

ENGINEERING GEOLOGY

CE1301

Lecture #2 Minerals

Muayad A. Al-Sharrad

Ph.D. Geotechnical Engineering

Assist Prof.- Department of Civil Engineering

University of Anbar

Room 012

Civil Engineering Building

Ramadi 31001

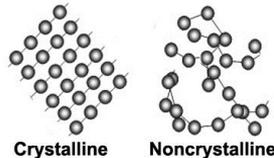
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Email: muayad.alsharrad@uoanbar.edu.iq

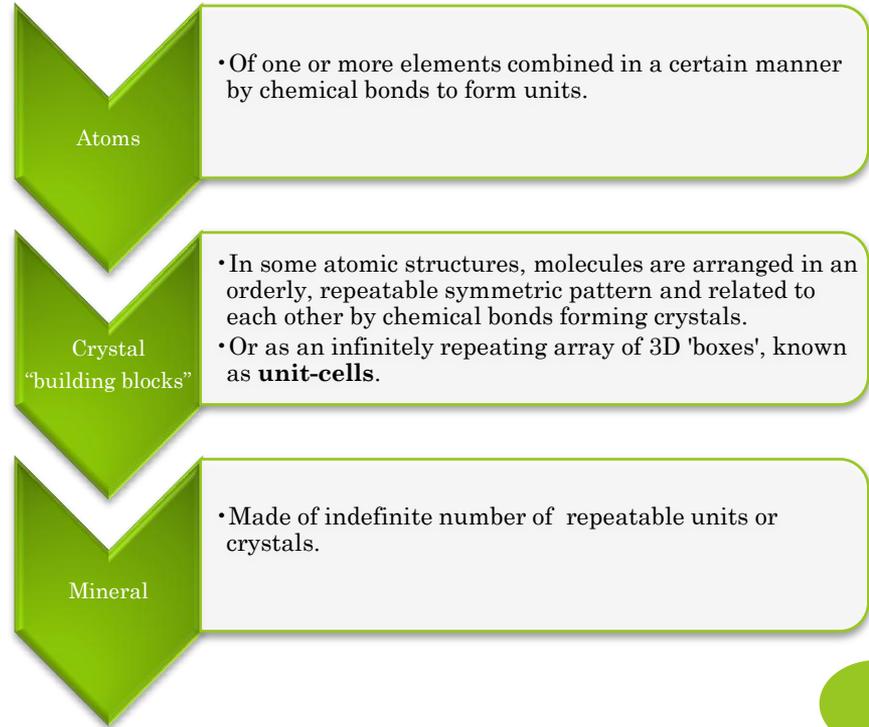


WHAT IS A MINERAL?

- A **mineral** is a natural inorganic solid substance having a particular chemical composition or range of composition, and a regular atomic structure to which its crystalline form is related.
- Therefore every mineral:
 - is naturally occurring;
 - is inorganic;
 - is solid;
 - has particular chemical composition;
 - has ordered atomic structure.
- A mineral is composed of atoms of one or more elements bonded by atomic bonding:
 - Covalent bond;
 - Ionic bond;
 - Van der Waals bond;
 - Hydrogen bond;
 - Metallic bond.
- A **crystal** is a piece of a homogeneous solid substance having a naturally geometrically regular form with symmetrically arranged plane faces.
- A **crystalline solid** is a solid material with its atoms, molecules or ions, are arranged in a highly ordered microscopic structure, forming a crystal structure that extends in all directions.
- **Non crystalline solid (amorphous)** (like glass) has no long-range orderly arrangement of atoms.

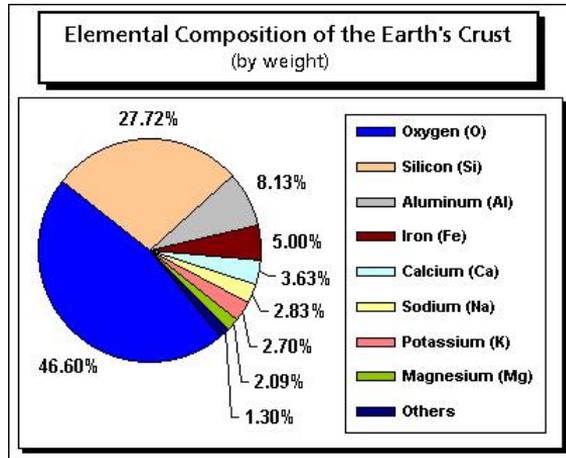


- **Cation:** is an ion with positive charge.
- **Anion:** is an ion with negative charge.



