Geology (II)

Second Year Students, Geology and Biology Class

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الرموز المستخدمة

🎞 فيديو للمشاهدة.

📖 نص للقراءة والدراسة.

🔗 رابط خارجي.

❓ أسئلة للتفكير والتقييم الذاتي.

📋 أنشطة ومهام.

🖥 تواصل عبر مؤتمر الفيديو.

Content

PART I: CRYSTALS & MINERALS

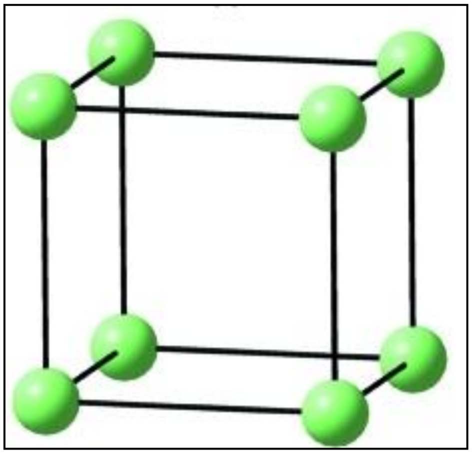
PART II: ROCKS

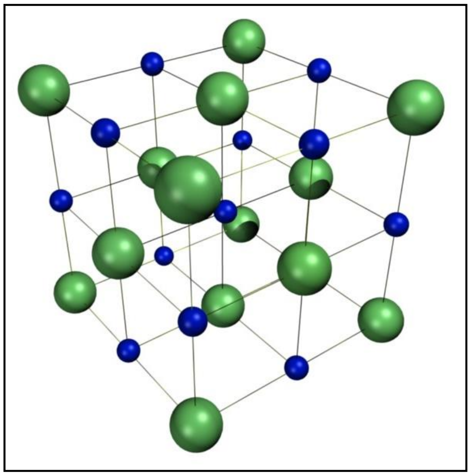
Introduction

- **Mineralogy** is the scientific study of minerals, comprising of crystallography, mineral chemistry, economic mineralogy, and determinative mineralogy (concerned mainly with physical properties).
- **MINERAL**: is a **naturally** occurring, **inorganic** solid with a characteristic chemical composition and a crystalline structure.
- An understanding of mineral structures and properties allows us to answer more immediate questions, such as why quartz and diamond are so hard, and why solid granite rock is destined to become soft, sticky clay.
- Minerals are **natural resources**, providing raw materials for many industries. Therefore, understanding minerals has geological as well as economic applications.

CRYSTALLOGRAPHY

- **Crystallography** is the study of crystals. It includes the study of crystal form, crustal structure and crystal symmetry.
- CRYSTALLOGRAPHY is a part of the entire study of mineralogy.
- Crystals are solids that form by a regular repeated pattern of molecules connecting together.
- In some solids, the arrangements of the building blocks (atoms and molecules) can be random or very different throughout the material.
- `In crystals, however, a collections of atoms called the Unit Cell is repeated in exactly the same arrangement over and over throughout the entire material.

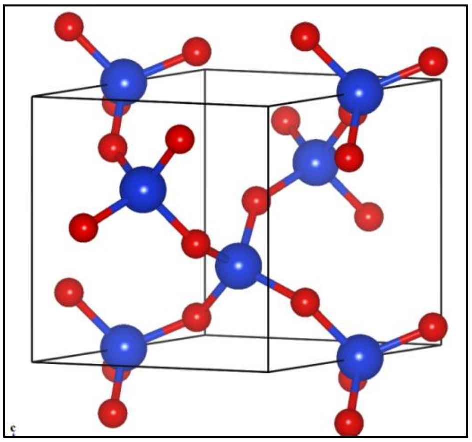




- Very slow cooling of a liquid allows atoms to arrange themselves into an ordered pattern, which may extend of a long range (millions of atoms). This kind of solid is called crystalline.

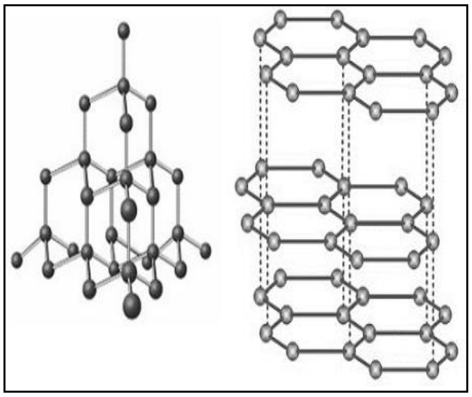
Why Crystallography in Geosciences?

- Most of the Earth is made of **solid rock**. The basic units from which rocks are made are **minerals**.
- There are well over 4,000 officially recognized mineral species and as many as a hundred new ones are described each year.
- The properties of rocks are ultimately determined by the properties of the constituent minerals.
- Many geological processes represent the culmination - on a very grand scale - of microscopic processes inside minerals.



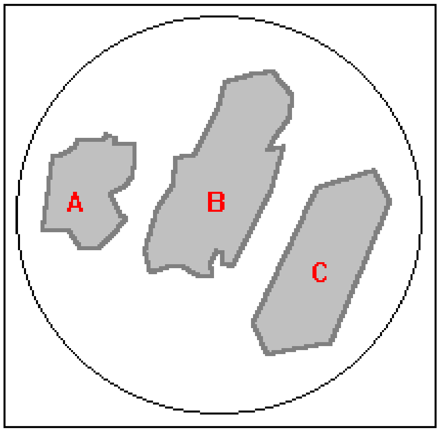
- For example, large-scale processes, such as rock formation, deformation, weathering and metamorphic activity, are controlled by small-scale processes.
- Movement of atoms (diffusion)
- Shearing of crystal lattices (dislocation movement)
- Growth of new crystals (nucleation, crystallization), and phase transformations.

Structural Properties of a Crystal



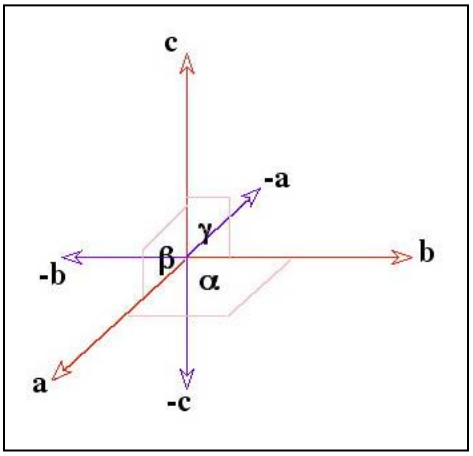
- All minerals are crystalline structures made from a mixture of different elemental compounds, and the shape of a crystal is based on the atomic structure of these elemental building blocks.
- Atoms within a mineral are arranged in an ordered geometric pattern called a "motif" which determines its "crystal structure. "
- A mineral's crystal structure will determine its symmetry, optical properties, cleavage planes, and overall geometric shape.
- A crystal's growth pattern is referred to as its "**Crystal Habit**."
- Shown here is the crystal structure of **Diamond** and **Graphite**.

Shapes of Crystals



- In rocks the shapes of crystalline grains/ crystals are often classified as **Euhedral**, **Anhedral** and **Subhedral**
- **Anhedral:** irregular; little or no evidence for its own growth faces (A)
- **Subhedral:** partly bound by its own growth faces, or growth faces only moderately well developed (B)
- **Euhedral**: grains bounded by its own perfect to near-perfect crystal growth faces (C)

Crystal Systems & Axial System



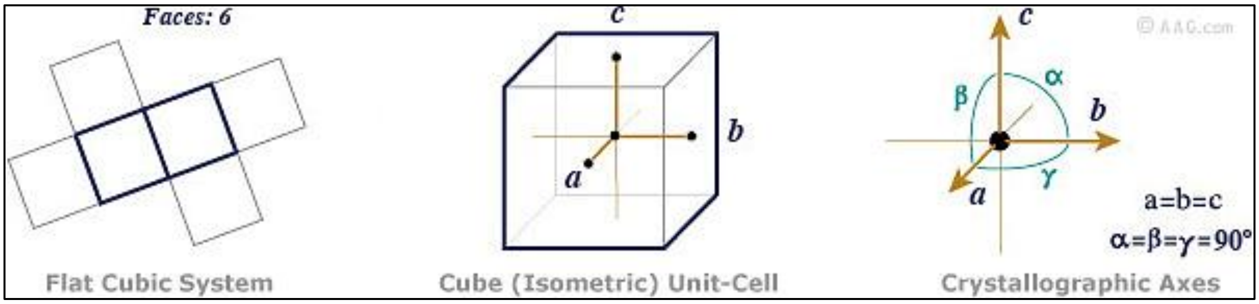
- Crystal system: grouping of crystal structures that are categorized according to the axial system used to describe their atomic "lattice" structure.
- A crystal's lattice is a three dimensional network of atoms that are arranged in a symmetrical pattern.
- Each crystal system consists of a set of three crystallographic axes (*a*, *b*, and *c*) in a particular geometrical arrangement.

The seven unique crystal systems, listed in order of decreasing symmetry, are:

1. Cubic System,
2. Hexagonal System,
3. Tetragonal System,
4. Trigonal System,
5. Orthorhombic System,
6. Monoclinic System,
7. Triclinic System.

