

2019

**Definitions:**

Economic geology is one of Geology (Earth sciences) branches, which is concerned with earth's crust or Lithosphere materials that can be used for economic or industrial purposes. These materials called economic resources, which include, metals (like gold, & platinum), nonmetallic minerals (like sulphur & graphite), industrial minerals & rocks (like limestone, claystone & gypsum) which is used in manufacture of (cement, ceramic, lime, & glass), energy resources or fuels (petroleum, coal, & natural gas) and water. With the exception of water these resources are called Economic minerals, they are an accumulation of minerals having economic value for the benefit of mankind, which are concentrated in sufficient quantity as to be capable of economic extraction. Different economic minerals presents as mineral deposits in earth's crust, they are concentrated accumulations of ore minerals and industrial minerals and rocks.

The elements that enter into the mineral deposits have been derived either from the rocks of the earth's crust and upper mantle or magma. 99 % of the earth's crust is made up of major elements (O, Si, Al, Fe, Ca, Na, K, Mg, & Ti), many other elements are 1 %. So geologic processes must concentrate these elements hundreds to thousands of times to make ore deposit.

**Classification of economic minerals about using as raw materials for the different industries (Gregory, 1980):****1- Metallic minerals** (minerals that yield metals):

Precious metals: gold, silver, platinum

Base metals: copper, lead, zinc, tin

Steel industry metals: iron, nickel, chromium, manganese, molybdenum, tungsten, vanadium

Light metals: aluminum, magnesium

Electronic industry metals: cadmium, bismuth, germanium

Radioactive metals: uranium, radium

**2- Nonmetallic minerals:**

Insulating materials: mica, asbestos

Refractory materials: silica, alumina, zircon, graphite

Abrasives and gems: corundum, emery, garnet, diamond, topaz, emerald, sapphire

General industrial minerals: phosphate rock, rock salt, limestone, barite, borates, feldspars, gypsum, potash, trona, clays, magnesite, sulphur

### 3- **Fuel minerals:**

Solid fuels: anthracite, coal, lignite, oil shale

Fluid fuels: petroleum oil, natural gas

With the exception of Fuel minerals, and Metallic minerals (ores geology), so the term nonmetallic minerals is brief and convenient, it is used to comparison with metallic minerals. But the expression industrial minerals and rocks is more accurate and descriptive. It indicates both a natural industrial minerals & rocks, and manufacturing product materials.

### **Exploration stages of Economic mineral deposits (nonmetallic ores):**

The mineral deposits ores can be described as concentrated accumulations of ore minerals or industrial minerals and rocks in sufficient quantity as to be capable of economic extraction.

The exploitation of mineral deposits falls into **four stages**:

- 1- Locate the deposits and geological studies.
- 2- Evaluation of mineral deposits and Estimation of their reserve, then studying the Technical and Economic Feasibility of exploitation these deposits.
- 3- Mining and Extraction (open-pit & underground mining methods).
- 4- Processing of treatment and beneficiation.

### **Mining operations:**

Minerals may be mined and processed for more than one purpose. The mineral may be a metal ore, when it is used to prepare the metal, as when bauxite (hydrated aluminium oxide) is used to make aluminium. The mineral is classified as a nonmetallic ore when bauxite is used to make material for refractory bricks or abrasives.

Mining is the process of extracting minerals of economic value from the earth's crust for the benefit of mankind.

A mine is an excavation made in the earth for the purpose of extracting useful minerals.

The **four main classes** of mining operations (Gregory, 1980):

- 1- **Underground mining**: (ore is far from surface, the covered rocks are hard & thick)  
Near vertical vein deposits,  
Horizontal bedded deposits (metals, nonmetals)
- 2- **Surface mining**: (ore is near from surface, the covered rocks are thin)  
Quarrying of construction (building) stones  
**Open-pit (cut) mining** of metals & nonmetals
- 3- **Alluvial mining**: (for alluvial deposits & heavy minerals)

Ocean mining, Beach dunes, Stream beds & terraces

4- **Non-entry mining:**

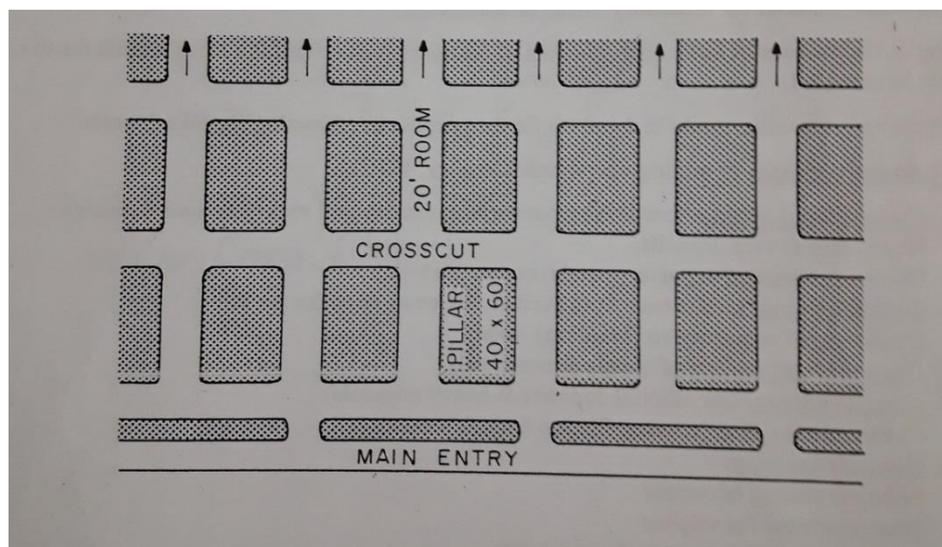
Solution mining of copper

Frasch process for sulphur

Oil wells (petroleum, natural gas, water)

1- **Underground or (rooms and pillars) mining method:**

Designing the mine is controlled by the shape of the ore body. Drilling and blasting underground are much more difficult than on the surface. In this method the ore is extracted by room, a pillar of ore is left intact between adjacent rooms to support the roof rocks. One of the disadvantages of the room and pillar method is that most of the ore is left behind in the pillars.

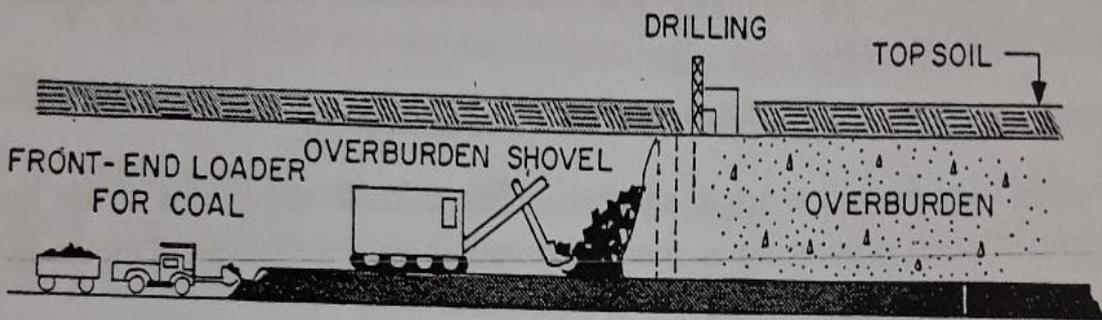


2- **Surface or open-pit mining method:**

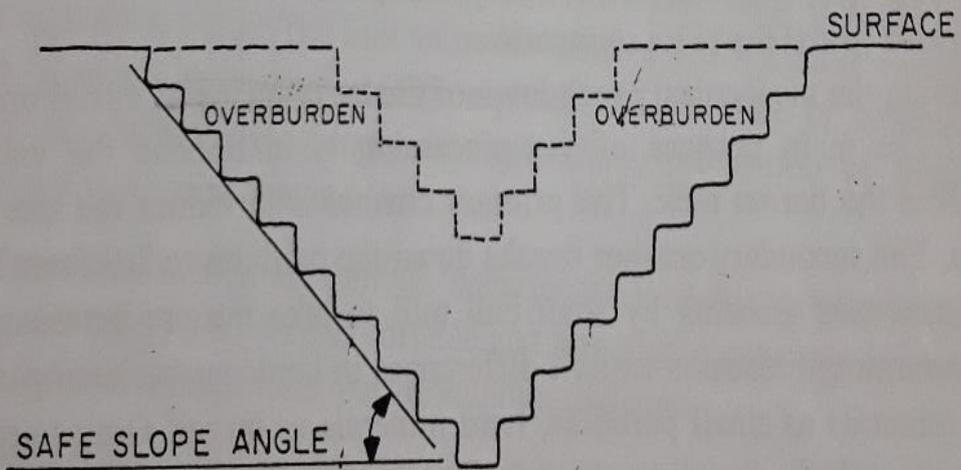
This method use where deposit occurs at or near the surface. An open-pit mine is a big hole in the ground with a series of step like terraces (benches) round the excavation, this is known strip mining. Drilling and blasting is required to loosen hard overburden material, it is removed to expose the ore deposits. The slope angle of the pit sides is controlled by the rocks properties (hard or soft). The gentle slope in soft rocks more than in hard. The space of terrace (bench) is allow shovels to move and load the ore into transport vehicles. The ratio of waste rock (overburden rock) to the ore deposit is known as the stripping ratio.