AVERAGE ELEMENTAL COMPOSITION OF THE CRUST

- Eight elements in their order of abundance in crustal rocks.
- Silicon and oxygen together make up nearly 75 per cent of crustal rocks, and the other elements over 98 per cent.
- Since silicon and oxygen preponderate in the rocks, the chief rock-forming minerals are silicates.



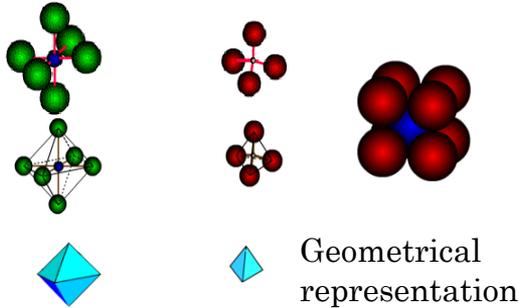
Source: www.geog.ucsb.edu

- The average composition of crustal rocks:

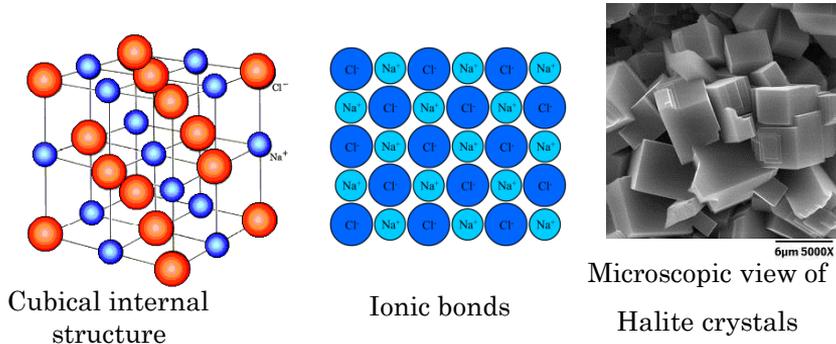
	%
SiO ₂	59.26
Al ₂ O ₃	15.35
Fe ₂ O ₃	3.14
FeO	3.74
MgO	3.46
CaO	5.08
Na ₂ O	3.81
K ₂ O	3.12
H ₂ O	1.26
P ₂ O ₅	0.28
TiO ₂	0.73
rest	0.77
<i>Total:</i>	<i>100.0</i>

ATOMIC STRUCTURES

- Refers to the arrangement and spacing of the atoms of a given crystal which controls its regular form and properties.
- In most cases bonds in minerals are combinations of covalent and ionic bonds.
- Octahedron, tetrahedron and cube units



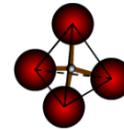
Halite: composition (NaCl)



- Chloride anions gain electrons to fill their outer shell.
- Sodium cations throw away their outer shell.
- Therefore, anions tend to occupy a much larger volume than cations of similar mass.
- The crystal structure is mostly determined by the packing arrangement of anions.

- Each Na⁺ ion is surrounded by 6 Cl⁻ ions.
- Each crystal has millions of Na⁺ and Cl⁻ ions.

Quartz: composition (SiO₂)



- Each SiO₄ tetrahedron is bonded to 4 other SiO₄ tetrahedrons in the 3D structure.
- Crystal structure: hexagonal continuous framework of SiO₄ tetrahedrons.

PHYSICAL PROPERTIES OF MINERALS

○ Colour

Some minerals have a distinctive colour, for example the green colour of **chlorite**, but most naturally occurring minerals contain traces of substances which modify their colour.

Thus **quartz**, which is colourless when pure, may be white, grey, pink or yellow, when certain chemical impurities or included particles are present.