Cubic Crystal System

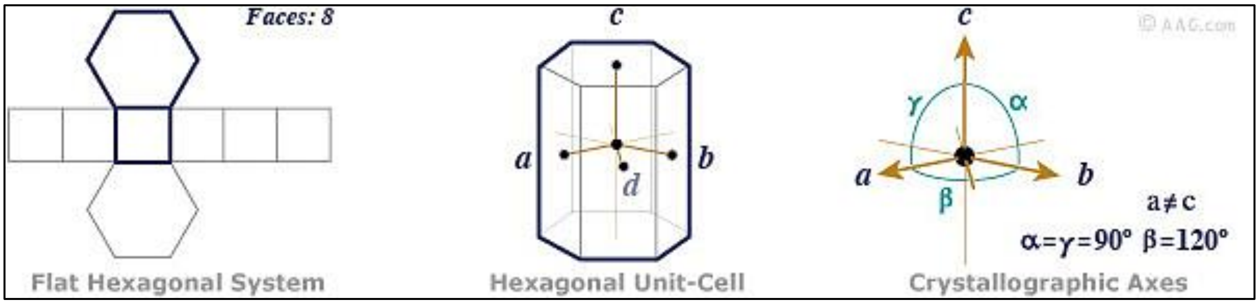
- This is also known as the isometric crystal system
- The cubic (Isometric) crystal system is characterized by its total symmetry.
- The Cubic system has three axes that are all perpendicular to each other, and equal in length and intersect at right angles (90 degrees) to each other.



Flat Cubic System   Cube (Isometric) Unit-Cell   Crystallographic Axes

The Hexagonal Crystal System

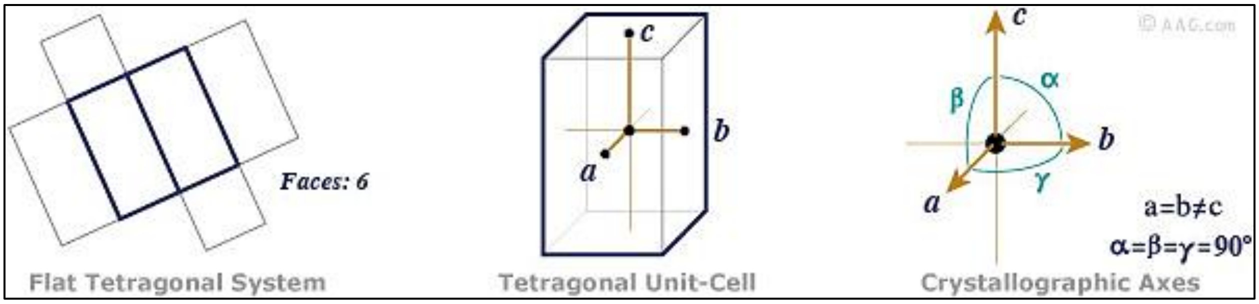
- Four crystallographic axes consisting of three equal horizontal or equatorial (a, b, and d) axes at **120°,** and one vertical (c) axis that is perpendicular to the other three.
- The **(c)** axis can be **shorter**, or **longer** than the horizontal axes.



Tetragonal Crystal System

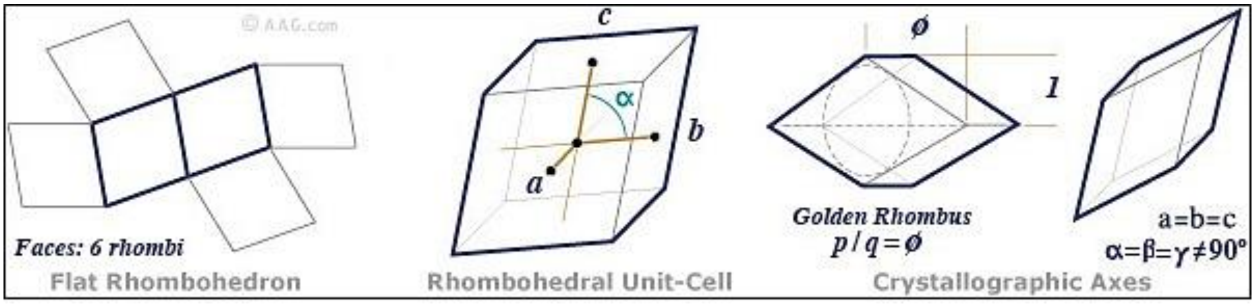
- A tetragonal crystal is a simple cubic shape that is stretched along its (c) axis to form a rectangular prism.
- The tetragonal crystal will have a square base and top, but a height which is taller.
- Three axes, all at right angles, two of which are equal in length (a and b) and one (c) which is different in length (Shorter or Longer).

Note: If c was equal in length to a or b, then we would be in the cubic system!



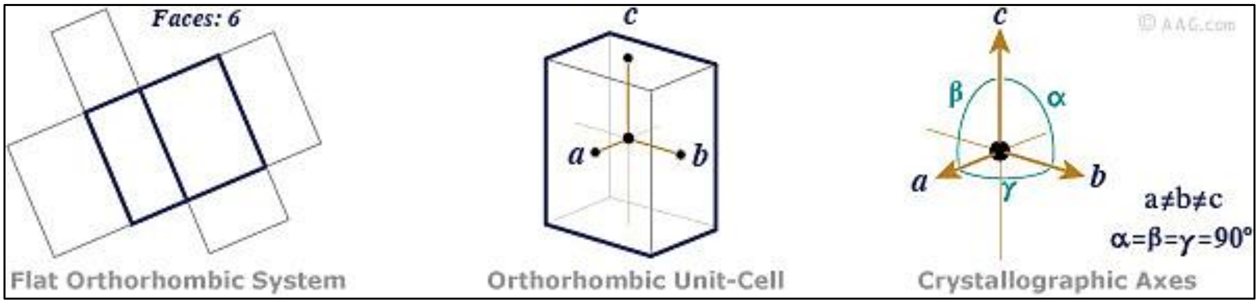
The Trigonal Crystal System

- A trigonal has a three-dimensional shape that is similar to a cube, but it has been skewed or inclined to one side making it oblique.
- A trigonal crystal has six faces, 12 edges, and 8 vertices.
- If all of the non-obtuse internal angles of the faces are equal, it can be called a trigonal-trapezohedron.



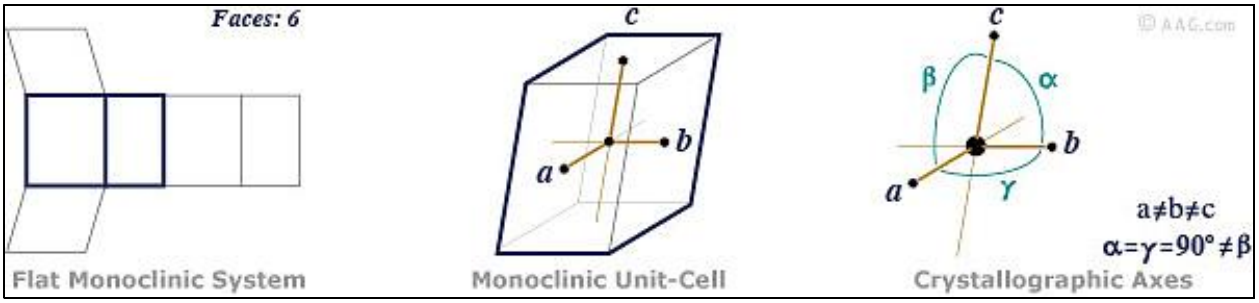
The Orthorhombic Crystal System

- Crystals have three mutually perpendicular axes, all with different, or unequal lengths.
- Is also known as Rhombic crystal system
- Three axes, all at right angles, and all three of different lengths.
- Note: If any axis was of equal length to any other, then we would be in the tetragonal system!



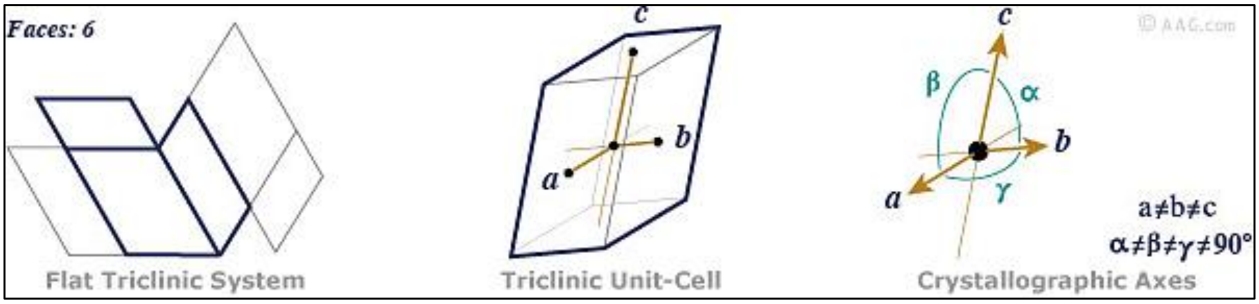
The Monoclinic Crystal System

- Crystals that form in the monoclinic system have three unequal axes.
- The (a) and (c) crystallographic axes are inclined toward each other at an oblique angle, and the (b) axis is perpendicular to a and c.
- The (b) crystallographic axis is called the "ortho" axis.
- Note: If a and c crossed at 90 degrees, then we would be in the orthorhombic system!

