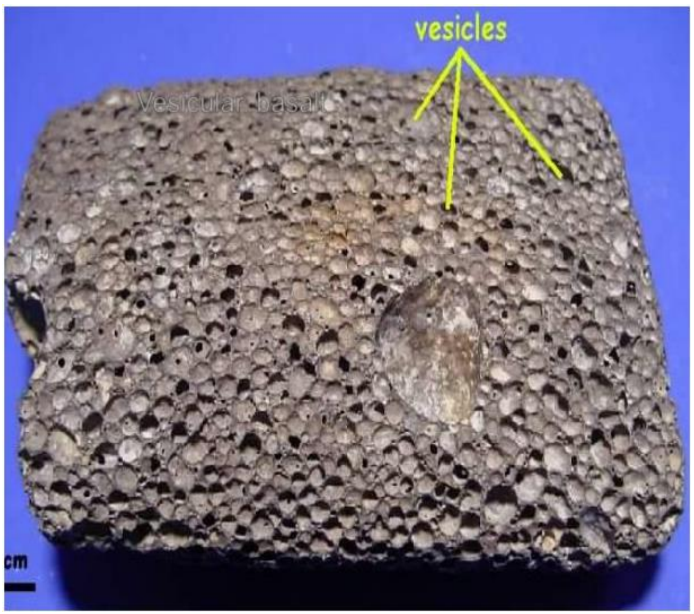
- The phenocrysts are formed when the magma solidifies beneath the surface of the earth while the ground mass is formed by rapid cooling of the magma

- which rises to the surface, containing the already formed phenocrysts with it.

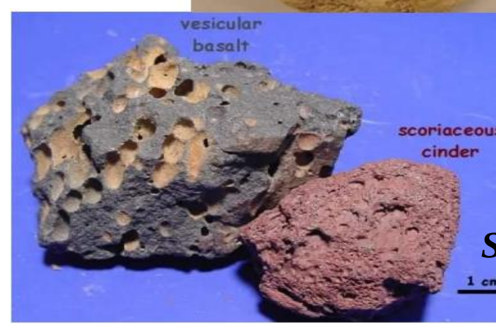
***5. Vesicular Rocks*; which have vesicles on their surfaces.**

- ✓ Vesicles are formed when the gases (volatiles) entrapped in the magma (lava) escaped rapidly in the form of bubbles when the lava rises to the surface and exposed to the atmosphere. **e.g.** vesicular basalt, scoria, pumice, etc.

Vesicular basalt



Pumice



Scoria

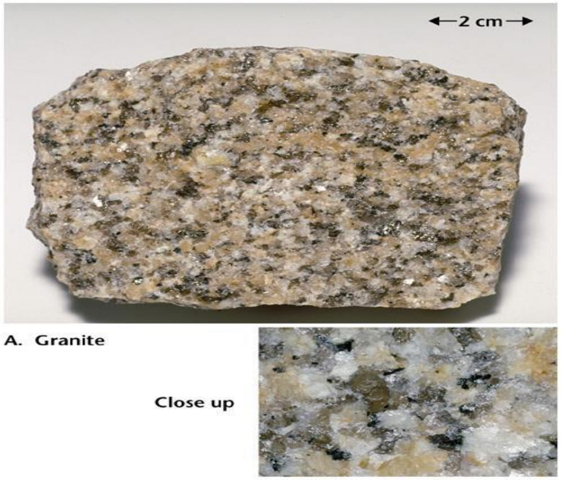
III. Composition

- Minerals of igneous rocks are grouped in to two major categories, primary and secondary.
- **Primary minerals** are those that are crystallized from the cooling magma.
- **Secondary minerals** are those formed after the magma has solidified, and include minerals formed by chemical alteration of the primary minerals. Secondary minerals are not important in the classification of igneous rocks.
- *The major components of magma are O, Si, Al, Ca, Na, Na, K, Mn ,Ti, P, water, and others being occurring in a very small proportion.*
- ✓ ***Silica (SiO_2)*** is the most important rock forming constituents and igneous rocks can be classified based on the proportion of silica (in weight as%)constituted in them as follow:

Rock	*SiO_2(wt %)*	*Example*	*Colour*
- Acidic (sialic)	***>66***	***granite/ rhyolite***	***light***
- Intermediate	***52-66***	***Diorite/ andesit***	***intermediate***
- Basic (mafic)	***44-52***	***Gabbro /Basalt***	***Dark***
- Ultrabasic (ultramafic)	***<44***	***peridotite / Dunite***	***Very dark***

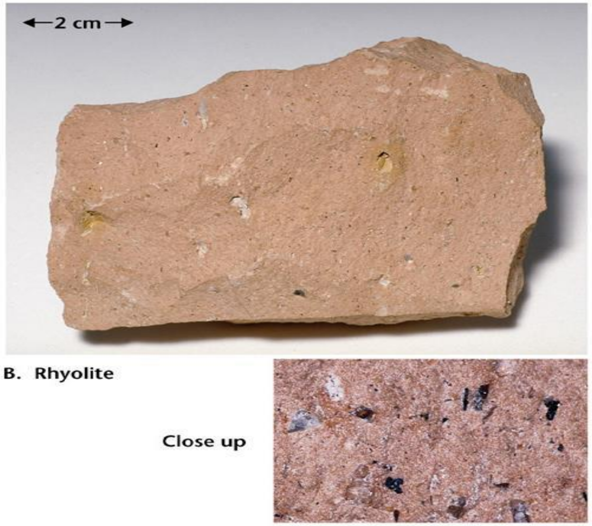
A). Granitic Composition:

- Light-colored silicates.
- Termed felsic (*feldspar and silica) in composition.*
- High amounts of silica (SiO_2).
- Major constituent of continental crust**.**



B). Rhyolite:

- Extrusive equivalent of granite.
- May contain glass fragments and vesicles,
- Aphanitic texture



C) Obsidian;

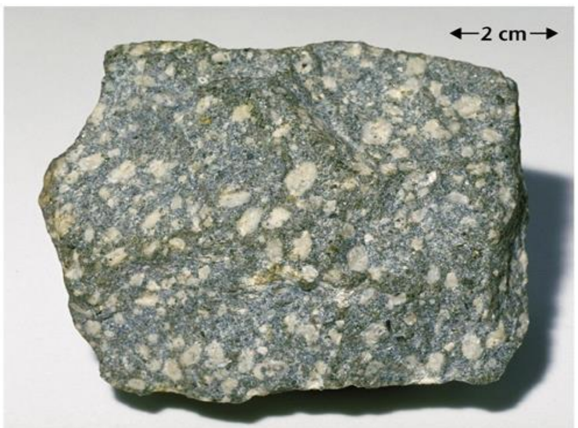
- Dark colored
- Glassy texture

A. Obsidian flow.

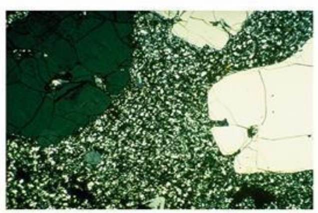
D) Pumice; Volcanic, and has Frothy appearance with numerous voids**, and with countless vesicles**

E) Andesite

- *Volcanic origin*
- *Aphanitic texture*



A. Andesite porphyry



B. Close up

F) Diorite

- *Plutonic equivalent of andesite*
- *Coarse grained*
- *Note: e and f are intermediate rocks*

Diorite

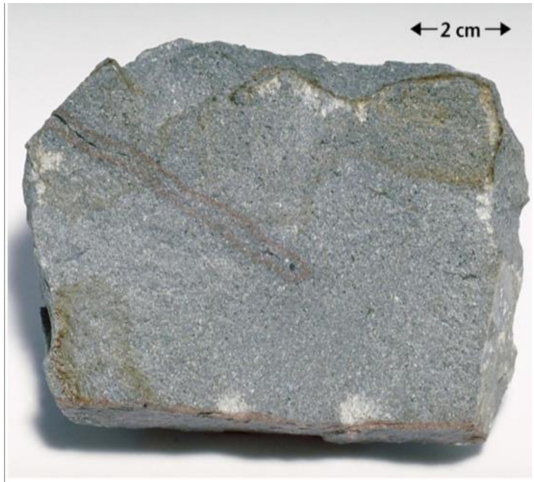
Close up

Basalt

- Termed mafic (*magnesium and ferrum, for iron) in composition.*
- Aphanitic texture *and Dark silicates*
- Composed mainly of pyroxene and calcium-rich plagioclase feldspar
- Most common extrusive igneous rock

Gabbro

- Intrusive equivalent of basalt.
- Phaneritic texture consisting of pyroxene and calcium-rich plagioclase.
- Significant % of the oceanic crust.