(a)



(b)



## **Mineral Processing Technology (Treatment and Beneficiation):**

The stages involves vary from one ore to another, different kinds and grades of ore need different treatments. Mineral processing is concerned mainly with the physical methods of separation:

### **1- Optical and radioactive separation:**

Separation depend on optical and radioactive properties.

### **2- Crushing and grains (particles) size separation:**

Crushing is involving the mechanical breakdown of the large lumps of mined ore into small fragments. The main purpose of the processing is to liberate the valuable particles of ore from the barren rock. The primary crusher is to reduce the size from 50cm to 20-10cm. The secondary crusher breaks down the particles to 2-0.5cm. These small fragments next was grinding by steel ball mill to take the ore between 300-100 $\mu$ m. The concentrating processes exploit differences in hardness between particles of minerals, soft minerals as small particles, hard minerals as larger. Grains separate about size by sieve analysis (handing or shaker) or sedimentation or by centrifuge instruments.

### **3- Specific gravity separation:**

Separation depend on specific gravity differences of minerals due to mass effects. Minerals are separated by heavy liquids like carbon tetrachloride ( $\text{CCl}_4$ ) (sp. gr. 1.58), bromoform (sp. Gr. 2.89), methylene iodide (sp. Gr. 3.72).

### **4- Froth Flotation separation:**

Separation utilizing the different surface physiochemical properties of the minerals, froth flotation as air bubbles.

### **5- Electrical conductivity separation:**

Separation depend on electrical conductivity properties, it use to separate conducting (Au, Cu, & Ag) from non-conducting (S & C) or semi-conducting (Si & Ge).

### **6- Thermal treatment separation:**

Like calcination of carbonate or sulphate to prepare lime or plaster & dehydration.

### **7- Magnetic separation:**

Separation depend on magnetic properties, ferromagnetic minerals like magnetite ( $\text{Fe}_3\text{O}_4$ ), paramagnetic minerals like hematite ( $\text{Fe}_2\text{O}_3$ ) and diamagnetic minerals like pyrite ( $\text{FeS}_2$ ). Magnetic separation is an important process in the beneficiation of iron ores, bauxite ore, silica sand, kaolin clays.

## **Characteristic properties of industrial minerals and rocks:**

- 1- Chemical purity & mining properties such as salts, limestone, sulphur.
- 2- Physical or mechanical properties such as porosity, compressive strength, shape and grain size. Example: crushed stone or sand & gravel in concrete.
- 3- Very fine grained, high porosity, super ability for absorption such as Diatomite.
- 4- Silicates fibers are used for fire proofing at high temperature.

## **Economic aspects:**

Most of industrial minerals and rocks are plentiful which they occur in bulk like clays, sands, gravels, limestone, and shale. The processing necessary to convert the raw materials into a usable product is simple, like sand & gravels are easy to excavate and require washing to remove clays and screening to get right proportion.

The materials which are large in bulk are low unit value (intrinsic or low monetary value) and high place value. The unit value for which a unit weight or volume of the product can be sold. They are rarely imported or exported and produced by common geological processes. They are affected by economic fluctuations, production of materials has increased in response to a rising demand.

The materials which are limited occurrences (low place value) and special properties are high unit value. They are exportable and importable, example is china clay (kaolin), marble, mica, asbestos, magnesite, barite, sulphur, diamond.

## **Classification of industrial minerals & rocks:**

Classifications of minerals and rocks is difficult because the diverse and changing industrial applications. Classification based on:

- 1- The nature of geological occurrences and origin.
  - 2- The chemical properties.
  - 3- The physical properties.
  - 4- Economical properties.
  - 5- Uses of materials.
- One of these classifications is classification of Bates, 1969, alphabetical listing of industrial minerals and rocks:

Asbestos Barite Cement Clay Diamond Gypsum Lime Magnesite Phosphate rocks  
Quartz Refractories Sand & Gravel Sulphur Talc Vermiculite

- Other classification is classification of **Bates, 1969**, according to economic aspects & some properties of industrial minerals and rocks:

<b>Aspect</b>	<b>1st group</b>	<b>2nd group</b>
1- Bulky produced	Large	Small
2- Unit Value	Low	High
3- Place Value	High	Low
4- Imports & Exports	Few	Many
5- Distribution	Distributed or wide Distribution	Restricted
6- Geology	Simple	Complex
7- Processing	Simple	Complex
8- Examples	Sand & Gravel, Crushed stone, Gypsum, Limestone	Mica, Asbestos, Sulphur, Magnesite
	Mostly industrial rocks	Mostly industrial minerals

- Other classification is classification of **Jensen and Bateman, 1981**, according to industrial applications of minerals and rocks (about physical, chemical properties), are grouped to:

**1- Building and Construction materials:**

Natural & artificial aggregate (sand & gravel), lightweight aggregates, cement, building stone, bricks, gypsum, anhydrite, technical plaster, local plaster (juss), crushed stone, insulating, filler, facing stone.

**2- Ceramic materials:**

Clays, feldspar, silica (quartz), bauxite, sillimanite group (sillimanite, andalusite, & kyanite), borax, zircon, magnesite.

**3- Metallurgical and refractory materials:**

**Metallurgical:** fluorspar (fluorite), graphite, lime (CaO), rhyolite (plutonic igneous rock).

**Refractory:** silica, bauxite, fireclays, magnesite ( $MgCO_3$ ).

**4- Industrial and manufacturing materials:**

Talc, asbestos, diatomite, bentonite clays, mica, barite ( $BaSO_4$ ), silica (glass) sand.

**5- Chemical minerals:**

Salts & over saturation solutions (brines), borax, borates, sodium carbonate, sodium sulphate, potash ( $K_2O$ ), sulphur.

**6- Abrasive materials:**

Corundum ( $Al_2O_3$ ), emery (black granular corundum mixed with magnetite, hematite), garnet, quartz, other silica types, calcium carbonate ( $CaCO_3$ ), talc.

**Building and Construction materials:**

It is any materials which is used for construction purposes. Many naturally occurring substances such as clay, rock, & sand, many industrial substances such as cement, plaster, & glass.