Chlorite



quartz

○ Streak

Is the color of the powder produced when the mineral is rubbed on a piece of unglazed porcelain (streak-plate). If no streak seems to be made, the mineral's streak is said to be white or colorless. Streak is particularly important as a diagnostic for opaque and colored materials. It is less useful for silicate minerals, most of which have a white streak or are too hard to powder easily.



○ Luster

is the way light interacts with the surface of a crystal, rock, or mineral.

- *Metallic*: having the look of a polished metal as in **pyrite** and **galena**.
- *Adamantine*: having a hard, sparkly look of a **diamond**
- *Resinous*: having a look of yellow, dark orange, or brown that is slightly reflective as in **amber**.
- *Vitreous*: having the look of glass as **quartz**.
- *Pearly*: having the look of a pearl as in **talca**.
- *Greasy*: having the look of an oil coated surface as in **chalcedony**.
- *Earthy*: having the look of soil or clay as in **sulfur**.
- *Silky*: having the look of fine, parallel fibers such as **satin spar** (fibrous gypsum).
- *Dull*: having no luster as in **kaolin**



Pyrite (left) and galena (right)



Diamond



Amber



Quartz



Talc



Chalcedony



Malachite (green), sulphur (yellow) and cinnabar (red)



Satin spar (fibrous gypsum)



Kaolin

PHYSICAL PROPERTIES OF MINERALS

○ Hardness

Hardness, or resistance to abrasion, is measured relative to a standard scale often minerals, known as Mohs' Scale of Hardness.

Moh's hardness	Mineral	Chemical formula	like
1	Talc	$Mg_3Si_4O_{10}(OH)_2$	
2	Gypsum	$CaSO_4 \cdot 2H_2O$	Fingernail (2.5)
3	Calcite	$CaCO_3$	
4	Fluorite	CaF_2	
5	Apatite	$Ca_5(PO_4)_3(OH^-, Cl^-, F^-)$	Glass plate (5.5)
6	Orthoclase	$KAlSi_3O_8$	Steel nail (6.5)
7	Quartz	SiO_2	
8	Topaz	$Al_2SiO_4(OH^-, F^-)_2$	Masonry drill bit (8.5)
9	Corundum	Al_2O_3	
10	Diamond	C	

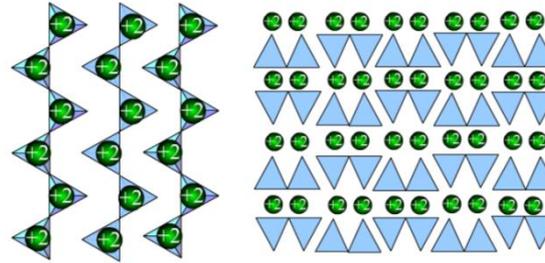


* Mineral strength is a function of hardness and lack of cleavage.

○ Cleavage

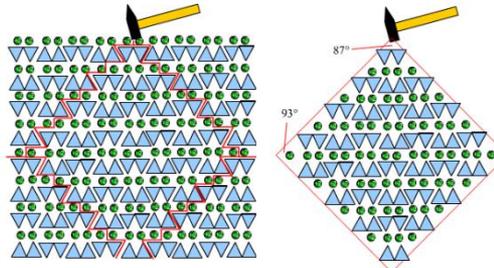
Many minerals possess a tendency to split easily in certain regular directions, and yield smooth plane surfaces called cleavage planes when broken. These directions depend on the arrangement of the atoms in a mineral, and are parallel to definite crystal faces. Perfect, good, distinct, and imperfect are terms used to describe the quality of mineral cleavage.

Cleavage in pyroxene



Cross sections through pyroxene structure, parallel and normal to the SiO_4 chains. The negatively charged chains are linked together by the positively charged cations. (each chain is negatively charged:
 $6Si^{+4} + 18 O^{2-} = -12$)

The structure breaks through the weak ionic bonds between the negatively and positively charged ions.



Source: <http://ansatte.uit.no/kare.kullerud/webgeology/>

PHYSICAL PROPERTIES OF MINERALS

○ Fracturing

As explained above, quartz has a structure made of 3D framework of SiO₄ tetrahedrons bonded by covalent bonds.