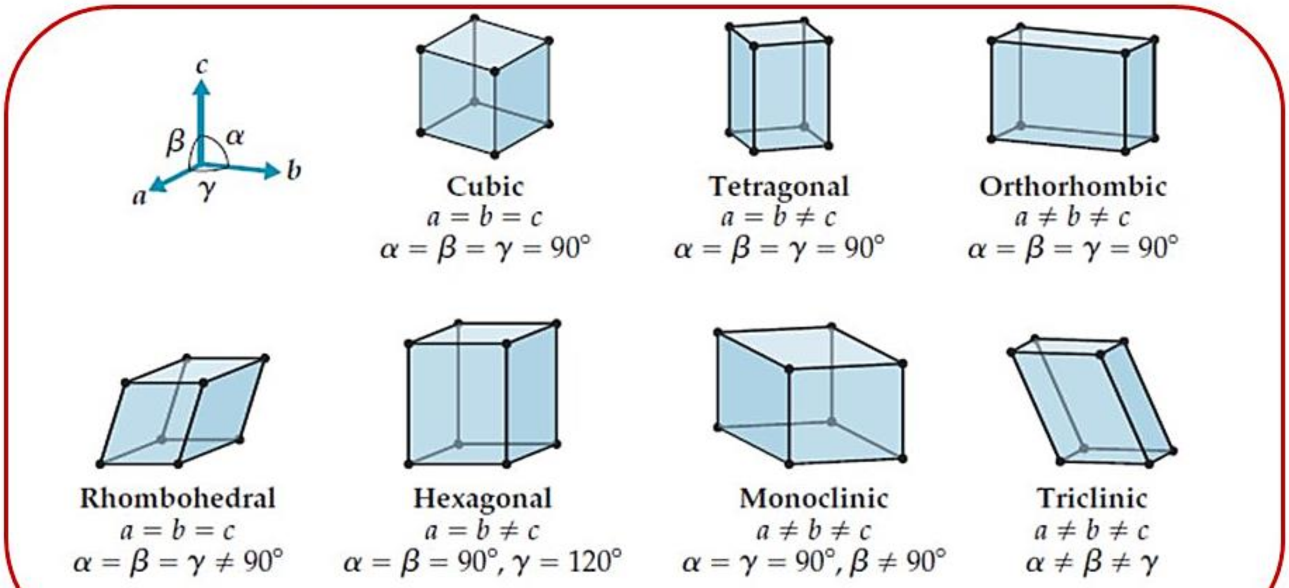


The Triclinic Crystal System

- Crystals have three unequal crystallographic axes, all of which intersect at oblique angles.
- Triclinic crystals have a 1-fold symmetry axis with virtually no discernible symmetry, and no mirrored or prismatic planes.
- Note: If any two axes crossed at 90 degrees, then we would be describing a monoclinic crystal!



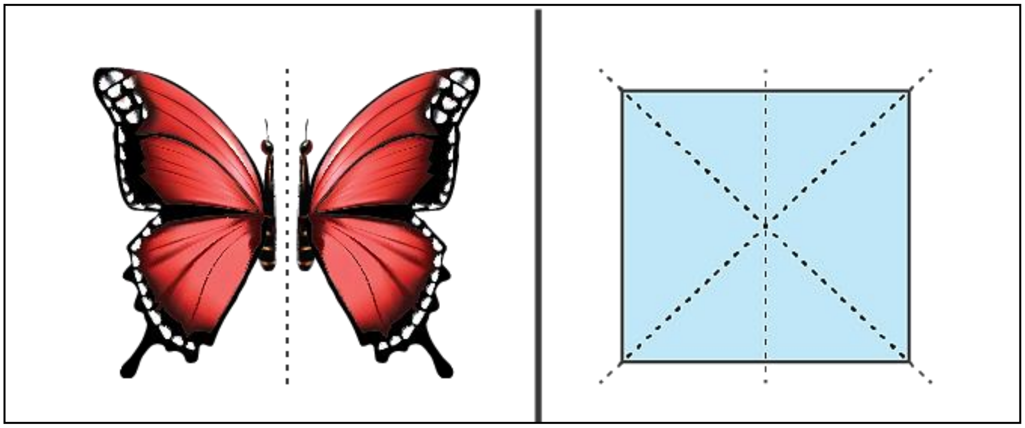
The 7 Crystal Systems: Summary



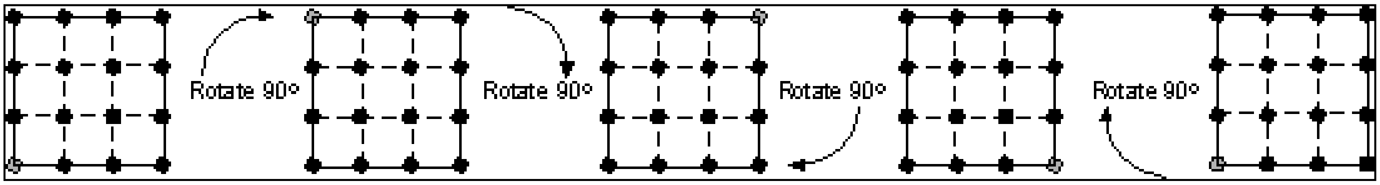
▲ FIGURE 12.6 The seven three-dimensional primitive lattices.

Crystal Symmetry

- Crystals, and therefore minerals, have an ordered internal arrangement of atoms.
- This ordered arrangement shows symmetry, i.e. the atoms are arranged in a symmetrical fashion on a three dimensional network referred to as a ***lattice***.
- A crystal is said to have a **symmetry** when one shape becomes exactly like another if you flip, slide or turn it.



- To see this, imagine a small 2 dimensional crystal composed of atoms in an ordered internal arrangement as shown below.
- Although all of the atoms in this lattice are the same, one of them is gray so that its position can be tracked.
- If we rotate the simple crystals by 90° notice that the lattice and crystal look exactly the same as what we started with.



- Rotate it another 90o and again its the same. Another 90o rotation again results in an identical crystal, and another 90o rotation returns the crystal to its original orientation.
- Thus, in 1 360o rotation, the crystal has repeated itself, or looks identical 4 times. We thus say that this object has 4-fold rotational symmetry.

There are four elements of symmetry for a crystal.

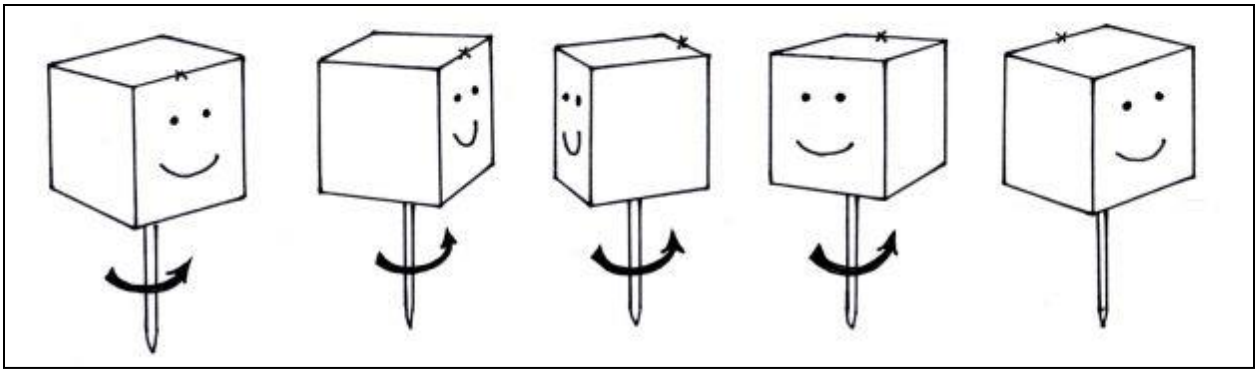
These include:

- *Axes of symmetry*
- *Plane of symmetry*
- *Center of symmetry*
- *Roto inversion*

These symmetry elements may be or may not be combined in the same crystal. Indeed, we will find that one crystal class or system has only one of these elements.

Axes of Symmetry/Rotational Symmetry

- If an object can be rotated about an axis and repeats itself every 90^o of rotation then it is said to have an axis of 4-fold rotational symmetry.
- The axis along which the rotation is performed is an element of symmetry referred to as a rotation axis.

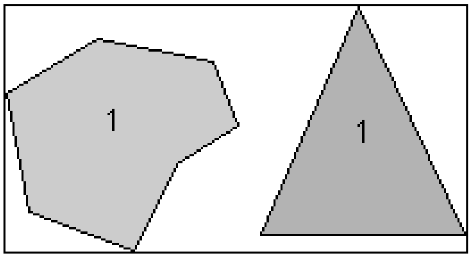


- When rotation repeats form every **60 degrees**, then we have six-fold or **HEXAGONAL SYMMETRY**. A filled hexagon symbol is noted on the rotational axis.
- When rotation repeats form every **90 degrees**, then we have fourfold or **TETRAGONAL SYMMETRY**. A filled square is noted on the rotational axis.
- When rotation repeats form every **120 degrees**, then we have threefold or **TRIGONAL SYMMETRY**. A filled equilateral triangle is noted on the rotational axis.
- When rotation repeats form every **180 degrees**, then we have twofold or **BINARY SYMMETRY**. A filled oval is noted on the rotational axis.
- When rotation repeats form every **360 degrees**, then we use a filled circle as notation. This is optional to list as almost any object has this symmetry. If you really want to know the truth, this means **NO SYMMETRY**!

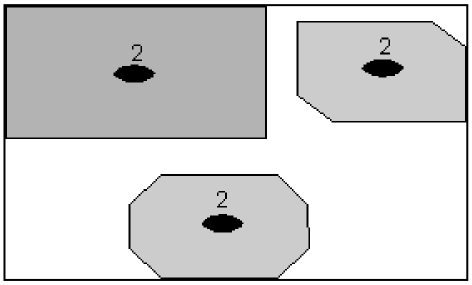
The following types of rotational symmetry axes are possible in crystals.

1-Fold Rotation Axis - An object that requires rotation of a full 360^{o} in order to restore it to its original appearance has no rotational symmetry.

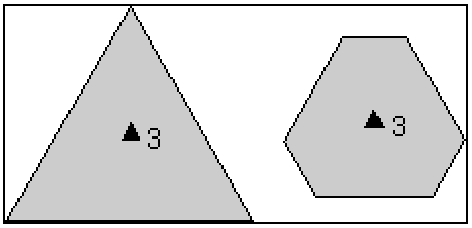
Since it repeats itself 1 time every 360^{o} it is said to have a 1-fold axis of rotational symmetry.