It comprise a great group of non-metallic materials for social and industrial developments (building schools, hospitals, health centers, road pavement, residential complexes, dams, and airports ---etc.) need finding and locating raw material resources such as those listed in the following table:

<b>Product</b>	<b>Sources</b>	<b>Desirable properties</b>
<b>Dimension stone and Ornamental stone</b>	limestone, hard sandstone, granite, marble, tufa(travertine), gypsum	regular widely spaced bedding & joints, high compressive strength, resistance to weathering especially in industrial regions
<b>Slate</b>	strongly cleaved fine grained metamorphic rocks	Regular closely spaced cleavage, resistance to weathering
<b>Road stone</b>	crushed basalt, fine granite , quartzite, flint, industrial waste, in combination with bitumen	Resistance to abrasion, fine-medium grain size, low porosity, binds well with bitumen

<p><b>Aggregate:</b> for <b>concrete</b> (cement + sand + gravel), for <b>mortar</b>(cement+sand), for <b>asphaltic concrete</b> or <b>asphalt pavements</b> (sand +gravel+cement or filler + bitumen), for <b>roads (sub base layer)</b>, for <b>building foundations &amp; dams</b>, for <b>water purification filters</b></p>	<p>sand and gravel (fluvial, glacial, marine), crushed sand and gravel, crushed rock, industrial waste (slag)</p>	<p>Range of particle sizes (grading), low impurities like (sulphate, sulphide, organic matter, chlorides, mica, fine clay materials)</p>
<p><b>Bricks and Tiles</b></p>	<p>clay (marine, alluvial, glacial) fired at high temperatures. sand, limestone</p>	<p>no excess water (plasticity index), low (iron, sulphide, sulphate <math>\text{CaSO}_4 &lt; 5\%</math>, carbonate <math>\text{CaCO}_3 &lt; 20\%</math>), assists firing</p>
<p><b>Cement</b></p>	<p>limestone mixed with clay converted to clinker in kiln, product ground to powder with gypsum</p>	<p>constant composition (<math>\text{CaO}</math>, <math>\text{Al}_2\text{O}_3</math>, <math>\text{SiO}_2</math>, <math>\text{Fe}_2\text{O}_3</math>), low (S, <math>\text{MgO}</math>, P, alkalis)</p>
<p><b>Glass</b></p>	<p>quartz or silica sand, quartzite</p>	<p>suitable grading grains, no impurities (low iron)</p>
<p><b>Juss, plaster, plaster boards</b></p>	<p>gypsum, anhydrite</p>	<p>no impurities (low clay and iron)</p>
<p><b>Insulating materials</b></p>	<p>fibrous and flaky metamorphic minerals (asbestos), mica, diatomite, vermiculite</p>	<p>not injurious to health</p>
<p><b>Bitumen</b></p>	<p>natural residues of oil, residue from distillation of oil</p>	<p>melting temperature for conditions of use (in roads pavement)</p>

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**Building materials:**

**Aggregates:** It is a mixture of rocks fragments. Aggregate comprise 3/4 volume of concrete (85-90% aggregate and 10-15% cement) and have physical, mechanical, thermal, and chemical properties.

Aggregates classify according to **source** to:

- 1- **Natural aggregates (sand and gravel):** it is extracted from quarries, which was formed by disintegration of rocks (igneous, sedimentary, & metamorphic) through weathering, erosion, transportation of fragments by (air, water, & glacier) & deposition.
- 2- **Artificial aggregates (slag, crushed stone):** it is formed by:
  - 1- By-product (blast furnace slag, fly ash, burned rocks)
  - 2- Thermal process (fired clay, vermiculite)
  - 3- Recycled concrete and municipal wastes

Natural aggregates classify according to **particles shape** about **BS 812 / 1975** to:

- 1- Rounded
- 2- Irregular
- 3- Flaky
- 4- Angular
- 5- Elongated
- 6- Flaky & Elongated

Natural aggregates classify according to **surface texture of grains** about **BS 812:1975** to:

- 1- Glassy (flint)
- 2- Smooth (chert)
- 3- Granular (sandstone)
- 4- Rough (basalt)
- 5- Crystalline (granite)
- 6- Honey combed or Porous (pumice)

Natural aggregates classify about **grain size** according to classification of **Wentworth scale and British institute of geological science** to:

- 1- Grains size  $> 4\text{mm}$  are called gravel (pebbles, cobbles, boulders) composed of rock fragments.
- 2- Grains size  $4 - 0.063\text{ mm}$  are called sand composed mostly of quartz.
- 3- Grains size  $< 1/16$  or  $0.063\text{ mm}$  known as fines consist of silt and clay fractions.

**Geological forms (occurrence) of sand & gravel deposits:**

- 1- River deposits (main source in Iraq)
  - 2- Glacial deposits
  - 3- Terrace deposits
  - 4- Continental shelf deposits
  - 5- Aeolian deposits (sand dunes)
  - 6- Beach deposits
- } un consolidation deposits

7- Lithified (solid deposits) beds or lenses like present in Injana Formation (Miocene age). Pliocene and Pleistocene (Quaternary) deposits cover vast areas of Iraq, underlying Mukdadiya and BaiHassan Formation (Pliocene).

**Uses of sand and gravel:**

- 1- Concrete & mortar
- 2- Filling & grouting
- 3- Road pavement & railway road ballast
- 4- Concrete products (Pipes, Blocks, Tiles, Thermstone, Kerbstone, and Lime-Sand brick)
- 5- Water purification filters & filter aid (sand)
- 6- Glass, Refractory, Foundry & Ceramic
- 7- Manufacture of Portland cement

**Road pavement or Road structure:**

Wearing course	Surfacing
Binder (base course)	
Road base	
Subbase (varies in thickness)	
Subgrade (rock)	

**Evaluation the natural sources aggregate using for concrete and building according to Iraqi standard specification (IQS) no. 45/1984:**

**1- Sieving and grading:**

Grain size distribution is termed grading. Grading must be well graded, not have one size. The constant grading increases the pores, so results a lessening in strength of concrete. The grain size of aggregate varies depending on the use of aggregate (subbase, road base & concrete is  $\leq 38$  mm and surfacing layer is  $\leq 25-19$ mm)

IQS no. 45/1984 classify Natural aggregates according to grain size to:

- 1- Fine aggregate (sand): grain size  $< 5$ mm or passing from sieve no. 4
- 2- Coarse aggregate (gravel): grain size  $> 5$ mm or retained on sieve no. 4
- 3- Total aggregate: mixture of the two sizes

Fine materials consist of silt & clay fractions or passing from sieve no.200. Upper limit of fine materials is 5% for fine aggregate, & 3% for coarse aggregate. Fine materials usually comprise  $< 10\%$  of total volume of aggregate, so need to be reduced to  $< 5\%$  by washing and sieving.

## 2- **Surface texture and shape:**

For **concrete**, aggregate should be rough or granular surface, with rounded shape grains make a good bond with cement.

For **road pavement**, aggregate should be rough surface, with sharp ends or angular grains make a good bond with asphalt (bitumen).

## 3- **Deleterious materials and its effects:**

Deleterious materials are alkalis, fines, flaky & elongated particles, organic materials, salts (chloride & sulphate), sulphide (pyrite).

**Alkali-silica reaction (concrete cancer):** If  $\text{SiO}_2$  minerals is present in the form of opal (finely crystalline), chalcedony (weakly crystalline) or volcanic glass (amorphous silica) (quartz is inert because coarse grained), react with alkalis from cement (K & Na) form alkaline siliceous gel, which absorbs water from the concrete, increases in volume and causes its cracking. So use low alkali cement (alkalis  $< 0.6\%$ ) as ordinary Portland cement contains alkalis  $< 1.5\%$ .

The **fines (silt & clay)** may be present as coatings the aggregates which is lessening the bond between aggregate and cement past. Low quantity (free) of fines make a good bond with cement.

**Flaky & elongated grains** of mica are harmful materials, they orient in a parallel direction and water accumulates beneath them.

The **organic impurities** products of decay the vegetable matter, then appears as organic loam on aggregate, which effect on hydration of cement.

**Salts (sulphate & chlorides)** adsorb moisture from air and cause efflorescence (white deposits) on the surface of the concrete. Chlorides may also cause corrosion of reinforced iron and lessening of concrete strength. Sulphate reacts with  $\text{C}_3\text{A}$  calcium aluminates phase in cement, so cause expansion and cracking. Sulphide (pyrite) oxidize to  $\text{FeSO}_4$ ,  $\text{H}_2\text{SO}_4$ , or  $\text{H}_2\text{S}$  causing cracking.

## 4- **Physical and mechanical properties of aggregate:**

Aggregate must be strong, low water absorption & porosity, and resist frost action.

Aggregate must be tested for:

1- Aggregate impact value (AIV)

2- Aggregate abrasion value (AAV): by los Angeles abrasion testing machine

3- Aggregate crushing value (ACV)

4- Polished stone value (PSV)

5- Water absorption, porosity & density of aggregate

6- Soundness test of aggregate: immersion in a saturated solution of  $\text{Na}_2\text{SO}_4$  or  $\text{MgSO}_4$  (ASTM C 88 / 99), the formation of salt crystals in the pores of aggregate in a similar manner of the ice.