A. Basalt

B. Gabbro

Engineering Considerations of Igneous Rocks

1. Fine-grained acidic igneous rocks cannot be used as aggregates in Portland cement due to volume expansion caused by the **Alkali-silica** reaction. The alkali-silica reaction problem can be alleviated by using;

- ✓ Can be used in low alkali cement
- ✓ Non-reactive aggregates go with the high alkali cement
- ✓ Add pozzolans, coal-ashes,etc.in the aggregate-cement mixture to minimize the reaction.

2. Coarse-grained igneous rocks (e.g., granite, syenite, etc.) are not used for aggregates for constructions because it slow abrasion resistance; but fine grained igneous rocks (e.g., basalt are good for aggregates paving aggregates goes with asphalt.)

- ✓ The reactive igneous rocks include those that contain volcanic glass with a composition ranging from ***Rhyolite through Andesite*** *(Acidic volcanic rocks).*
- ✓ Basaltic glass contains too little silica to be reactive.

3. Very coarse grained igneous rocks are undesirable for use as aggregates for construction.

- ✓ Crystal size of igneous rocks inversely affects strength.
- ✓ With increasing grain size, abrasion resistance is reduced, and the rock is less suitable for use as a base course (road base), concrete aggregate, or source of riprap (large stone used for slope protection along rivers and sea coasts).

4. The presence of certain minerals in igneous rocks makes the rock undesirable for some engineering uses.

- ➢ **Zeolite minerals** are undesirable in aggregates that will be exposed to weathering process.

5. In foundations for engineering structures such as dams, bridge piers, and underground installations, weathered igneous rock and/or any other rock is to be avoided.

- ➢ Excavation must extend through this material in to sound rock.
- ➢ Sitting of foundations needs to avoid weathered rocks.

6. Igneous rocks are good for dimension stone because their resistance to weathering, but need to avoid fractures.

7. Active land sliding, or evidence of past land sliding, is relatively common in steep country underlain by **weathered rocks**, particularly in areas with high rainfall.

8. Although some landslides in weathered granitic rocks no doubt occur by failure through the fabric of extremely weathered material, it is probable that in many landslides failure occurs wholly or partly along relict **joints** or other defects (Fell et al, 2006).

9. Fresh granitic rocks are commonly quarried for rip-rap, rock-fill, but mica-rich granites may be unsuitable for use as fine aggregates in concrete due to excessive amounts of fine, platy particles in the products.

***10**. Pyroclastic rocks containing glass with a high silica composition also can be reactive E.g. Tuff, Volcanic breccia, Obsidian, and Pumice.*

Sedimentary rocks

- Sedimentary rocks are formed from deposit of materials and distinguished from other rock types by the layering or stratification characteristic.

Formation of sedimentary rocks

- The formation of sedimentary rocks begins when weathering and erosion produce sediments.

1. Weathering*:* Weathering produces rock and mineral fragments known as sediments. These sediments range in size from huge boulders to microscopic particles.

- Chemical weathering occurs when the minerals in a rock are dissolved or chemically changed**.**
- While the less-stable minerals are chemically broken down, the more resistant grains are broken off the rock as smaller grain during physical weathering, however, mineral chemically unchanged.

2. ***Erosion*;** After rock fragments and sediments have been weathered out of the rock, they often are transported to new locations through the process of erosion.

- ✓ Eroded material is almost always carried downhill except fine sands transport by wind . Four main agents of erosion are: wind, moving water, gravity, and glaciers. Glaciers are large masses of ice that move across land.

3. ***Deposition*:** The process by which the transported sediments settle or rest when the agent of transportation no longer has sufficient energy to move them any further.