Because that these bonds are equally strong in all directions, no cleavage exists. Instead, the mineral would fracture when stressed (just like glass).



○ Specific gravity

Is the ratio of the density of a substance to the density (mass of the same unit volume) of water. The specific gravity of a mineral determines how heavy it is by its relative weight to water.

Specific gravity of most minerals ranges between 2 and 7, see the table below.

halite	2.16	muscovite	2.8–3.0	rutile	4.2
glauconite	2.3	apatite	3.2	zircon	4.7
gypsum	2.32	hornblende	3.2 (av.)	haematite	4.72
feldspar	2.56–2.7	tourmaline	3.0–3.2	ilmenite	4.8
clays	2.5–2.8	sphene	3.5	pyrite	5.01
quartz	2.65	topaz	3.6	monazite	5.2
calcite	2.71	kyanite	3.6	magnetite	5.2
dolomite	2.85	staurolite	3.7	cassiterite	6.9
chlorite	2.6–3.3	garnet	3.7–4.3		

○ Magnetism

Most of iron bearing minerals like Magnetite are magnetic.



○ Crystal systems

- When a mineral substance grows freely from a liquid state (or out of solution, or by sublimation), it tends to assume its own characteristic crystal shape.

- **Crystal Faces** are conveniently defined by reference to *crystallographic axes*. Crystal faces are formed during crystallization process whereas cleavage faces formed when mineral breaks.

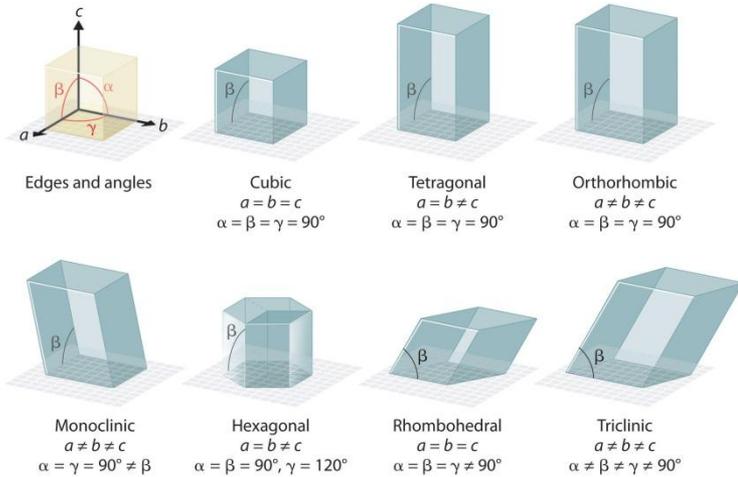
- The arrangements of faces in crystals possess varying degrees of symmetry, and according to their type of symmetry, crystals can be arranged in seven Systems, which are summarized below and illustrated in the figure next page.

- A **plane of symmetry** divides a crystal into exactly similar halves, each of which is the mirror image of the other; it contains one or more of the crystallographic axes.

- A **crystal structure** describes a highly ordered repeatable arrangement of atoms within a given type of crystal.

- The **unit cell** is the smallest complete unit of pattern in the atomic structure of a crystal. The unit cell is represented in terms of the lengths of the cell edges (a, b and c) and the angles between them (alpha, beta and gamma).