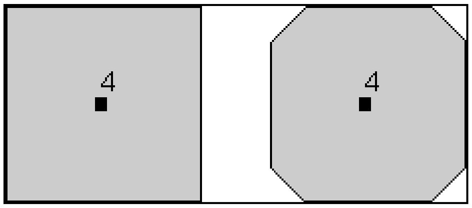


2-fold Rotation Axis - If an object appears identical after a rotation of 180^{o}, that is twice in a 360^{o}, then it is said to have a 2-fold rotation axis **(360/180 = 2).**



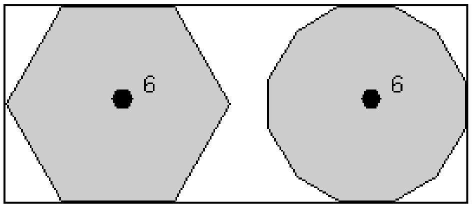
Note that in these examples the axes we are referring to are **imaginary lines** that extend toward you perpendicular to the page or blackboard. A filled **oval shape** represents the point where the 2-fold rotation axis intersects the page.





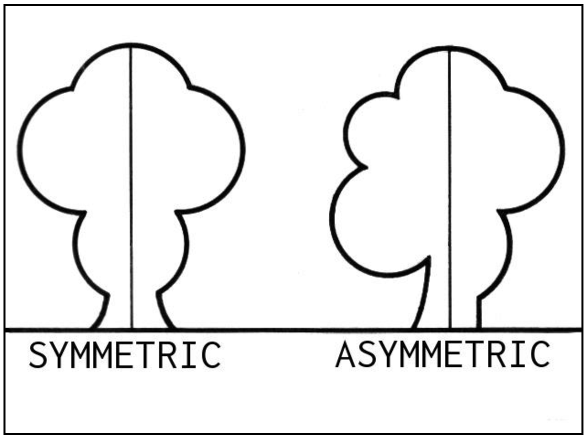
3-Fold Rotation Axis- Objects that repeat themselves upon rotation of 120^{o} are said to have a 3-fold axis of rotational symmetry **(360/120 =3)** and they will repeat 3 times in a 360^{o} rotation. A **filled triangle** is used to symbolize the location of 3-fold rotation axis.

4-Fold Rotation Axis - If an object repeats itself after 90^{o} of rotation, it will repeat 4 times in a 360^{o} rotation, as illustrated previously. A **filled** square is used to symbolize the location of 4-fold axis of rotational symmetry.



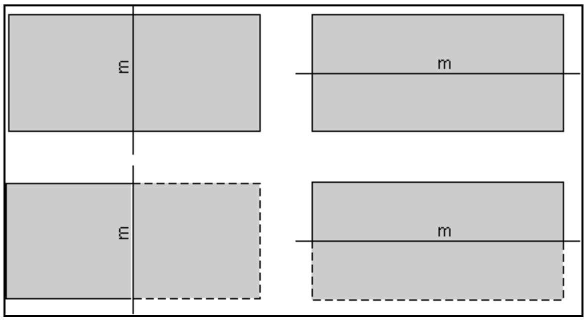
6-Fold Rotation Axis - If rotation of 60^{o} about an axis causes the object to repeat itself, then it has 6-fold axis of rotational symmetry **(360/60=6).** A filled **hexagon** is used as the symbol for a 6-fold rotation axis.

Plane of Symmetry/Reflection Symmetry/ Mirror Symmetry

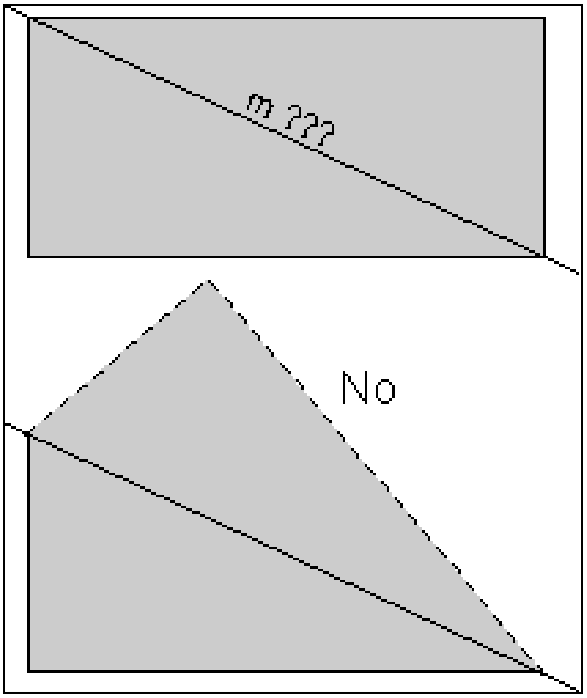


- Any two dimensional surface that, when passed through the center of the crystal, divides it into two symmetrical parts that are **MIRROR IMAGES** is a **PLANE OF SYMMETRY**.
- A **mirror symmetry** operation is an imaginary operation that can be performed to reproduce an object.
- The operation is done by imagining that you cut the object in half, then place a mirror next to one of the halves of the object along the cut.
- If the reflection in the mirror reproduces the other half of the object, then the object is said to have mirror symmetry.
- The plane of the mirror is an element of symmetry referred to as a ***mirror plane***, and is symbolized with the letter **m**.

- As an example, the human body is an object that approximates mirror symmetry,

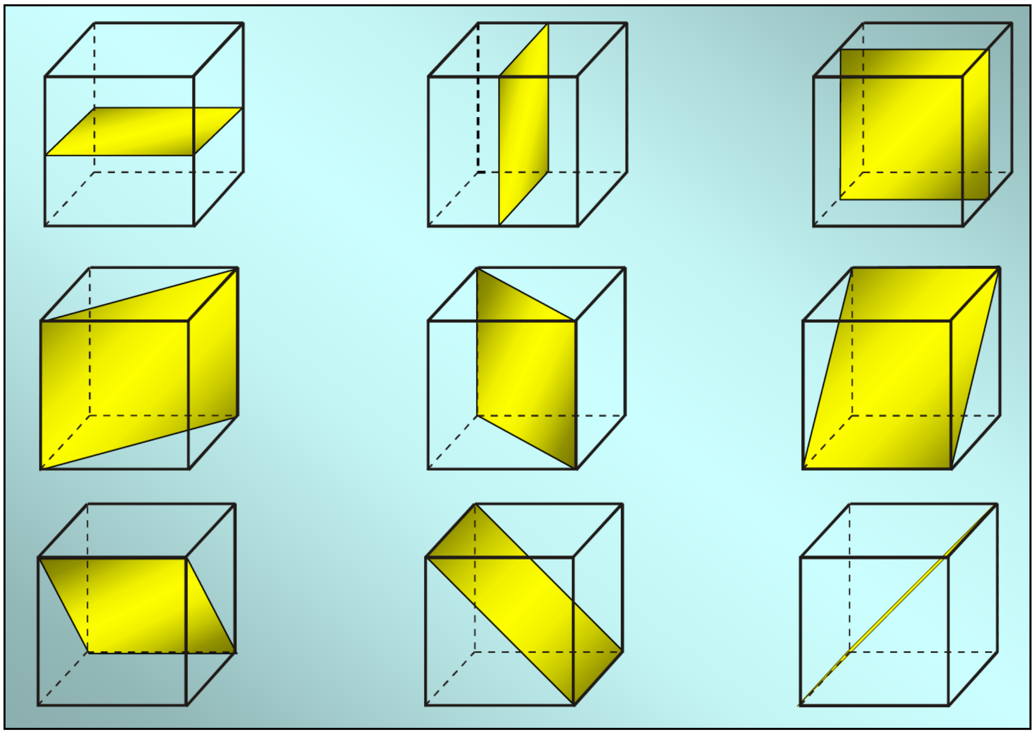


- The rectangles shown here have two planes of mirror symmetry.
- The rectangle on the left has a mirror plane that runs vertically on the page and is perpendicular to the page.
- The rectangle on the right has a mirror plane that runs horizontally and is perpendicular to the page.
- The dashed parts of the rectangles below show the part the rectangles that would be seen as a reflection in the mirror
- The rectangles shown above have two planes of mirror symmetry.



- Three dimensional and more complex objects could have more. For example, the hexagon, not only has a 6-fold rotation axis, but has 6 mirror planes.
- Note that a rectangle does not have mirror symmetry along the diagonal lines. If we cut the rectangle along a diagonal such as that labeled "m ???", as shown in the upper diagram, reflected the lower half in the mirror, then we would see what is shown by the dashed lines in lower diagram.
- Since this does not reproduce the original rectangle, the line "m???" does not represent a mirror plane.

Plane of Symmetry for the crystals in cubic system



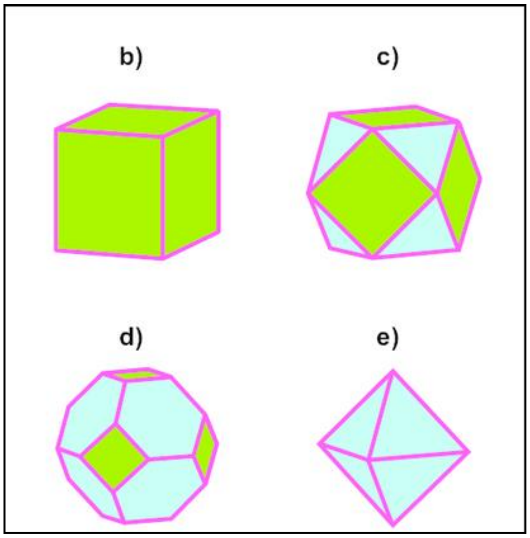
Crystal Forms

A crystal form is a set of crystal faces that are related to each other by symmetry or any group of crystal faces related by the same symmetry is called a form.