4. ***Lithification:*** The process by which the loose deposited (unconsolidated) sediments are converted into a coherent (consolidated) sedimentary rock.

- ✓ Lithification of sediments may occur by one or combination of the following processes.

A. Cementation**:** is then the filling of spaces between the individual particles of unconsolidated sediments by cementing materials such as calcite, silica, iron oxide, clays.

- Cementation results in a decrease in porosity,
- Cementation also results in lithification, the diagenetic process by which soft sediment is hardened in to rock.

B. Compaction and Densification: Compaction is the squeezing of sediment grains during burial due to the weight of the overlying material.

- ✓ ***Densification*** is the expulsion of pore fluids from water laid deposits, which is a direct consequence of compaction.
- ✓ Both compaction and densification cause re-organization of grains, closely packing them to reduce the original porosity, decrease the thickness and increase the coherence until the deposit is changed to a hard rock.

5. Diagenesis; After sediments are deposited and buried, they are subjected to diagenesis.

- ✓ Many physical and chemical changes that continue until the sediment is either exposed to weathering or metamorphosed by heat and pressure.
- ✓ Burial promotes these changes because buried sediments are subjected to increasingly high temperature and pressure in the earth's interior.
- ❖ ***Diagenesis includes such processes as:***
  - dewatering and further decrease in porosity
  - bacterial decomposition of organic matter
  - removal of soluble substances such as calcite by dissolution. Diagenetic process produce changes in composition and structure ***e.g. aragonite to calcite.***
- ✓ In short the formation of sedimentary rock involves a series of processes in which one process is a result of the previous one. The simplified flow chart of sedimentary rocks formation is:

Parent rocks
(Igneous, Sedimentary, and Metamorphic)