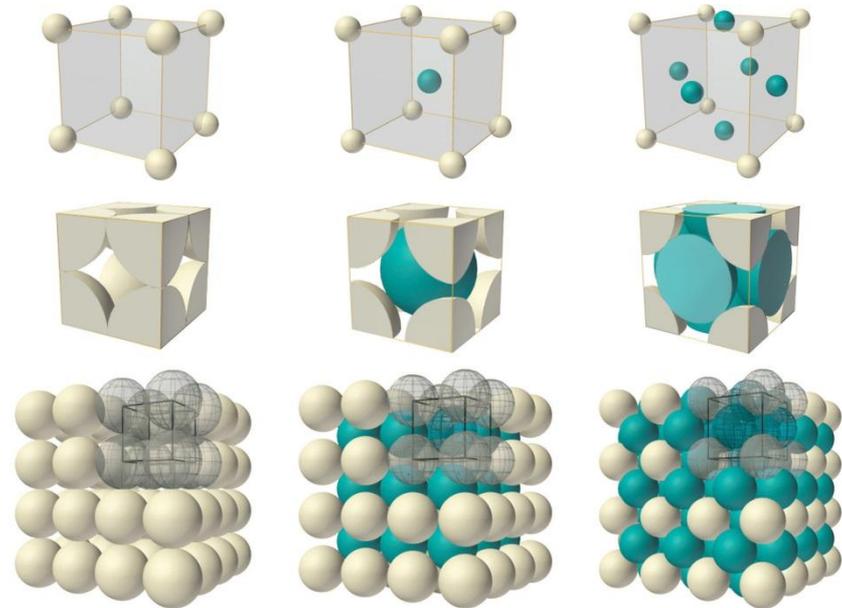
THE UNIT CELL



[source: http://chemwiki.ucdavis.edu/](http://chemwiki.ucdavis.edu/)

The General Features of the Seven Basic Unit Cells.

- If the cubic unit cell consists of eight component atoms, molecules, or ions located at the corners of the cube, then it is called simple cubic (Figure a).
- If the unit cell also contains an identical component in the center of the cube, then it is body-centered cubic (Figure b).
- If there are components in the center of each face in addition to those at the corners of the cube, then the unit cell is face-centered cubic (Figure c).



(a) Simple cubic

(b) Body-centered cubic

(c) Face-centered cubic

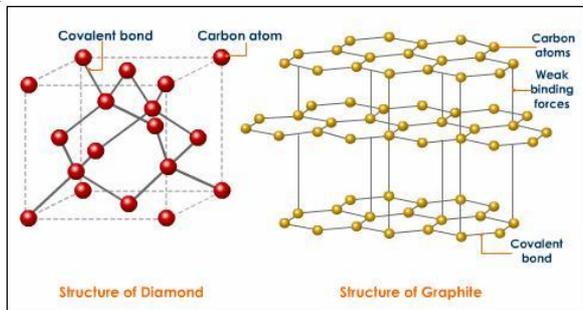
The figure above suggests that mineral density is directly affected by the atomic arrangement within the unit cell.

- **Factors controlling the minerals type:**

- chemical composition of the mineral;
- the crystal structure and the type of bonds.

Polymorphs:

Minerals with the same chemical composition but with different crystal structure:

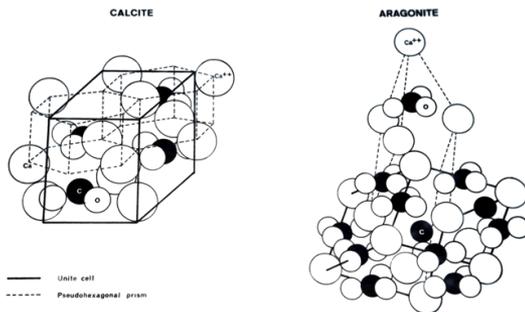


Source: openstudy.com

- Diamond/graphite: both composed of carbon (C)



Calcite/aragonite (CaCO₃)



Source: <http://itsedimentary.tumblr.com/post/79587108044/a-tale-of-two-caco3s-calcite-and-aragonite>

- Pyrite/marcasite (FeS₂)
- Quartz/cristobolite (SiO₂)

- **Cation substitution**

- Ions have different sizes and charges.
- If two cations have *similar size* and *similar charge*, a cation substitution is possible. Anions are usually much larger than cations and anions usually are very tightly bonded (covalent bond) so it is not easy to break them loose and reconnected with substituted anions. Many cations are loosely bonded and allow some substitution.
- The mineral olivine, as common example, may have magnesium (Mg₂SiO₄) or iron (Fe₂SiO₄) or a combination of both ((Fe₂Mg₂)SiO₄).