### **Lightweight aggregates:**

Aggregate Classify according to **bulk density** to: ordinary, light, and heavy aggregate. Density of lightweight aggregate  $< 1 - 1.6 \text{ gm/cm}^3$  while ordinary aggregate is  $1.8 - 2.7 \text{ gm/cm}^3$ .

### **Characteristic properties of lightweight aggregates:**

- 1- Thermal and sound insulation
- 2- Resist fire
- 3- Lightweight & high porosity and easy to move, transport and cut
- 4- Need less iron for reinforcement (lightweight concrete)

### **Uses of Lightweight aggregates:**

- 1- Lightweight concrete & light blocks
- 2- As filler in roofs and walls of Cooling stores
- 3- Building suspension bridges & multistory buildings
- 4- Water treatment as Water purification filters

### **Classification of Lightweight Aggregates:**

- 1- **Natural Lightweight Aggregate:** Diatomite, pumice, scoria & tuff, volcanic cinders, all are of volcanic origin except diatomite.
- 2- **By-product Lightweight Aggregate:** Foamed slag & fly ash, waste product from coal mines and slate quarries.
- 3- **Manufactured Lightweight Aggregate:** Firing clays, slate and shale → bloating and expansion, then rapid cooling.  
Lightweight Aggregates for structural concrete in Iraq are tested according to IQS no. 2550 / 1986.

### **Building stones:**

#### **During history use of local stones:**

Pyramids 2800 years B.C built from limestone blocks, Defense and religious buildings, Winged Bull in Nineveh, Nineveh walls 5000 years B.C, Trade in ornamental stones, Facing with a veneer of natural stone 2 inches (Granite, Marble, Sandstone, Limestone and Slate).

Building stone comprises solid igneous, sedimentary, and metamorphic rocks, usable in its natural state or prepared by hand or mechanically. Building stone is a raw materials for the production of crushed aggregate and dimension stone (paving stone and construction products). Stone for several purposes is quarried from one deposit by blasting, breaking and dressing their size, shape and surface texture.

## Types of building stones:

Common building stones: granite, syanite, basalt, trap rock, slate, gneiss, sandstone, limestone, marble, quartzite, chalk, gypsum --- etc.

**IQS no.1387/1989** classify the **Natural building stones** in Iraq to:

- 1- **Marble** which classes to (calcite, dolomite, serpentine, or travertine)
- 2- **Sandstone** which classes to (sandstone  $\text{SiO}_2 > 60\%$ , quartz sandstone  $\text{SiO}_2 > 90\%$ , quartzite  $\text{SiO}_2 > 95\%$ )
- 3- **Limestone** which classes to (low density, moderate density, high density)
- 4- **Granite**

The required tests according this specification are absorption, density, compressive strength, resistance to abrasion, and soundness.

## Features of building stone (Geological, physiomechanical & texture properties):

### 1- **Strength, porosity and water absorption:**

Should be strong, resistance to compressive strength, low porosity and water absorption.

$$\text{Compressive strength} \propto \frac{1}{\text{porosity}} \propto \frac{1}{\text{water absorption}}$$

Compressive strength influenced by degree of crystallization, grains size, pores size, rock texture, type of cement in sedimentary rocks, and direction of bedding. Fine grains (granite), interlocking massive texture (quartzite), and well cemented with siliceous cement (sandstone) are stronger, but Porous stones (sandstone, chalk, tuff, and shale) are weak.

### 2- **Durability of stone:**

Should be Compact, homogeneous, and nonabsorbent.

Durable stone means long lasting under temperature variation (day & night, or summer & winter), surface expands more than inner part (differential stresses).

Durability of stones are tested as soundness test (Freezing and thawing), immersion the stone 18h in a saturated solution of  $\text{Na}_2\text{SO}_4$  or  $\text{MgSO}_4$ .

Cleopatra needle persisted 3000 years in Egypt but start decaying after 25 years in New York (spallation and exfoliation) as a result of climatic change and industrial pollution.

### 3- **Stone decay causes of stone damage:**

Physical (frost action of water), and chemical (acid rain). An increases in  $\text{CO}_2$  and  $\text{SO}_2$  levels in the atmosphere as a result of industrial processes ( $\text{H}_2\text{CO}_3$ ,  $\text{H}_2\text{SO}_4$  emission) have serious effects especially on limestone buildings. So stones must be resistant to climatic effects.

### 4- **Pores size distribution:**

Movement of water by capillarity through pores, in small pores (fine) water rise rapidly in comparison with large ones.

**5- Spacing of joints & bed thickness:**

Stone beds must be free from closely spaced joints, so easy to cut stone blocks.

**6- Appearance after polish:** Polishing depend on stone hardness.

**7- Colour:** Colour vary about mineral content variation.

**Economic features in consideration:**

- 1- Easy of quarrying and processing
- 2- Thickness of overburden rocks and stone beds
- 3- Distance to the quarry and roads state
- 4- Drainage of quarry
- 5- Processing: used as quarried, after cutting into sizes, after dressing by calcination, crushing, sieving, and washing.

Igneous rocks, quartzite, & some sandstone have high values.

**Slate rock uses as roofing stone because:**

- 1- High ability to split into thin & parallel planes
- 2- Strong and durable
- 3- Resist firing and noncombustible
- 4- Various colors (grey, black, red, green, spotted)

**Building stones in Iraq:**

Limestone, Gypsum, Marble, and Igneous rocks (granite and gabbro) are mostly available.

The main limestone are in the Eocene–Miocene (Dammam, Ratga, serikagni, Euphrates, & Fatha) Formations.

Most of the economic gypsum deposits occur in the middle Miocene Fatha Formation.

Granite in the katar rash volcanic series and gabbro in the mawat and bulfat igneous complexes, used as decorative stone.

Marble is found in the penjween walash zone. Pure marble > 99%  $\text{CaCO}_3$  is white.

Impurities in marble like quartz, chlorite, tremolite, diopside, and other silicates plus graphite. Hematite and limonite are the causes of various colors in marbles.

Gray marble contains homogeneously distributed graphite, while red and pink colors are due to hematite. Distribution traces of limonite give yellow and creamy colors.

Many marbles contains veins or bands of graphite or silicates giving nice and beautiful textures.

Marble quarries are present in Erbil and sullimania in Galala, rayat, kalaa dizah, chwarta, and khan khosh.

### **Properties of limestone deposits of Fatha formation in Mosul city:**

- 1- Layers with suitable thickness
- 2- Easy to quarry without blasting because having joints and fractures systems
- 3- Outcropping on the surface without overburden deposits (thin deposits)
- 4- Layers have small dip so easy to quarry
- 5- Having many fossils with different colors, white, grey, yellow, & milky

### **Gypsum:**

The name gypsum is from the Greek gypsos. Gypsum is common evaporate mineral, it is widely used in the construction industry and agriculture. The most widely distributed sulphate ore which can be a mineral or rock, present on or near the surface, with depth it losses water of crystallization:



Uses of gypsum dated back thousands years by Assyrians in Nineveh (winged bulls) and old Egyptians (pyramids). In Mosul it is known as Mosulian marble, locally known as AlFarsh, used in building and facing due to its easy of cutting & polishing, insulating and fire resistance.

### **Kinds of gypsum: Gypsum occurs in five kinds:**

- 1- Rock gypsum (as evaporates)
- 2- Gypsite (mixture of gypsum, sand, and clay) commonly found in semi-desert localities.
- 3- Alabaster, a massive, compact, and dense (used as decorative stone and ornamental stone), like winged bulls.
- 4- Satin spar, fibrous and silky luster.
- 5- Selenite, transparent and crystal.

**Uses of gypsum:** Gypsum economically important as a cap rocks for oil reservoirs. Gypsum uses in many industries:

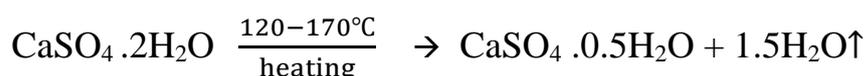
- 1- As a dental stone

- 2- In agriculture as soil conditioner and fertilizer (to add calcium and sulphate needed by some vegetables).
- 3- Plaster industry, making local and technical plaster and plaster board (wallboard).
- 4- In cement making, gypsum is added about 3 – 5 % to the clinker of Portland cement during grinding as a retarding agent to control cement setting time.
- 5- As building, decorative, and ornamental stone, used in sheltered areas.
- 6- As filler in paints and papers, as insecticides carrier.