Weathering
(Physical, chemical)
Erosion

Sediments, organic remains

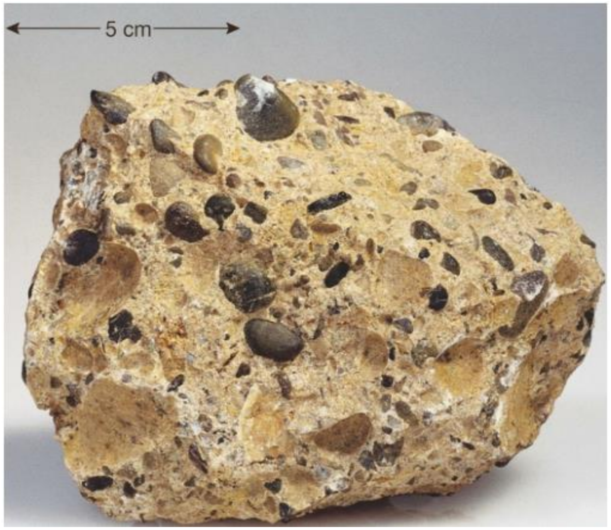
Transportation
Deposition
Lithification

Sedimentary Rocks— Digenesis

Classification of sedimentary rocks

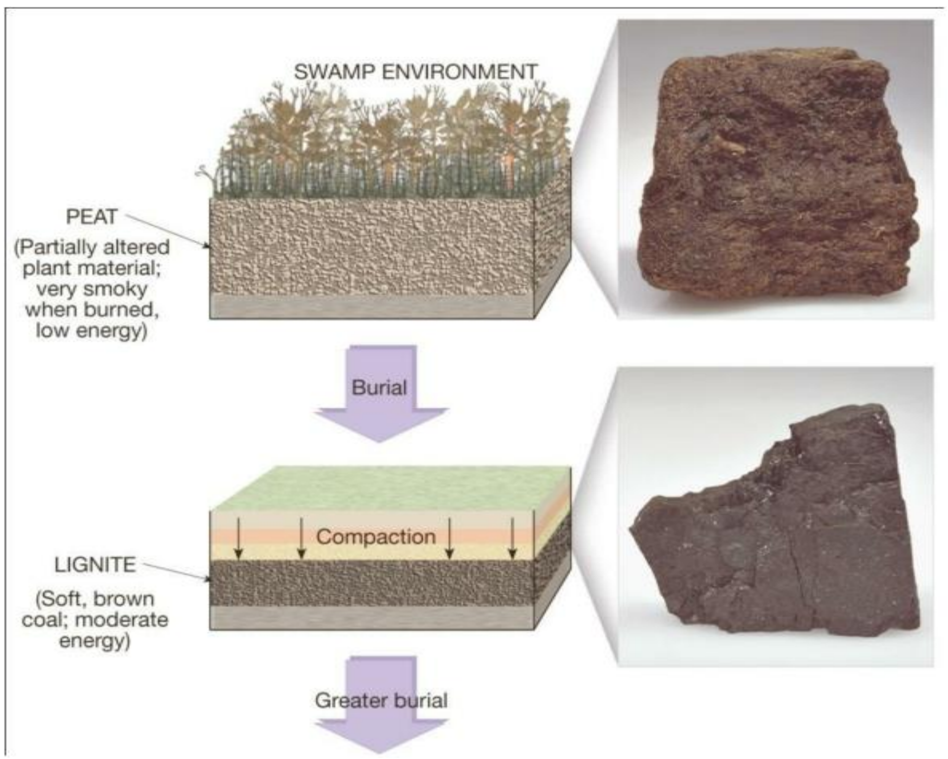
- Sedimentary rocks are classified based on:
  - mode of occurrence and
  - the character or the type of material they are composed of
- Accordingly sedimentary rocks are grouped into three main categories:

1. ***Clastic (detrital) Sedimentary Rocks*:** those rocks formed from preexisting rocks by the process of weathering, transportation, deposition & lithification **e.g**. sandstones, siltstones, conglomerates, etc.



2. ***Organic sedimentary rocks*;** Are those rocks which are formed from the accumulation of organic matter (remains of plants and/or animals). ***They include***:

- ***Limestone*** **-** which are composed of carbonates secreted from animals and plants, and accumulated from calcareous skeleton.
- ***Chalk*** **-** accumulation of foraminiferal microscopic alga.
- ***Phosphatic deposits*** **-** accumulation of bird excrete



3. **Chemical sedimentary rocks;** Are those rocks which are formed by chemical processes such as evaporation, replacement reactions(oxidation and reduction processes) and recrystallization.

- As more dissolved minerals are carried out into basins, evaporation continues to remove fresh water and maintains mineral concentration.
- When the concentration of dissolved minerals in a body of water reaches saturation, crystal grains precipitate out of solution and settle to the bottom. **E.g**. rock salt, gypsum, crystalline limestone…

Structures of sedimentary rocks

- **sedimentary rocks** are easily distinguished from other rock types by their structures.
- The most important and common sedimentary structures are;

1. Bedding (stratification):Refers to distinct layers separated by bedding planes, resulting from variation in particle size (texture) and /or composition, during deposition. Each bed represents a single act of sedimentation or deposition.

- ✓ Bedding planes in their original condition are nearly horizontal

2. Mud cracks; polygonal pattern of cracks formed in fine-grained sediments as they dry, resulting from reduction in volume due to alternating drying and wetting conditions.

Engineering Considerations of Sedimentary Rocks

1. The sedimentary rocks also have the reaction problem when used as aggregates with Portland cement. The sedimentary rocks with this problem are chert and greywacke.

2. Fine-grained sedimentary rocks like limestone and dolomite are the best for being used as aggregates; siltstone, shale, conglomerate, and quartz sandstone are not acceptable

3. Coarse-grained limestone is not good for aggregates by reducing particle size.

4. Any Civil Engineering structures to be constructed on carbonate rocks needs a very careful study as they can have sinkholes, karstic features and different solution structures.

5. When conglomerates are found in dam abutments & foundation, they need special treatment to increase their strength and reduce permeability.