- There are 48 possible forms that can be developed as the result of the 32 combinations of symmetry.

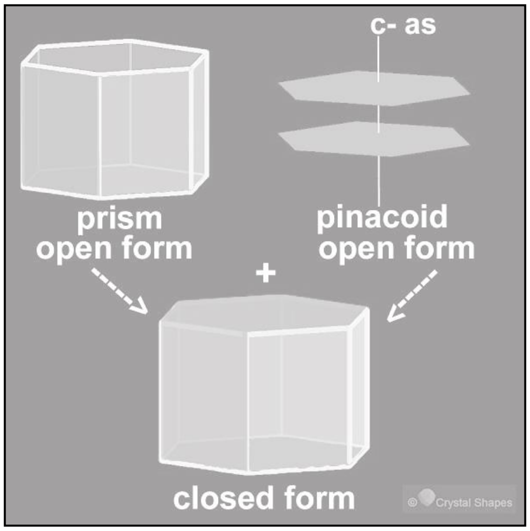
Closed forms are those groups of faces all related by symmetry that completely enclose a volume of space.

- It is possible for a crystal to have faces entirely of one closed form.



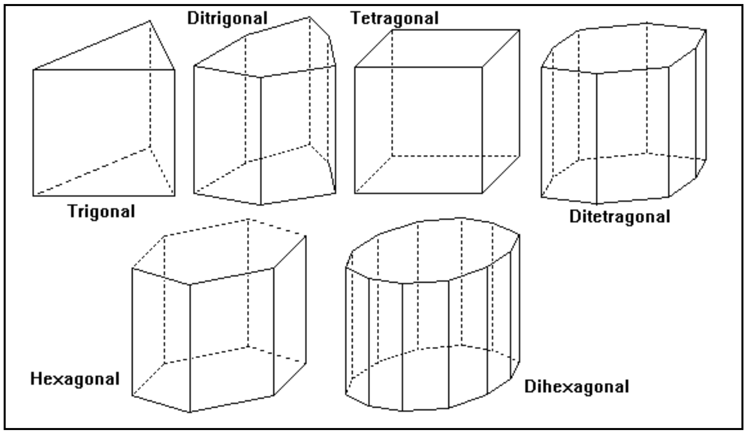
Open forms are those groups of faces all related by symmetry that do not completely enclose a volume of space.

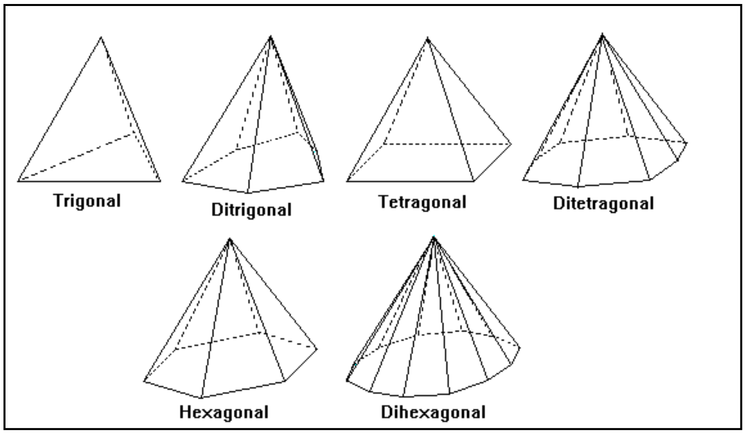
- A crystal with open form faces requires additional faces as well.
- There are 18 open forms and 30 closed forms.



Prism: A prism is composed of a set of 3, 4, 6, 8, or 12 geometrically equivalent faces which are all parallel to the same axis.

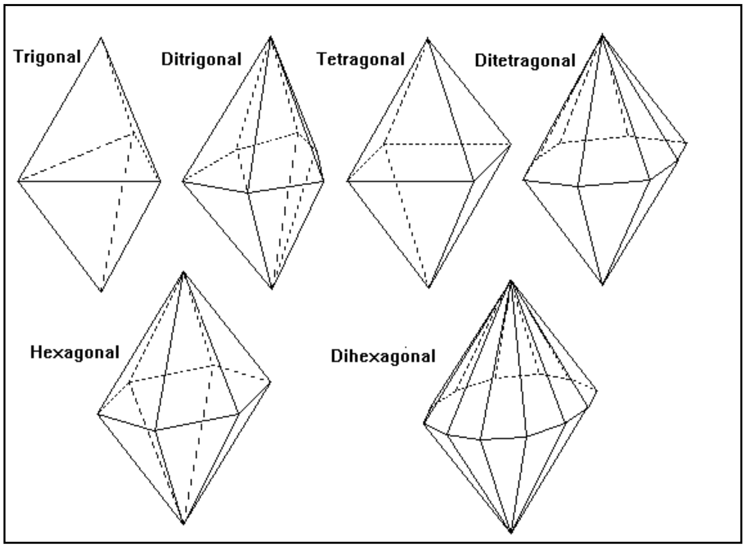
- Each of these faces intersects with the two faces adjacent to it to produce a set of parallel edges.
- Variants of the prism form include the rhombic prism, tetragonal prism, trigonal prism, and hexagonal prism.
- These are open crystal forms.





Pyramid: A pyramid is composed of a set of 3, 4, 6, 8, or 12 faces which are not parallel but instead intersect at a point.

- The orthorhombic, tetragonal and hexagonal crystal systems all produce pyramids.
- Variants of the pyramid include rhombic pyramid, tetragonal pyramid, trigonal pyramid, and hexagonal pyramid.
- These are open crystal forms.



Dipyramid: The pyramidal crystal form is composed of two pyramids placed base-to-base and related by reflection across a mirror plane which runs parallel to and adjacent to the pyramid bases.

- The upper and lower pyramids may each have 3, 4, 6, 8, or 12 faces; the dipyramidal form therefore possesses a total of 6, 8, 12, 16, or 24 faces.
- The orthorhombic, tetragonal and hexagonal crystal systems all produce dipyramids.
- They can be called as rhombic dipyramid, trigonal dipyramid, tetragonal dipyramid, and hexagonal dipyramid.
- They are closed crystal forms.

Trapezohedron: A trapezohedron is a crystal form possessing 6, 8, or 12 trapezoidal faces.

- The tetragonal crystal system, the trigonal and hexagonal crystal system produce trapezohedral crystal forms.
- Trigonal trapezohedra possess three trapezoidal faces on the top and three on the bottom for a total of six faces;
- Tetragonal trapezohedra have four faces on top and four on the bottom for a total of eight faces; and hexagonal trapezohedra have six faces on top and six on the bottom, resulting in twelve faces total.
- They are closed crystal forms.

Rhombohedron: The rhombohedral crystal form possesses six rhombus-shaped faces.

- The rhombohedral crystal form is produced only by members of the trigonal /rhombohedral crystal system.
- They are closed crystal forms.
- **Tetrahedron**: A tetrahedron is composed of four triangular faces.
- The tetrahedron crystal form is produced by the members of the isometric crystal system.
- They are closed crystal forms.

MINERALS

Crustal abundance of elements

Oxygen	**47%**
Silicon	27%
Aluminum	8 %
Iron	5%
Calcium	3.6%
Sodium	2.8%
Potassium	2.6 %
Magnesium	2 %
all other elements	1 %

- Earth resources include thousands of minerals.
- Minerals which have commercial and industrial importance.
- The Earth’s crust is dominated by eight abundant chemical elements.
- Silicon and oxygen are the two most abundant elements present in the earth’s crust.
- Other elements, are aluminum, iron, calcium, sodium, potassium, magnesium, hydrogen, phosphorous, barium, and strontium.
- Note: Metals like copper, lead, zinc, nickel, and tin which play an important role in modern technology, are present only in very small proportions.
- The most abundant minerals in the earth's crust are the silicates.
- Non-silicates constitute less than 10% of the Earth's crust.
- The most common non-silicates are the carbonates, the oxides, and the sulfides.
- There are also naturallyoccurring phosphates and salts.
- Every mineral can be identified by several of its physical properties and crystal chemistry.
- There are nearly 3700 minerals occurring on the earth, out of which about 24 are common, making up to 90% of the mineral constituents in the earth’s crust.
- Minerals may be composed of a single element, like gold (Au) or a combination of elements.
- Minerals which are composed of more than one element are bound together by chemical bonding.

- All minerals formed by more than one element are bound together by positive and negative ions.

The main classes are:

- Elements, Oxides, Halides, Sulfides, Carbonates, Phosphates, and Silicates.
- There are many subclasses still based on composition.

Chemical classification of minerals

The chemical classification of minerals divides them into the following ten classes:

- Native elements, Native metals and Alloys, Carbides, Silicides, Nitrides & Phosphides.
- Sulfides, Sulfosalts, Sulfarsenates & Sulfantimonates
- Halogenides, Oxyhalides & Hydroxyhalides.
- Oxides and Hydroxides, Antimonites, Iodates
- Carbonates and Nitrates
- Borates
- Sulfates, Selenates, Chromates
- Phosphates
- Silicates
- Organic Compounds.

Native Metals and Alloys

The native metals include the following:

Aluminum	Al
Cadmium	Cd
Chromium	Cr
Copper	CU
Gold	Au
Indium	In
Iridium	Ir

Some **20 elements** occur in nature in a pure or nearly pure form known as the **native elements**, they are three families: metals, semimetals, and nonmetals.