**Plaster (juss) industry:** The name juss is from the Assyrian word Jusso mean plaster.

**Two kinds** of plaster:

- a) **Local plaster (juss):** produced in a primitive way in koor, in the form of cone where crushed gypsum particles are burned for 30 hours at temperature reaching 1000°C, then left to cool for a day or more and the product is crushed in a mechanical grinder. The resulting fine plaster (juss) consists of anhydrite plus secondary amounts of unburned gypsum and  $\beta$  – hemihydrate (bassanite,  $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$ ).
- b) **Technical plaster (juss):** produced under controlled condition in a rotary or vertical shaft kilns. It consists mostly (95%) of hemihydrate ( $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$ ) plus few gypsum (5%), because it is burned at a temperature range 120 - 170°C for 3 hours. It is stronger than local plaster with better physical properties.



In Iraq plaster produced according to IQS 28 / 1988.

### **Environmental effects of quarrying:**

Quarry operations are concentrated in Fatha Formation, due to:

- 1- Suitable thickness
- 2- Presence of joints and fractures system
- 3- Exposed at surface with no or thin overburden rocks
- 4- Layers are of low dip
- 5- Present in various colours

Open pits, shallow depth, no benches thus disturbing large areas with no land maintenance or reclamation and in some localities pushing quarry wastes into drainage vallies.

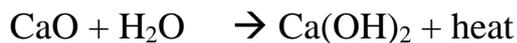
## Lime (CaO):

Lime is CaO product by heating the limestone or other calcareous rocks in kilns to 900-1100°C, when the CO<sub>2</sub> is driven off and quicklime remains.



For chemical and metallurgical uses lime needs to be of pure quality, while for constructional purposes use impure lime (hydraulic). Lime prepare from the rocks, limestone, chalk, travertine, sea shells, wastes from cutting marbles or limestone.

Lime have high ability to absorption the moisture & CO<sub>2</sub>, and loss its industrial property. Commonly is prepared as hydrated (slaked) lime, Ca(OH)<sub>2</sub>, by adding the necessary water.



Lime product in Iraq according to requirements of IQS 807 / 1983

## Lime uses:

- 1- **Soil stabilization:** expansive soil rich in Na-Montmorillonite, add about 6% lime and mix. Due to cation exchange property Ca replaces Na in Montmorillonite and convert it into Ca-Montmorillonite (not expansive clay).  
In Iraq, Lime stabilized subgrade or sub-base due to SORB/R6F by quicklime (CaO) or hydrated (slaked) lime (Ca(OH)<sub>2</sub>).
- 2- **Lime silica Bricks:** consist of (80% silica sand plus about 10% lime + water + pigments), then press the mix under high pressure, move to autoclave where the Brick is subjected to high pressure and moisture.
- 3- **Chemical industries:** for smelting and concentration of metalliferous ores, in agriculture as fertilizer, sugar industry, purification (vegetable oils & water), industrial water treatment, leather tanning.

2019

**Geology and the Cement Industry:**

Old industry in Iraq, since forties and early fifties. Binding materials use dated back to old Iraqis. They used tar or asphalt to bind building units, while old Egyptians used plaster and lime mixed with sand to bind the large blocks of limestone in making pyramids.

Pozzolan cement discovered by old Romans by mixing lime with volcanic ash of Pozzuoli in Italy.

Since then lime and plaster were the main binding materials. Later the need was for a material that could be harden in air and under water and resist dissolution in water and climatic changes i.e. durable, as a result cement industry started in the 18<sup>th</sup> century.

English man Joseph Aspdin noticed in 1824 that burning a mixture of limestone and clay give a substance which becomes very hard after adding water. He named it Portland cement because it is similar in strength to a building stone present in Portland Island in SW England. This was the reason behind calling the cement produced since then ordinary Portland cement.

**Definition of cement:**

Fine grains, dark Colour binding material, manufactured material, when mixed with water that could set and become hard in air or under water. It is composed of mixture of chemical compounds resulting from burning a mixture rich in calcium carbonate and clay at high temperatures (1500°C) in a rotary kiln. The product is known as clinker, which after grinding and adding 3 – 5 % gypsum (to retard its setting), it becomes cement.

**Raw materials:**

- 1- **Calcium carbonate:** usually in the form of limestone, chalk or marble, about  $\frac{3}{4}$  (four parts) of the feeding (raw) mix, the main source for CaO.
- 2- **Clay sediments:** in the form of claystone or shale, the main source for SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, comprise about  $\frac{1}{4}$  (one part) of the mixture.
- 3- **Argillaceous limestone or marl** containing the four main oxides. These rocks are called natural cement rock because it contains both clay and calcium carbonate, and may need some additives to control the composition of the mix. Sand may be added to adjust the silica content, iron ore to correct iron oxides, and bauxite for aluminium oxide.

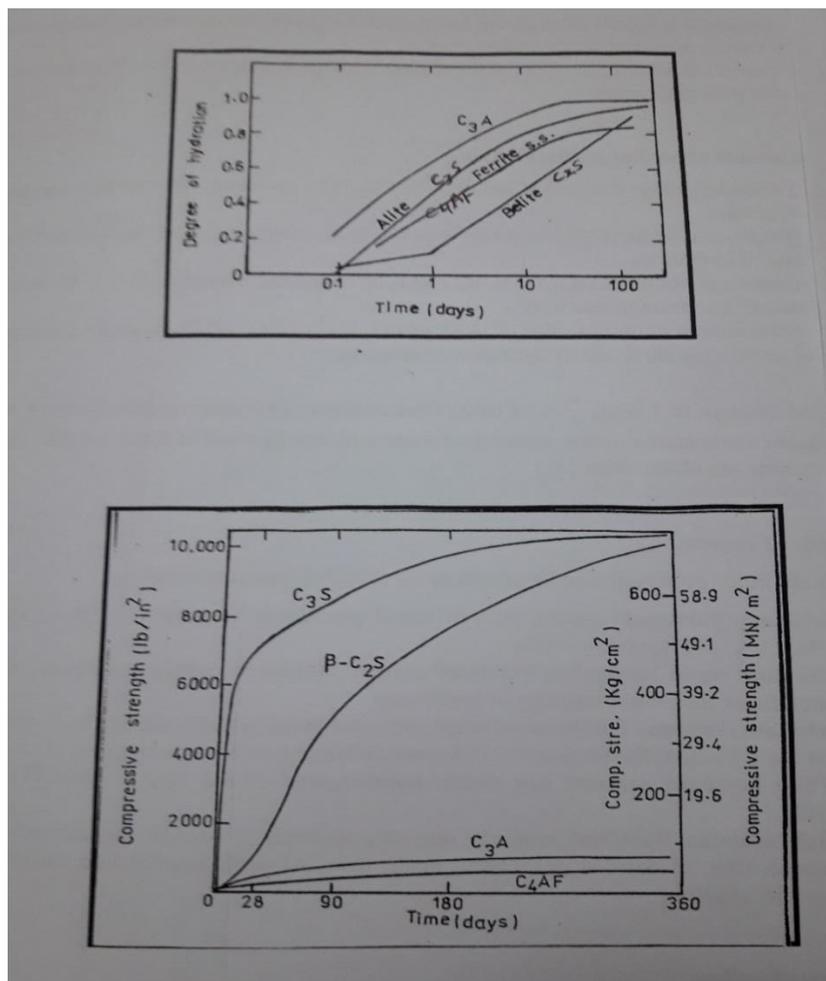
**Manufacture of Portland cement:**

- 1- Quarrying
- 2- Raw material preparation as mixture or raw mix

- 3- Clinkering: the raw materials are dried, heated in rotary kiln at very high temperatures to form mineral phases of cement clinker.
- 4- Cement clinker milling: ground the clinker nodules to fine powder of Portland cement after adding gypsum.