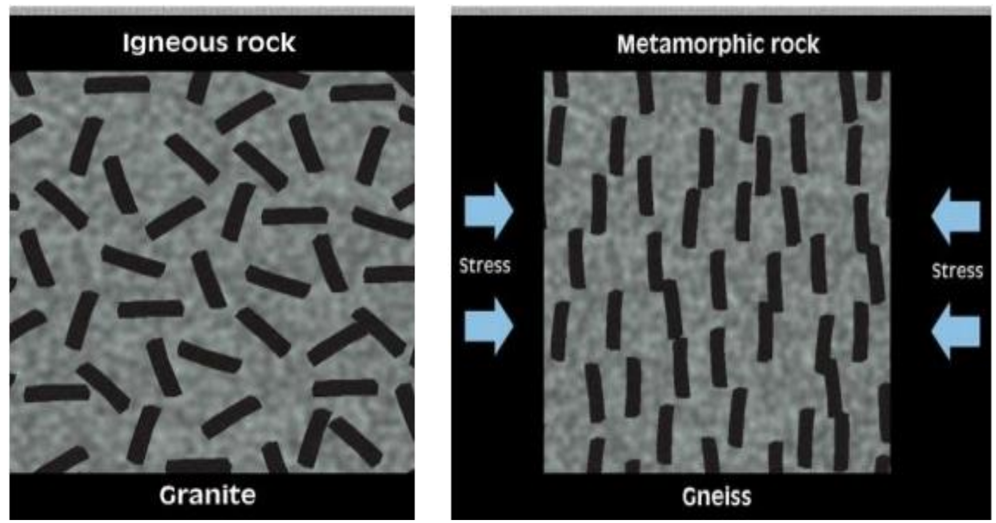
6. Sedimentary rocks containing anhydrite/gypsum are troublesome to Engineering Structures such as dams, high ways, tunnels, etc.

Metamorphic rocks

- They result from the transformation of other rocks by metamorphic processes that usually occur beneath the earth's surface.
- During metamorphism, rocks are subjected to sufficient heat, pressure, and fluid activity to change their mineral compositions, and/or texture thus forming new rocks. These transformations take place in the **solid state**.

❖ Agents of Metamorphism are;

- Temperature
- Pressure
- chemically active Fluids.



Classification of metamorphic rocks

- ❖ Metamorphic rocks are commonly divided in to two groups: those exhibiting a foliated texture and those with a non foliated texture.

I. Foliated Metamorphic Rocks

- ✓ Rocks subjected to heat & differential pressure during metamorphism typically minerals arranged in a parallel fashion that gives them a foliated texture.
- ✓ Foliation may be fine or coarse depending on the size and shape of the mineral grains.
- ❖ ***Foliated metamorphic rocks*** can be arranged in order of increasingly coarse grain size & perfection of foliation.

A) Slate: It is a very fine grained metamorphic that commonly exhibit slaty cleavage.

- It is the result of low grade regional metamorphism of shale or volcanic ash.

B) Phyllite: is slightly higher grade than the slates but are of similar character & origin.

- ✓ Phyllite tends to have a more or less glassy or lustrous shine from crystals of mica & chlorite that have grown a little larger than those of slates.

C) Schist: is most commonly produced by regional metamorphism.

- ✓ Metamorphism of many rock types can yield schists, but most schist appear to have formed from clay-rich sedimentary rocks.
- Their mineral composition imparts a schistosity or schistose foliation to the rock that commonly produces a wavy type of parting when split.
- Schist is common ***in low to high-grade*** metamorphic environments.

D) Gneiss: is a ***high-grade*** metamorphic rock that is streaked or has segregated bands of light and dark minerals (banding feature).

- ✓ Gneisses are composed mostly of granular minerals such as quartz and/or feldspars with lesser percentages of platy or elongated minerals such as micas or amphiboles.

II. Non-foliated metamorphic Rocks

- Some metamorphic rocks show a very weak preferred orientation of crystals, which results in little or no foliation.
- Non-foliated rocks are composed mainly of crystals that grow in (equidimensional) shapes such as cubes and sphere rather than in platy or elongate shapes.

Engineering Considerations of Metamorphic Rock

1. The metamorphic rocks also have the Alkali-silica reaction problem when used as aggregates with Portland cement. The metamorphic rocks with this problem are argillite, phyllite, impure quartzite, and granite gneiss;

2. For metamorphic rocks the stability of rock mass greatly affected by the foliation orientation;

3. Marble as a metamorphic rock from carbonate sedimentary rocks can cause similar problems, e.g., leakage of reservoirs, sinkhole collapse, solution cavities, and channels.