The native metals make up three groups:

- **The gold group**, consisting of gold, silver, copper, and lead;
- **The platinum group**, composed of platinum, palladium, iridium, and osmium
- **The iron group**, containing iron and nickel-iron.

Native Non-metals and Semi-metals

The Native Non-metals and Semi-metals include the following:

- Antimony (Sb)
- Arsenic (As)
- Bismuth (Bi)
- Diamond (C)
- Graphite (C)
- Selenium (Se)
- Silicon (Si)
- Sulfur (S)
- Tellurium (Te)

Sulfide class

- The sulfide class includes four categories of minerals as Sulfides, Sulfosalts, Sulfarsenates and Sulfantimonates.
- Compounds of one or more metallic elements combined with the non-metallic element Sulfur.
- The Sulfides are economically important.
- Most major ores of important metals such as copper, lead and silver are all occurring as sulfide minerals in nature.

- **Galena (PbS)** is a common sulfide mineral, it is the ore mineral of lead.
- **Pyrite ($FeS2$) is a** common sulfide
- **Sphalerite (ZnS),** each zinc atom is surrounded by four sulfur atoms.
- **Chalcopyrite ($CuFeS2$)** copper and iron ions can be thought of as having been regularly substituted in the zinc positions of the original sphalerite atomic arrangement.

Halogenides, Oxyhalides & Hydroxyhalides

- The Halides are a group of minerals whose principle anions are halogens.
- Very soft and easily dissolved in water.
- Halite and Fluorite are the well-known examples of this group.
- The halogens that are found commonly in nature include Chlorine, Bromine, Iodine and Fluorine

Fluorite

This group of minerals includes:

- Anhydrous Chlorides, Bromides, Iodides, and Fluorides.
- Oxychlorides and Oxyfluorides
- Hydrous Chlorides and Hydrous Fluorides.
- The common minerals of Anhydrous Halides include Calomel – (horn quicksilver) - which is Mercurous Chloride.

Calomel

Oxides and Hydroxides

Oxides and Hydroxides include awide variety of minerals.

- It bonds with a number of metallic ions to form the oxides.
- These oxides form important ores for the metal resources.
- Most of the **industrial minerals belong to this group**.
- Important minerals of the Oxide Group are the following:
    - Oxides of Silicon
    - Oxides of semi-metals
    - Oxides of metals and
    - Intermediate oxides.

Oxides of Silicon

- Quartz is one the major mineral group present in almost all rocks of the earth due to its abundance.

The major minerals are:

- **Quartz** minerals contains SiO2 as their composition.
- **Tridymite** which is also a pure silica
- **Opal** which is a gem mineral containing Hydrous Silicate
- And **Amethyst** which is a Purple quartz.

Oxides of Semi-metals

Oxides of semi-metals include minerals like:

- **Arsenolite** containing Arsenic Trioxide **(As_2O_3)**
- **Valentinite** containing antimony trioxide **(Sb_2O_3)**
- **Tungstite** containing Tungsten trioxide **(WO_3)**

Oxides of metals

The oxide mineral class includes minerals in which the oxide anion (O^{2-}) is bonded to one or more metal ions.

- **Cuprite** is an oxide mineral composed of copper oxide **Cu_2O**, and is a minor ore of copper.

Two other groups belong to the oxides of metals.

- They are **Periclase Group (MgO)** and **Hematite Group (Fe_2O_3).**

Cuprite

Periclase

Hematite

Periclase Group

The minerals of these groups are as follows:

- **Periclase** containing Magnesia
- **Manganosite** containing Manganese protoxide
- **Zincite** containing Zinc Oxide.

Hematite Group

- **Corundum** containing Al_2O_3
- **Hematite** containing Fe_2O_3 and
- **Ilmenite** containing $(Fe, Mg) O. TiO_2$.
- **Corundum** is one of the dominant Aluminum Oxide. It is the second hardest natural mineral known to science.

Intermediate oxides

The intermediate oxides comprise of three mineral groups.

- **Spinel** group, **Rutile** group and **Hydrous** oxides.

Spinel group is comprised of:

- **Aluminum Spinel** called as **Spinel**
- **Iron Spinel** which forms a group including **Magnetite, Jacobsite,** and **Franklinite**
- **Chromium Spinel** forming **Chromite**

Rutile group is comprised of

- **Cassiterite** (SnO_2)
- **Rutile** (TiO_2)
- **Pyrolusite** which is a Manganese dioxide.

Hydrous oxides group comprised of:

- **Limonite**, **Bauxite**, and **Gibbsite**.

Limonite

Gibbsite

Rutile

Carbonates and Nitrates

- Carbonates and nitrates are very separate classes of minerals.
- The carbonate ion can bond with a variety of other ions to produce the carbonate minerals.
- The bonding with calcium to form the mineral calcite produces one of the most abundant of the non-silicate minerals.
- All carbonates have the property of dissolving easily in acidic water.
- Carbonates are further classified into two major classes as anhydrous Carbonates and Basic-hydrous carbonates.
- The Anhydrous Carbonates includes two groups as Calcite Group and Aragonite Group of Minerals.

Calcite Group

The calcite group includes important minerals:

- **Calcite** which consists of Calcium carbonate.
- **Dolomite** - Calcium Magnesium Carbonate.
- **Ankerite-** Calcium Magnesium Iron Carbonate.
- **Magnesite-** Magnesium Carbonate.
- **Siderite:** consists of Iron Carbonate
- **Rhodochrosite:** consists of Manganse Carbonate
- **Spaerocobaltite:** consists of Cobalt Carbonate.
- **Smithsonite:** consists of Zinc Carbonate

Aragonite Group

The aragonite group includes the following minerals:

- **Aragonite** - consists of Calcium carbonate.
- **Bromlite** - consists of Calcium Barium Carbonate.
- **Strontianite** - consists of Strontium Carbonate.
- **Cerussite** - consists of Lead Carbonate.

Basic and Hydrous carbonate

Basic and hydrous carbonates include minerals as:

- **Malachite** - consists of Basic cupric hydrous carbonate
- **Azurite** - consists of Basic cupric hydrous carbonate.

Sulfates

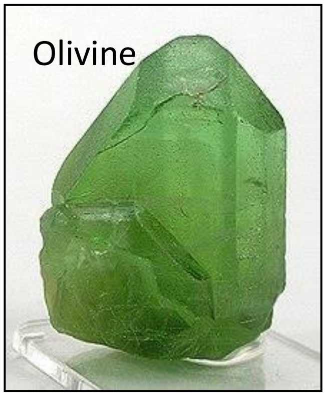
- The Sulfates are an important mineral class and include some very interesting and attractive specimens.
- Although many minerals belong to this class, only **barite, gypsum, Celestite, and anhydrite can be considered common**.

Silicates

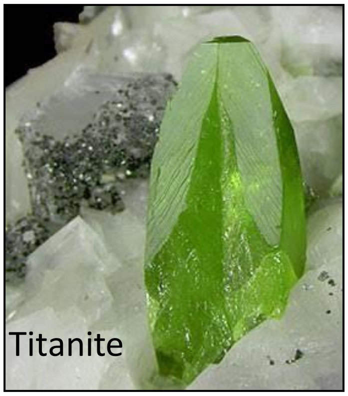
- The class of silicate includes a vast number of minerals.
- **Silicates** are the largest, and the most complicated classes of minerals.
- **Approximately, 30%** of all minerals present on the earth are silicates.
- Some geologists estimate that **about 90% of the Earth's crust is made up of mainly silicates.**
- The abundance of silicates is **because Oxygen and silicon are the two most abundant elements** in the earth's crust.
- The basic chemical unit of silicates is the **SiO_4** tetrahedron.

The major groups of minerals are

- **Olivine** group,
- **Garnet** group
- **Zircon** group,
- **Alumino-silicate** group
- **Humite** group,
- **Titanite** and
- **Chloritoid** group of minerals.


Olivine


Garnet


Titanite


Zircon

Physical Properties of Minerals

Introduction

Minerals differ from each other in chemical composition and architecture, and these factors produce distinctive physical properties that enable minerals to be identified.

What Is A Mineral?

A mineral satisfies all four of the following criteria:

- It is a naturally occurring substance;
- It is an inorganic substance;
- It has an orderly internal structure, and;
- It has a fixed, (or uniformly variable) chemical composition.

That they are naturally occurring and inorganic separates minerals from most manufactured substances as well as materials formed only in biological processes. Their internal structure and chemical composition gives minerals characteristic physical and chemical properties that provide clues to the identity of the minerals.

- Most minerals form by inorganic processes but some, identical in all respects to inorganically formed minerals, are produced by organic processes (for example, the calcium carbonate in the shells of clams or snails).
- A few naturally occurring substances called mineraloids have characteristic chemical compositions but are amorphous. Opal is an example.

In most cases, general appearance and a few easily determined physical properties are sufficient to identify the mineral.

Color, luster, streak, hardness, cleavage, fracture, and crystal form are the most useful physical properties for identifying most minerals. Other properties-such as reaction with acid, magnetism, specific gravity, tenacity, taste, odor, feel, and presence of striations-are helpful in identifying certain minerals.

Luster

Luster describes the appearance of a mineral when light is reflected from its surface. Is it shiny or dull: does it look like a metal or like glass? Generally the first thing you notice when identifying an unknown sample is the mineral's luster. Important examples of mineral luster are shown below.

Examples of mineral luster, clockwise from top left: Metallic (galena); Metallic (pyrite); Vitreous (quartz); Waxy (chalcedony); Pearly (talc); and Earthy (goethite).