**Compounds of cement (mineralogy):**

- 1- Tricalcium silicate ( $C_3S$ ),  $3CaO.SiO_2$  or  $Ca_3SiO_5$ ; comprise 40 – 80 %; rapid rate of hydration.
  - 2- Dicalcium silicate ( $C_2S$ ),  $2CaO.SiO_2$  or  $Ca_2SiO_4$ ; comprise 0 – 30 %; very slow and gradual rate of hydration.
  - 3- Tricalcium aluminate ( $C_3A$ ),  $3CaO.Al_2O_3$  or  $Ca_3Al_2O_6$ ; comprise 7 – 15 %; very rapid rate of hydration or reaction.
  - 4- Tetracalcium aluminoferrite ( $C_4AF$ ),  $4CaO.Al_2O_3.Fe_2O_3$  or  $Ca_4Al_2Fe_2O_{10}$ ; comprise 4 – 15 %; slow rate of hydration or reaction.
- $\frac{1}{3}$  of strength in 3 days,  $\frac{3}{4}$  in 28 days, final strength after many months. Cement mineral phases are unstable in the presence of water and rapidly react to form complex hydrated silicates and aluminates.



## Kinds of cement:

Different kinds of cement can be produced by changing raw materials:

- 1- **Ordinary Portland cement:** 90% of world production. Consist of ( $C_3S \sim 45\%$ ,  $C_2S \sim 27\%$ ,  $C_3A \sim 11\%$ ,  $C_4AF \sim 8\%$ ).
- 2- **Ultrafine rapid hardening Portland cement:** similar to ordinary Portland cement but much finer, thus rapid setting and hardening.
- 3- **Sulphate resistant Portland cement:** salts (sulphate) usually attacks  $C_3A$ , thus  $C_3A$  is restricted by specifications to  $< 3.5\%$  through adding iron ore to mix, i.e., increase  $C_4AF$ .
- 4- **White Portland cement:** use white kaolin instead of red clay + white limestone or chalk.
- 5- **High alumina Portland cement:** one day strength = strength of ordinary Portland cement after 28 days,  $C_3A = 58\%$ , made from Al rich material like bauxite without gypsum addition.

## Cement ratios:

The factors controlling the production of good quality cement is the exact chemical composition of the raw mix feeding the kiln. The feed should contain the right concentration of the oxides of Ca, Si, Al and Fe. To control the composition of the mix, the following ratios must be considered:

1- **Lime Saturation Factor (LSF)** = 
$$\frac{100 \times \text{CaO}\%}{2.8\text{SiO}_2\% + 1.2\text{Al}_2\text{O}_3\% + 0.65\text{Fe}_2\text{O}_3\%}$$
 --- (66 - 102) BS 12 & IQS 5/1984

In good quality cement LSF not  $< 90$ , Reduction in  $C_3S$  content if LSF is low, accordingly cement strength is reduced. If LSF is  $> 100$ , the mix will be rich in lime above the allowed limit, and the excess lime will expand on hydration and failure of cement. Addition of clay or limestone is recommended to control the value of LSF and thus the composition of the mix.

Lime saturation factor of raw mix take account of the possible presence of MgO which can replace up to 2% (by weight) of CaO:

$$\text{Lime Saturation Factor (LSF)} = \frac{100(\text{CaO}\% + 0.75 \text{MgO}\%)}{2.8\text{SiO}_2\% + 1.2\text{Al}_2\text{O}_3\% + 0.65\text{Fe}_2\text{O}_3\%}$$

$$2- \text{ Silica Ratio (SR)} = \frac{\text{SiO}_2 \%}{\text{Al}_2\text{O}_3 \% + \text{Fe}_2\text{O}_3 \%} \quad \text{----- (1.5 - 4)}$$

This factor represent the ratio of solid (C<sub>2</sub>S, C<sub>3</sub>S) to liquid phases (C<sub>3</sub>A, C<sub>4</sub>AF).

$$3- \text{ Alumina Ratio (AR)} = \frac{\text{Al}_2\text{O}_3 \%}{\text{Fe}_2\text{O}_3 \%} \quad \text{----- (1.4 - 3.5)}$$

This ratio controls quantities of C<sub>3</sub>A and C<sub>4</sub>AF.

When ratios are not within the limits of specification, a corrective material is added which may be rich in silica, alumina or iron.

To control the chemical composition of the product cement, according to IQS 5/1984, uses same ratios. Only LSF calculates as the following express:

$$\text{Lime Saturation Factor (LSF)} = \frac{100(\text{CaO}\% + 0.7 \text{SO}_3\%)}{2.8\text{SiO}_2\% + 1.2\text{Al}_2\text{O}_3\% + 0.65\text{Fe}_2\text{O}_3\%}$$

#### **Deleterious materials:**

Magnesia (max. 5%), {MgO (periclase) + H<sub>2</sub>O → Mg(OH)<sub>2</sub> (brucite)};

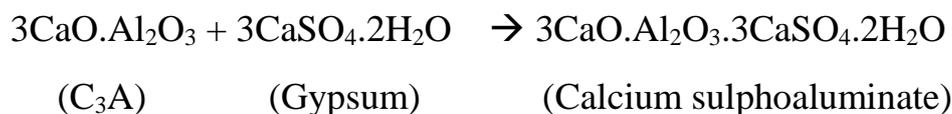
Alkalis (max. 1.5%) (Alkalis equivalent not exceed 0.6%); Sulfate; Chlorides;

P<sub>2</sub>O<sub>5</sub> (max. 2.25%); Sulfide (S); and (chert, opal, chalcedony, volcanic glass).

#### **Setting of cement:**

As mentioned before cement mineral phases are unstable in presence of water and rapidly react to form complex hydrated silicates and aluminates:

C<sub>3</sub>S + C<sub>2</sub>S + C<sub>3</sub>A + H<sub>2</sub>O → Gel of hydrated Ca–aluminate and silicates → crystallization → setting and hardening



## **Constructional clays:**

### **Structural clay products:**

Products made from clays are known from old ages. Bricks, walls and ground tiles dried in sun or fired at high temperatures are used in Mesopotamia, old Egypt and china. Babylon historic city, Al-Zaggora (2500 years b.c), Sumerians and other places.

Man was always seeking material that protect him from climatic changes and should be durable, strong, good insulation, fire resistant and above all cheap.

In Europe, the Romans was the beginners. London burning in 1666 was the main cause behind converting from wooden into brick city.

### **Clays:**

Earthy materials composed mainly of hydrous aluminium silicates, on adding water it become plastic. The last property enabled early man of shaping clay into brick, pots and various wares and potteries (sun-baked or fired).

Clay minerals result from disintegration of pre-existing minerals in the environment of weathering or due to hydrothermal solution effects. Minerals like olivine, pyroxene, amphibole and biotite are unstable due to chemical weathering. They suffer from chemical decay by organic acids resulting from plant cover, and in the presence of dissolved CO<sub>2</sub> (acidic water) giving rise to clays + dissolved constituents.

In general feldspars give kaolinite, while ferromagnesian give smectite (Montmorillonite). Later clays are transported (sedimentary) or remain in situ (residual). The two types differ in properties (like particle size, plasticity, degree of crystallinity) and accordingly their uses are different also.

### **Composition of brick clays:**

Consist of the following minerals:

- 1- Clay minerals (kaolinite, illite, some smectite, chlorite, and mixed layers clays)
- 2- Quartz
- 3- Feldspar
- 4- Carbonate
- 5- Iron oxides
- 6- Sulphate
- 7- Organic materials

Clays rich in Na-montmorillonite are unsuitable, due to high water needed to make it plastic so as to be shaped and on drying and firing shrinkage happened as a result of water expulsion.

Best clays or soil consist of some kaolinite + illite and quartz and less than 20% carbonate. Carbonate rich soils are not suitable because of excess free lime which expands on wetting. Iron oxides and feldspar act as fluxes facilitating reactions to be carried out at low temperature, and quartz melting. During cooling the silica melt harden into glass binding the constituents thus giving the brick its hardness.

The amount of water needed to change clay into plastic state (plastic limit) depend on kind of clay minerals and their proportions, as clay fraction increase, water increase, sand reduces plasticity and shrinkage.