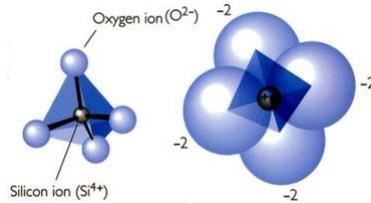
MAJOR MINERAL GROUPS

Minerals are grouped Based on the chemical, minerals are classified into seven groups:

- Silicates
- Oxides
- Sulfates
- Sulfides
- Carbonates
- Native Elements
- Halide

SILICATE MINERALS

Silicate structure



In most silicate minerals, a large number of silicate tetrahedrons are linked together to form chains, sheets, or three-dimensional frameworks.

Isolated tetrahedron: no oxygen is shared between SiO_4 tetrahedrons. The mineral is held together by the attraction between SiO_4 tetrahedrons and other positive ions. Example mineral: Olivine.

Net charge: $\text{Si}(-4) + \text{O}_2(-2 \times 4) = -4$

Single chain silicates: two oxygen atoms are shared between SiO_4 tetrahedrons to form a chain. Example mineral: pyroxene.

Double chain silicates: formed when two single chains share oxygen atoms. Example mineral: amphibole.

Sheet Silicates: formed when each SiO_4 tetrahedron shares three oxygen atoms with the adjacent SiO_4 tetrahedrons. Example minerals: Muscovite mica.

Framework Silicates formed when each SiO_4 tetrahedron shares the four oxygen atoms with the adjacent SiO_4 tetrahedrons. Example mineral: potassium feldspar.



Isolated silicate structure



Example

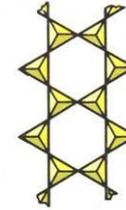
Olivine

Single chain structure



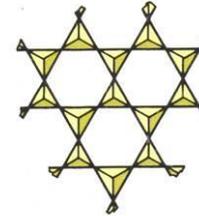
Pyroxene group

Double chain structure



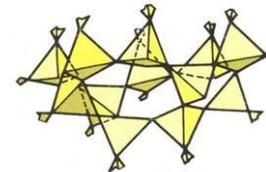
Amphibole group

Sheet silicate structure



Mica group
Clay group

Framework silicate structure



Quartz
Feldspar group

Source: <http://www.thisoldearth.net/>

COMMON ROCK-FORMING MINERALS

○ Silicate minerals

The most important rock-forming minerals are quartz, feldspars, micas, amphiboles, pyroxenes, and olivine.

Source: <http://www.oakton.edu/user/4/billtong/eas100lab/mintable.htm>

Name	H	Color	Streak	Luster	Prominent Cleavage	Composition	Other Properties
Augite (pyroxene)	6	dark green to black	gray	vitreous	YES - 2 dir. at nearly 90°	complex silicate	Most common pyroxene; often appears as short, stubby, prismatic crystals in rock.
Hornblende (amphibole)	6	black, dark green, or brown	grayish-white	vitreous	YES - 2 directions, ith angles at 56° and 24°	complex silicate	Most common amphibole; found in many igneous rocks. Characterized by dark, elongated crystals
Olivine	6	olive green or brownish	white or gray	vitreous to adamantine	Not obvious - indistinct	(Mg,Fe) ₂ SiO ₄	Often found as "sugary" granular masses of dunite (olivine rock); gem variety called peridot
Plagioclase feldspar (including Albite, Labradorite, etc.)	6	white to dark gray	colorless or white	vitreous	YES - 2 dir. at nearly 90°	NaAlSi ₃ O ₈ to CaAlSi ₂ O ₈	Sodium-rich varieties are white or light gray; calcium-rich varieties are medium to dark gray.
Potassium feldspar (Orthoclase, Microcline)	6	white, tan to orange, red, green, also colorless	colorless or white	vitreous or pearly	YES - 2 dir. at nearly 90°	KAlSi ₃ O ₈	Most commonly found in granites and pegmatites.
Biotite Mica	2.5	Black, dark green, or brown	gray to white	vitreous or pearly	YES - 1 dir. (sheets)	K(Mg,Fe) ₃ (AlSi ₃ O ₁₀)(OH) ₂	Flexible and elastic sheets
Muscovite Mica	2.5	Colorless, gray, or green	white	vitreous	YES - 1 dir. (sheets)	KAl ₂ (AlSi ₃ O ₁₀)(OH) ₂	Flexible and elastic sheets
Quartz (crystalline varieties)	7	colorless, white, gray, purple, pink, black, yellow, green	colorless	vitreous	NO - shows conchoidal fracture	SiO ₂	Varieties named by color: Rock crystal (colorless), Milky (white), Smoky (gray), Amethyst (purple), Rose (pink), Citrine (yellow); 6-sided crystals common

THE ROCK-FORMING MINERALS

- Other common rock-forming minerals Including calcite, magnetite pyrite and clay minerals.