- Minerals with a metallic luster look like a metal, such as steel or copper. They are both shiny and opaque, even when looking at a thin edge.
- Many metallic minerals become dull or earthy when they are exposed to the elements for a long time (like silver, they tarnish).
- To determine whether or not a mineral has a metallic luster, you must look at a recently broken part of the mineral.
- Minerals with an earthy luster look like earth, or dirt. Like metallic minerals these are completely opaque, but dull. Again, think of rust on iron or tarnish that forms on precious metals.

Types: Any mineral will have either a *metallic* or a *non-metallic* luster. If the mineral reflects light very well, the luster is considered metallic (e.g. Galena, PbS). Non-metallic lusters result when some of the light rays pass through (or are absorbed by) the mineral. Several kinds can be identified:

- Adamantine: e.g. diamond
- Vitreous: glassy (e.g. quartz)
- Resinous: e.g. sphalerite
- Greasy
- Pearly
- Silky: e.g. asbestos
- Dull or earthy: e.g. Kaolinite.

Vitreous luster is like that of glass, shiny and translucent to transparent. Remember that glass can be almost any color, including black, so don't be fooled by the color. Also, a dark piece of glass may appear to be opaque if it is thick enough. If you hold a thin edge up to the light you should be able to see light bleeding through.

- Minerals with a waxy luster look like paraffin, typically translucent but dull.
- Minerals with pearly luster have an appearance similar to a pearl– translucent and shiny but with a bit of light refraction, producing a rainbow effect on the surface (similar to an oil slick).

Color

Color is one of the most obvious properties of a mineral but it is often of limited diagnostic value, especially in minerals that are not opaque. While many metallic and earthy minerals have distinctive colors, translucent or transparent minerals can vary widely in color.

- Quartz, can vary from colorless to white to yellow to gray to pink to purple to black Colors of some minerals, such as biotite (black) and olivine (olive green) can be distinctive.
- Never use color as a final diagnostic property -- check other properties before making an identification.

Quartz varies in color

Streak

- Streak refers to the color of the mineral in its powdered form.
- May or may not be the same color as the mineral.
- Streak is helpful for identifying minerals with metallic or earthy luster, because minerals with nonmetallic luster generally have a colorless or white streak
- Streak is obtained by scratching the mineral on an unpolished piece of white porcelain called a streak plate.
- Because the streak plate is harder than most minerals, rubbing the mineral across the plate produces a powder of that mineral.
- When the excess powder is blown away, what remains is the color of the streak.
- Because the streak of a mineral is usually the same, no matter what the color of the mineral, streak is commonly more reliable than color for identification.

Hardness

Hardness is the resistance of a mineral to scratching or abrasion by other materials. Hardness is determined by scratching the surface of the sample with another mineral or material of known hardness. The standard hardness scale, called Mohs Hardness Scale, consists of ten minerals ranked in ascending order of hardness with diamond, the hardest known substance, assigned the number 10. The hardness kits we use in class contain only minerals 2-7, as these are the most useful for testing most of the minerals we will encounter in this class. Since most of us don’t wander the outdoors with a pocketful of standard minerals table one also lists the relative hardness of other common items.

Relative hardness

Mohs scale of Hardness   Common objects (hardness)

1.	Talc		
2.	Gypsum	Fingernail	(2.5)
3.	Calcite	Copper penny	(3-3.5)
4.	Fluorite		
5.	Apatite	Glass	(5.5)
6.	Feldspar	Steel nail or knife blade	(6-6.5)
7.	Quartz		
8.	Topaz		
9.	Corundum		
10.	Diamond		

To determine hardness, run a sharp edge or a point of a mineral with known hardness across a smooth face of the mineral to be tested. Do not scratch back and forth like an eraser, but press hard and slowly scratch a line, like you are trying to etch a groove in glass. Sometimes powder of the softer mineral is left on the harder mineral and gives the appearance of a scratch on the harder one. Brush the tested surface with your finger to see if a groove or scratch remains.

A piece of glass is provided in the hardness kits as a standard for determining hardness. There are several reasons for this:

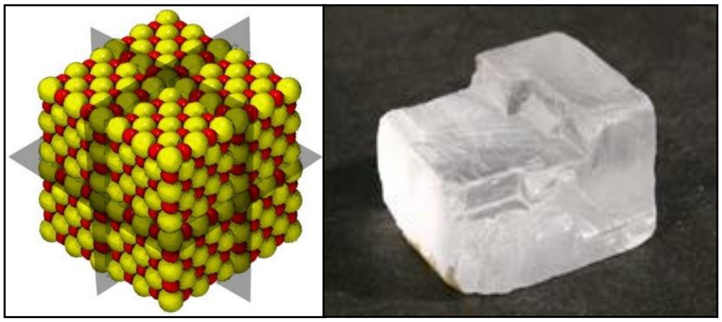
- It is easy to see a scratch on glass;
- The hardness of glass (5 to 5½) is midway on the Mohs scale; and
- Glass is inexpensive and easily replaced.

The Mohs scale was developed by Friedrich Mohs in 1822 as a diagnostic tool.

Cleavage and Fracture

The way in which a mineral breaks is determined by the arrangement of its atoms and the strength of the chemical bonds holding them together.

- A mineral that exhibits cleavage consistently breaks, or cleaves, along parallel flat surfaces called cleavage planes.
- A mineral fractures if it breaks along random, irregular surfaces.
- Some minerals break only by fracturing, others both cleave and fracture.



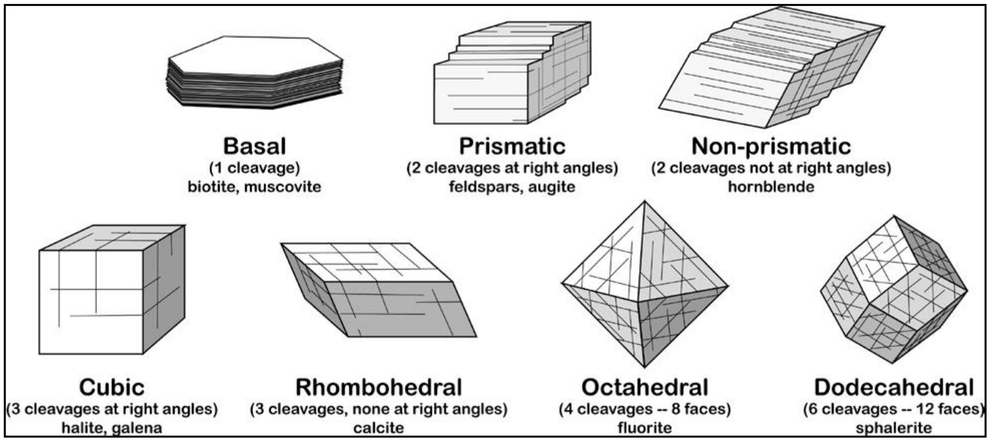
The illustration shows that atoms of sodium (red) and chlorine (yellow) in the mineral halite are parallel to three planes that intersect at 90°.

Halite breaks, or cleaves, most easily between the three planes of atoms, so it has three directions of cleavage that intersect at 90°.

The mineral halite (NaCl, or sodium chloride) illustrates how atomic arrangement determines the way a mineral breaks.

Because there are three directions in which atom density is equal, halite has three directions of cleavage, each at 90° to each other.

The number of cleavage directions and the angles between them are important in mineral identification because they reflect the underlying atomic architecture that defines each mineral.



Types of cleavage common in minerals with examples of minerals.

Cleavage quality is described as perfect, good, and poor.

- Minerals with a perfect or excellent cleavage break easily along flat surfaces and are easy to spot.
- Minerals with good cleavages do not have such well-defined cleavage planes and reflect less light.
- Poor- cleavages are the toughest to recognize, but can be spotted by small flashes of light in certain positions.

Minerals have characteristic numbers of cleavages (Figure 8). This number is determined by counting the number of cleavage surfaces that are not parallel to each other. For example, the mineral in Figure 9 has two planes of cleavage, one that is visible and one lying on the table. However, each of these cleavage surfaces is parallel to the other, so this mineral is said to have only one cleavage direction. Minerals with one cleavage are often said to have a basal cleavage.

Some minerals have three planes of cleavage:

- If the three cleavages intersect at 90° the mineral is said to have cubic cleavage.
- If none of the cleavage planes intersect at right angles the shape is a squashed cube known as a rhombohedron (called rhombohedral cleavage).
- Minerals with four or six cleavage directions are not common.
- Four cleavage planes can intersect to form an eight sided figure known as an octahedron.
- Fluorite is the most common mineral with an octahedral cleavage.
- Six cleavage directions intersect to form a dodecahedron, a twelve-sided form with diamond-shaped faces.
- A common mineral with dodecahedal cleavage is sphalerite.

Fracture

Describes the appearance of all surfaces of breakage of a mineral other than planes of cleavage or parting.

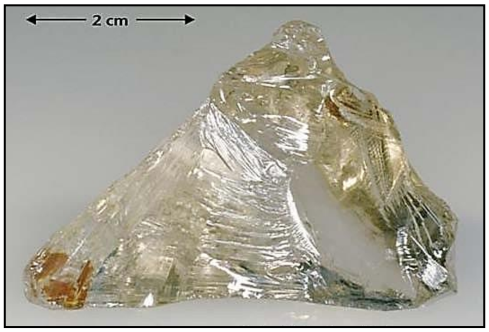
Types:

- Conchoidal: characterized by smooth curved surfaces (e.g. quartz).
- Splintery: when the mineral breaks into small, thin, slightly elongated pieces.
- Hackly: a very irregular, sharp edged surface
- Uneven: or earthy: an uneven surface with many small irregularities.

Fracture surfaces can cut a mineral grain in any direction.

Fractures are generally rough or irregular, rather than flat, and thus appear duller than cleavage surfaces.