The plasticity of clays can be defined in terms of two limits (Atterberg limits):

**The liquid limit:** which is the water content at which the clay will begin to flow.

**The plastic limit:** the minimum water content at which the clay can be rolled by hand into threads 3mm thick without crumbling.

**Plasticity index:** the arithmetical difference between the two limits is known as the plasticity index, which a measure of the moisture range over which the clay will behave plastically.

Plasticity index = liquid limit – plastic limit

Efflorescence: due to salts (sulphate and chlorides) in clays or soil. Clays should be washed to remove it. Salt may form due to reaction of  $\text{SO}_3$  from fuel + CaO from carbonates causing expansion of brick due to gypsum formation.

### **Brick making industry:**

In middle and south Iraq due to availability of alluvial and recent flood plains sediments, while in Nineveh and Kurdistan regions the soil is carbonate rich.

### **Stages of Brick manufacturing due to IQS 25 / 1988:**

Quarry → Crush and Grind → Sieving → Add water → Mechanical extrude and cutting → Drying → put on moving carriage → Tunnel kilns → cooling

Drying (one day) → Calcining (reactions) → Cooling

$\text{SiO}_2, \text{Al}_2\text{O}_3, \text{Fe}_2\text{O}_3 + \text{CaO} \rightarrow \text{CS} + \text{Siliceous liquid (change into glass on cooling)}$

### **Changes during firing:**

Chemical changes (phase transformations), like kaolinite ( $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$ ) → metakaolinite ( $\text{Al}_2\text{O}_3\text{SiO}_2$ ) → mullite ( $\text{Al}_6\text{Si}_2\text{O}_{13}$ )

Physical changes (shrinkage ---- increase in density), due to silica melting

Through dealing with ceramic clays, we have to consider the following:

- 1- Shaping of the ware (product); dust pressing, plastic forming, slip casting
- 2- Drying of the ware
- 3- Firing
- 4- Evaluation

### **Ceramic materials:**

Ceramic products and the understanding of the term ceramic, which is associated historically with pottery and stonewares. Ceramic is an art and old applied subject of forming and firing clays to changing them into inert durable and strong products, like tablewares, ceramic tiles (floor tiles or roofing tiles like red tiles), brick, porcelain, chinawares----etc.

The common thing between all products is that they are formed totally or partially from clays at ordinary temperature and fired at high temperature. Feldspar (flux) and quartz (to form glass) are added to some products like porcelain, while bauxite, sillimanite group ( $Al_2SiO_5$ ) are essential for refractory substances.

### **Properties of ceramic:**

- 1- Stable under high temperature of use.
- 2- High thermal shock resistance.

### **Role of clays in ceramic industry:**

- 1- To give the plasticity, thus enabling clays to be shaped
- 2- Clay react with other minerals (feldspar + clay) forming silica melt and other minerals responsible about ceramic properties.

### **Role of silica:**

- 1- To regulate plasticity of clays, which cause shrinkage and cracking of ceramic body during drying and firing.
- 2- During firing it melts forming the glassy groundmass after cooling

### **Role of feldspar:**

Act as flux, enabling raw mix melting at low temperature.

### **Fusibility of clays:**

Varies depending on the grade of clay (purity) and on content of fluxes. Some start melting at low temperature  $< 1100^\circ C$  because it contains alkalis and iron oxides, apart from being

composed of non-refractory clay rich in illite, some montmorillonite and chlorite + some kaolinite. This type of clay is called **low grade clays** and is used for cheap potteries.

Clay melting at 1200 - 1350°C, **middle grade clays**, used for making chinawares and tablewares.

Clays melting at temperature reaching around 1700°C are called **high grade clays** like ball clays, fireclays and refractory clays. They usually used in making refractories, thermal and electrical insulator and some kinds of porcelains.

Generally it is possible to know the thermal properties of clays from its chemical analysis, i.e., to know the concentration of the oxides of Ca, Mg, Fe, alkalis and other fluxing compounds. Increase in alumina and decrease in alkalis make the clay of high resistance to fusion.

Iron oxides also cause coloring of the ceramic body, white when < 1%, red > 5% and brown to yellow 1 - 5%.

**Glaze:** glassy materials which coat the surface of ceramic body to make it strong, nice and impermeable. It is composed of mixture of kaolin, feldspar, silica, borax, carbonate of calcium & sodium and lithium mineral.

### **Kaolins:**

**Kaolin or china clays:** kao = village name, ling = hill in china

The clays are composed primarily from kaolinite plus non clay fractions like quartz, feldspar, and mica, remaining from the source mother rock after erosion.

Kaolinite is much finer than the mentioned minerals, thus it is easy to isolate by precipitation.

Kaolins are the purest, whitest, and most expensive clays. Processed kaolin are used as a filling and coating material in paper industry due to its whiteness, fineness, flaky, absorb ink, untransparent. Some of the *mentioned* properties enable kaolins to be used in paints, rubber, plastic, cosmetics, and white cement industries. It is necessary to process kaolins so as to improve its technological properties like brightness, fineness and refractoriness.

### **Types of Kaolin or china clays:**

**Ball clays:** it is called so because during quarrying and extraction it changes into ball like bodies. It consist mainly of sedimentary kaolinite plus secondary amounts of illite. It is fine and highly plastic refractory clays, resulting in high drying strength. It also contains quartz, mica, iron & titanium oxides and organic materials which causes dark colours. It is used mainly in making stonewares, sanitary wares and porcelains.

**Fire clays:** very plastic and fire resistance clays with melting temperature > 1500°C, thus it is considered one of the principal materials in refractory making. It is very rich in sedimentary kaolinite. It is found in **four types:**

- A- **Plastic clay**: composed of poorly crystallized kaolinite + illite as major impurity.
- B- **Semi flint clay**: composed of well crystallized kaolinite + some impurities.
- C- **Flint clay**: composed of well crystallized kaolinite with no impurities. Very hard with conchoidal fracture, very fine grained and hard to slake.
- D- **Nodular flint clay**: composed of well crystallized kaolinite and containing diaspore or bohemite as a result rich in alumina.

### **Montmorillonite (smectite group):**

Structurally it is composed of two layers of silica tetrahedral and one octahedral layer. In this structure it may happen that Al replaces Si, Fe, and Mg, Zn, Ni, & Li replace some Al ions, as a result –ve charges originate causing unstability in the structure. These charges are balanced by ions usually of Na or Ca, a part from water which lay between sheets as a result montmorillonite minerals have high ion exchange property.

Depending on the kind of exchangeable ion in the atomic structure, the following types of montmorillonite minerals are found:

- 1- Na-Montmorillonite (Bentonite)
- 2- Ca-Montmorillonite (Fuller's earth)
- 3- Mg-Montmorillonite (Saponite)
- 4- Li-Montmorillonite (Hectorite)

### **Properties and uses:**

Na and Ca-montmorillonite are the most important:

#### **Na-Montmorillonite (Bentonite):**

The Na-montmorillonite can swell 15-20 times after absorbing water. It is called bentonite due to its presence in Benton district in Wyoming State in the USA. Adding Na-montmorillonite to some water will increase its viscosity and make it able to keep things suspended in it. This is the main reason behind using this clay in oil drilling, grouting, and purification:

1) 4 - 8% of Na-montmorillonite is added to drilling fluids to:

- 1- Form impermeable coat for the sides of the wells.
- 2- Increase the viscosity to lift the cuttings during well drilling.
- 3- Keep cuttings in suspension and not allowing them falling down to the bottom of the well if drilling stopped immediately due to some reasons.
- 4- Lubricate drilling bits

2) Other important uses is for bonding foundry sand and iron ore pellets.

3) In some civil engineering works like dams, tunnels, foundations and restoring old buildings the need arise to seal cracks and cavities through injecting bentonite and ultrafine cement. Lakes and channels coating with this clay will preserve water from loss.

#### **Ca-Montmorillonite (Fuller's earth):**

Has good ability of adsorbing and attracting ions and molecules of gases or liquids and keeping inside. It also has the ability to absorption. It is used since the past in cleaning and bleaching color, remove odder, drying agent, clarifying and processing vegetable oils, oils in general, sugar, & wines, removing grease and chemicals from floors, as a carrier for insecticides & fertilizers, and as a filler in paints.