Source: <http://www.oakton.edu/user/4/billtong/eas100lab/mintable.htm>

Name	H	Color	Streak	Luster	Prominent Cleavage	Composition	Other Properties
Calcite	3	Colorless or white; impurities may discolor it yellow or brown	white	vitreous	YES - 3 dir., not at 90°(rhombic)	CaCO ₃	Effervesces vigorously with cold dilute hydrochloric acid. Transparent calcite shows double refraction.
Pyrite	6 - 6.5	Pale brassy yellow	greenish to brownish black	-	NO	FeS ₂	Known as "Fool's Gold." Brittle, common in crystals, but also granular and massive (no obvious form).
Magnetite	5.5 - 6.5	Black	black	-	NO (but sometimes shows parting)	Fe ₃ O ₄	Strongly magnetic; lodestone variety shows polarity; often in octahedral (8-sided) crystals
Bauxite	2 - 7	White to brown	white	earthy-dull	NO	Mixture of AlO(OH), Al(OH) ₃ , and HAIO ₂	Mixture of 3 clay minerals: Boehmite, Gibbsite, and Diaspore. Earthy odor when breathed on.
Gypsum	2	Colorless; white, gray, yellowish	white	vitreous	Only obvious in the selenite variety - 3 dir. (rhombic)	CaSO ₄ ·2H ₂ O	3 common varieties: -selenite: clear, transparent -satin spar: fibrous, silky -alabaster: granular, sugary
Dolomite	3 - 3.5	White, gray, brown, pink	white	vitreous to pearly	YES, but not always obvious (rhombic).	CaMg(CO ₃) ₂	Effervesces slowly with dilute cold hydrochloric acid, but only when powdered

INDUSTRIAL USE SOME OF MINERALS

Source: <http://www.nma.org/index.php/minerals-publications/40-common-minerals-and-their-uses>

○ Sulfur

Used in the manufacture of sulfuric acid, fertilizers, petroleum refining; and metal mining.

○ Phosphate rock

Used to produce phosphoric acid for ammoniated phosphate fertilizers, feed additives for livestock, elemental phosphorus, and a variety of phosphate chemicals for industrial and home consumers.

○ Halite (sodium chloride—salt)

Used in human and animal diet, food seasoning and food preservation; used to prepare sodium hydroxide, soda ash, caustic soda, hydrochloric acid, chlorine, metallic sodium; used in ceramic glazes; metallurgy, curing of hides; mineral waters; soap manufacturing; home water softeners; highway de-icing; photography; in scientific equipment for optical parts.

○ Gypsum

Processed and used as prefabricated wallboard or an industrial or building plaster; used in cement manufacturing; agriculture and other uses.

○ Quartz (silica)

As a crystal, quartz is used as a semiprecious gem stone. Crystalline varieties include amethyst, citrine, rose quartz, smoky quartz, etc. Piezoelectric forms include agate, jasper, onyx, etc. Because of its piezoelectric properties quartz is used for pressure gauges, oscillators, resonators and wave stabilizes; because of its ability to rotate the plane of polarization of light and its transparency in ultraviolet rays, it is used in heat-ray lamps, prism and spectrographic lenses.

Also used in manufacturing glass, paints, abrasives, refractory materials and precision instruments.

○ Feldspar

A rock-forming mineral; industrially important in glass and ceramic industries; enamelware; soaps; bond for abrasive wheels; cements; insulating compositions; fertilizer; tarred roofing materials; and as a sizing, or filler, in textiles and paper.

○ Clays

Used in floor and wall tile as an absorbent, in sanitation, mud drilling, foundry sand bond, iron pelletizing, brick, light weight aggregate and cement. Bentonite is used for drilling mud, pet waste absorbent, iron ore pelletizing and foundry sand bond. Kaolin is used for paper coating and filling, refractory products, fiberglass, paint, rubber and catalyst manufacture. Common clay is used in brick, light aggregate and cement.

○ Iron Ore

Used to manufacture steels of various types. Powdered iron: used in metallurgy products; magnets; high-frequency cores; auto parts; catalyst. Radioactive iron (iron 59): in medicine; tracer element in biochemical and metallurgical research. Iron blue: in paints, printing inks, plastics, cosmetics, paper dyeing. Black iron oxide: as pigment; in polishing compounds; metallurgy; medicine; magnetic inks.

○ Aluminum

Aluminum originates as an oxide called alumina. Bauxite ore is the main source of aluminum. Used in transportation (automobiles), packaging, building/construction, electrical, machinery and other uses.

○ Pyrite

Used in the manufacture of sulfur, sulfuric acid and sulfur dioxide; pellets of pressed pyrite dust are used to recover iron, gold, copper, cobalt, nickel; used to make inexpensive jewellery.

MINERAL RESOURCES OF IRAQ

Geosery, Iraq Source:

http://iraqmining.com/index.php/index.php?option=com_content&view=article&id=19&Itemid=7

Native sulfur:- About 600 m.t. of proved reserves were discovered in Nineva Governorate, 60% of which is extractable by modified Frash method. Mining in MI field started in 1969 at 1 m.t./year designed production capacity. Mostly used in chemical industries and for export.

Phosphorite:- More than 10 000 m.t. of proved reserves were discovered in Akashat and surrounding areas (Anbar Governorate). Mining started in 1983 at 3.2 m.t./year designed production rate to supply the phosphate fertilizer plant at Al-Qaim.

Salt (NaCl):-About 50 m.t. of proved reserves are located at Samawa saltern (Muthana Governorate) in addition to several smaller salterns in the Jazira area. Used in chemical and petrochemical industries, as well as in food industry. Production rate about 200 000 t/year.

Glauberite:- About 22 m.t. of proved reserves are found in the Shari Saltern (Salahudin Governorate). Used in the production of sodium sulfate. New plant is needed.

Gypsum:- More than 130 m.t. are proved in several localities of the Low-Folded Zone (Northern Zone) of Iraq. Mostly used in the production of plaster.

Limestone:- More than 8000 m.t. are proved in various parts of Iraq and are being exploited for the production of cement.

Quartz-sand:- More than 850 m.t. of proved reserves are available of almost pure quartz-sand. Presently mined from one site in Anbar Governorate and used in glass, ceramics and refractories production.

Feldspathic sand:- A small reserve (about 2 m.t.) of silica sands containing up to 20% feldspar minerals are located in Najaf Governorate. Used for ceramic industry and need a floatation plant for upgrading.

Kaolinitic claystones:- These deposits are found in several localities in Anbar Governorate with total reserves reaching up to 1200 m.t. of various grades (white and colored). Mostly used in ceramic industry, but is considered the only source in Iraq for alumina in the future.

Bentonite:- About 22 m.t. of Ca-montmorillonitic clay are found in Anbar Governorate. At present it is mainly used for oil-well drilling after on-site Na-activation. A plant for Na-activation is needed with 75000 t./year production capacity.

Ironstone:- A sedimentary pisolitic medium grade ironstone deposit is located in Anbar Governorate with about 60 m.t. of reserves. The quality and grade permit using the ore in cement industry only. A new mine is needed.

Bauxite:- Very small and scattered Karst bauxite and bauxitic claystones are found in Anbar Governorate. Locally used for refractories.

Metallic Minerals:- A few deposits of Zn-Pb-pyrite deposits are located in Kurdistan Region. Non of them is exploited. Some are associated with barite. Numerous showings of Cu, Cr-Ni, Mn-Fe and Fe are found in the igneous complexes of the Zagros Suture Zone of Kurdistan Region. All of them require more exploration work to show their economic potential.