#### **Clays in Iraq:**

Ranges from recent alluvials to old claystones and shales. They vary in their genesis and environment of deposition and accordingly vary in their properties and applications.

#### **Kaolins:**

Present in the western desert in Ga'ara depression in the upper part of Ga'ara sandstone formation (Permian age). It is present as massive bodies or in the form of lenses or plates between beds, usually white in colour. It also occurs in Hussainiyat formation (Lower Jurassic) along wadi Hussainiyat, and in Amij formation (middle Jurassic) at wadi Amij. These clays contain > 5% iron oxides, and considered as low grade clays.

The origin of all these clays is most probably kaolinite transported after the erosion of the acidic igneous rocks of the Arabian shield present in Saudi Arabia.

These clays are used in Iraq for making ceramics and various potteries, in white cement and refractories.

#### **Bentonite:**

These deposits are present in restricted areas in north eastern Iraq within the Mukdadiya formation (Pliocene), in the southern part of Jabal Hemrin. It also occurs along the highway between Baghdad and Kirkuk in areas like Qaratapa and Zarlokh. These sediments originated from the transported flying ash ejected from Zagros belt volcanos, which later precipitated within the Mukdadiya formation in alkaline lakes and suffered diagenesis and changed into Bentonite.

The presence of glass shards, zircon, apatite, and pyroxene support this genesis.

In Iraq is used as additive to oil drilling fluids, in foundations, and in clarification and bleaching of vegetable oil and sulphur.

**Industrial and Manufacturing Materials :**

Group of unrelated nonmetallic materials used in the manufacturing and preparing of industrial products like, Glass (silica sand), Heat resistant objects like Gloves, Firemen Clothes, Conveyer belts, Gaskets, Brakes and Clothes (Asbestos), Talc, Mica, Barite, ---- etc.

**Silica Sand :**

Usually contains 95 - 99.8 %  $\text{SiO}_2$ , its main sources are loose sandstone, from Crushing cemented sandstone, and Quartzite. Due to its hardness (7 on Moho's scale) and high resistance to physical and chemical weathering quartz is concentrated during sedimentary processes. Feldspar, Mica, some clays, and secondary minerals (heavy minerals) are present with quartz.

Natural sands seldom contain more than 95 % quartz. Impurities occur with quartz such as feldspar, mica, clays iron oxides, and heavy minerals like rutile, zircon, ilmenite and chromite.

Sand should be processed according to the required specification of use. For colourless glass making iron must be  $< 0.035\%$ , and refractory minerals (heavy minerals) must also remove because they resist melting at glass making temperature.

In addition the silica sand for glass should be of narrow grain size (0.125 – 0.5 mm) so as to control melting of the sand. Accordingly the sand should be processed through washing, sieving (to control size), magnetic (to remove iron oxides) and gravity separation to remove heavy minerals. That is why glass factories contain many units to process sand in order to be homogenous in size and mineralogy (chemistry).

In Iraq, economic silica sand deposits are located in the western desert within Naher Omar and Rutba Formations. Besides very pure silica sand layers are present within Ga'ara formation in Ga'ara depression. Their source is most likely from the erosion and weathering of acidic igneous rocks of the Arabian Shield located in Saudi Arabia. The quartz resists weathering and accumulated through time with good sorting (0.1 – 0.5 mm) with rounded to sub rounded shape.

**Preparation and Manufacturing of Glass :**

Sand is prepared after the necessary treatments and processing (mention them), then fluxes are added (soda ash,  $\text{Na}_2\text{CO}_3$ ) so as to lower the melting temperature of silica ( $1710^\circ\text{C}$ ) and make the melt less viscous. Limestone is added to the mix (silica-soda mix) to improve its

consistency, stability, chemical, and mechanical properties. At the end a silica-soda-lime glass is obtained.

During melting of the mix,  $\text{CO}_2$  is escaped;  $\text{Na}_2\text{O}$  and  $\text{CaO}$  are combined with silica forming a network of silicates, which are cooled gradually and shaped according to need (bulbs, flat window, plates, jars, bottles, ---- etc.

Mix of Glass window		Mix of Pyrex Glass	
$\text{SiO}_2$	72 %	$\text{SiO}_2$	80 %
$\text{CaO} + \text{MgO}$	15 %	$\text{B}_2\text{O}_3$	13 %
$\text{Na}_2\text{O}$	12 %	$\text{Na}_2\text{O}$	4 %
$\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 + \text{others}$	1-2 %	$\text{Al}_2\text{O}_3$	3%

Other materials may be added to glass mix, like colouring elements and fluxes, and to improve brightness and transparency of glass. For example borax is added to Pyrex glass mix to reduce the thermal expansion of glass and increase its durability and brightness. Pyrex glass resists heat and thermal shocks, and is used in houses and laboratories.

Optical glass needs adding increasing amounts of  $\text{K}_2\text{O}$  which equal twice the amount of  $\text{Na}_2\text{O}$ , while production of crystal glass needs adding at least 7- 8 % of potash ( $\text{K}_2\text{O}$ ) to the mix which consists from silica and lead oxide, causing the glass to be of high quality, and more durable and chemically stable.

### Colours of added elements :

Se = red      Cr, Cu = green      Co =blue      Mn = violet

### Chemical Minerals :

A number of nonmetallic substances used for chemical purposes. Some are used in the raw state for chemical or medical reasons, and others are prepared to supply the desired chemical elements and to control the environment of the reaction, acidic or basic.

They are used because of their chemical composition and not their physical properties such as Chlorides, Sulphates, Nitrates, or others.

The important chemicals which will deal with are Salt, Na-Sulphate, Na-Carbonate, Potash, and Sulphur.

## **Sulphur :**

### **Important Uses :**

Most Sulphur goes into **Sulphuric acid ( $H_2SO_4$ ) production** which is used for the phosphate fertilizer industry. The rest enter in the making of many products like **drugs, food products, soaps, detergents, paper making, paints, explosives, water treatment, oil purification, and road pavement by mixing with asphalt.**

### **Properties of Sulphur :**

Well known by its **yellow colour, hardness (2), sp. gr. (2), crystal system (monoclinic), melting temperature ( $113\text{ }^\circ\text{C}$ ), insoluble in water and most acids.**

### **The most important sources of Sulphur :**

- 1- As native Sulphur (S) as in the evaporate deposits of Fatha formation in Mishraq area 45 km south Mosul, in USA, Russia, and Polonia.
- 2-  $H_2S$  gas associated with oil.
- 3- Treatment of hydrocarbons.
- 4- Iron Sulphide like Pyrite.
- 5- Noniron Sulphide like Galena ( $PbS$ ), Sphalerite ( $ZnS$ ), and Covellite ( $CuS$ ).
- 6- Gypsum and Anhydrite  
(Cost increase from 1 – 6)

### **Production :**

Sulphur is mostly produced by non-entry (Frasch) mining method through injecting boiled water through wells drilled to the S bearing rocks (note the following diagram). Three concentric pipes are supplied, one for boiled water ( $160\text{-}170^\circ\text{C}$ ), the second for recovery of molten S to the surface, and the third for injecting compressed air under high pressure in order to force the molten S to be recovered.

### **Sulphur in Iraq :**

The main source for production of sulphur in the world is from the treatment of  $H_2S$  gas and oil, but in Iraq native S is the main source.

Iraq is the main country in S reserves. Huge amounts occur in Nineveh Governorate in the geological structures extending from south of Mosul to Al-Fatha area on both sides of Tigris river. At Mishraq area the subsurface layers are composed of gypsum, anhydrite and

limestone (M. Miocene) with inter beds of marl and sandstone. In this formation native S is present in the vugs and cavities in three zones within the bituminous limestone.

Sulphur originates through the alteration of gypsum and anhydrite to S and calcite with the aid anaerobic bacteria. This bacteria depends on organic materials and hydrocarbons for its metabolism and as source for energy so as to take its need of carbon and hydrogen, and consumes sulphate (SO<sub>3</sub>) and consequently release CO<sub>2</sub> and H<sub>2</sub>S gases. The H<sub>2</sub>S gas accumulates in the crest of the geological structure for long period and later suffered from oxidation and changing into free sulphur. The sulphate rich water changes into carbonate rich water suitable for the precipitate of calcite as indicated in the following equation :