Some minerals fracture in a way that helps to identify them.



- For example, **quartz** has no cleavage but, like glass, it breaks along numerous small, smooth, curved surfaces called conchoidal fractures.
- In the field you will often have to break samples into pieces to observe cleavages and fractures on fresh surfaces.

Additional Properties

Special properties help identify some minerals. These properties may not be distinctive enough in most minerals to help with their identification. or they may be present only in certain minerals.

Magnetism

Some minerals are attracted to a hand magnet.

Magnetite is the only common mineral that is always strongly magnetic.

Reaction with Acid

Some minerals, especially carbonate minerals (calcite), react visibly with acid.

When a drop of dilute hydrochloric acid is placed on calcite, it readily bubbles or effervesces, releasing carbon dioxide.

Specific Gravity

The specific gravity of a mineral is the weight of that mineral divided by the weight of an equal volume of water.

The specific gravity of water equals 1.0, by definition.

Most silicate, or rock-forming, minerals have specific gravities of 2.6 to 3.4; the ore minerals are usually heavier, with specific gravities of 5 to 8.

If you compare similar- sized samples of two different minerals, the one with the higher specific gravity will feel the heaviest; it has a greater heft.

High specific gravity is distinctive (examples are **barite** and **galena**).

Taste, Odor, Feel

Some minerals have a distinctive taste (halite is salt, and tastes like it).

Some have a distinctive odor (the powder of some sulfide minerals, such as sphalerite, a zinc sulfide, smells like rotten eggs), and some a distinctive feel (talc feels slippery).

ROCKS

ROCKS

Naturally-occurring mixtures of minerals, mineraloids, glass or organic matter.

Rocks are divided into 3 groups based on how they were formed:

- Igneous
- Sedimentary
- Metamorphic

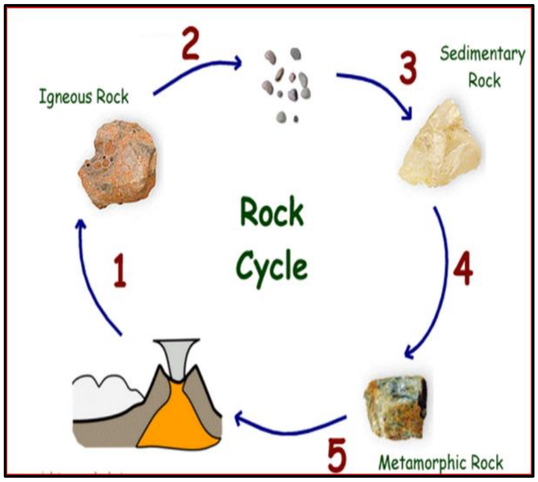
Rocks are continually changed to and from the three types by many processes, such as:

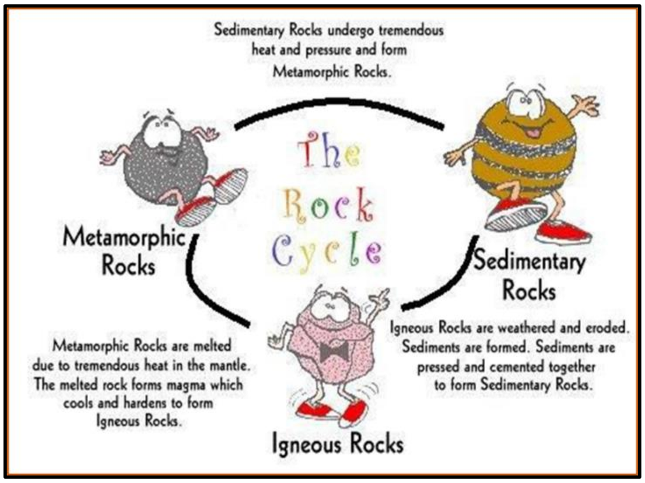
- Weathering
- Erosion
- Compaction
- Cementation
- Melting
- Cooling

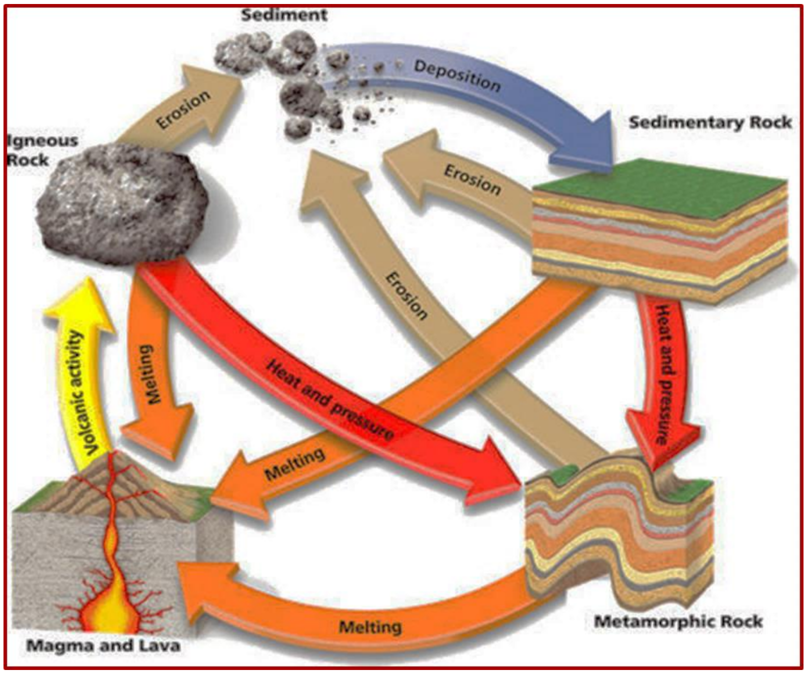
What is the process through which rocks change?

The Rock Cycle

Earth materials change back and forth among the different types of rocks







No set path a rock takes to become another type of rock.

How Rocks Change

All rocks change slowly from one type to another, again and again. The changes form a cycle, called "the rock cycle. “ The way rocks change depends on various processes that are always taking place on and under the earth's surface.

Heat & Pressure

Heat

- Below the earth's surface, temperatures are hot enough to melt most rocks.
- Before the melting point is reached, a rock can undergo many changes while in a solid state.
- Changing from one type to another without melting.

Pressure

- An additional factor that can transform rocks is the pressure caused by tons of other rocks pressing down on it from above.

Heat and pressure usually work together to alter the rocks under the earth's surface. This kind of change is called metamorphism which results in a metamorphic rock.

Melting & Cooling

Melting

- The high temperatures required to melt a rock are generally found only deep within the earth.
- It takes temperatures between 600 and 1,300 degrees Celsius to melt a rock, turning it into a substance called magma (molten rock).

Cooling

- Liquid magma also turns into a solid — a rock — when it is cooled.
- Any rock that forms from the cooling of magma is an igneous rock. Magma that cools quickly forms one kind of igneous rock, and magma that cools slowly forms another kind.

Extrusive Igneous

- When magma rises from deep within the earth and explodes out of a volcano, it is called lava, and it cools quickly on the surface.
- Rock formed in this way is called extrusive igneous rock. It is extruded, or pushed, out of the earth's interior and cools outside of or very near the earth's surface.

Intrusive Igneous

- Magma that cools at a much slower rate than lava. The type of rock formed in this way is called intrusive igneous rock. It intrudes, or pushes, into the earth's interior and cools beneath the surface.

Weathering & Compacting

Weathering

- Weathering, such as rain or wind, cause rocks to get eroded or broken down into smaller pieces.
- These small pieces of rock form the sediment that creates sedimentary rock.

Compacting

- As these little pieces of sediment get compacted together, they eventually for a sedimentary rock.

Types of Rocks

The three main types, or classes, of rock are sedimentary, metamorphic, and igneous and the differences among them have to do with how they are formed.

1. Sedimentary rocks

- Formed from particles of sand, shells, pebbles, and other fragments of material.
- Particles or sediments accumulate and harden into rock.
- You can often see sand, pebbles, fossils or stones in the rock. **Examples**: Conglomerate and Limestone.

Conglomerate

2. Igneous Rocks

- Formed when magma or lava cools and hardens.
- When lava cools very quickly, no crystals form and the rock looks shiny and glasslike.
- Sometimes gas bubbles are trapped in the rock during the cooling process, leaving tiny holes and spaces in the rock.
- **Examples**: Basalt and Granite.

Basalt

Granite

3. Metamorphic rocks

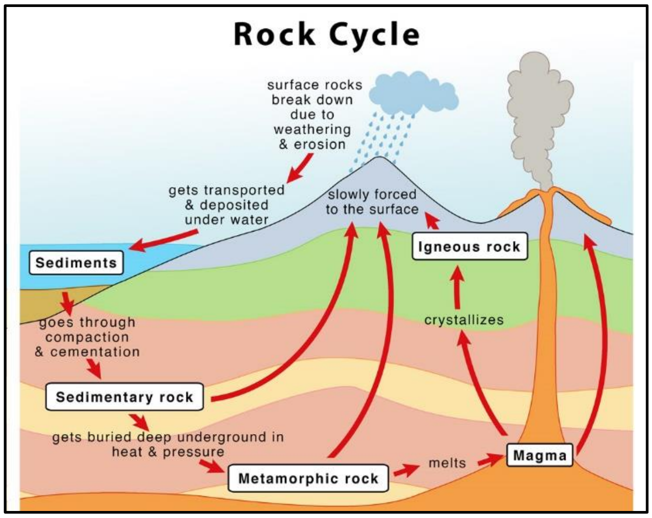
- Formed under the surface of the earth.
- Go through metamorphism (change) that occurs due to intense heat and pressure (squeezing).
- Usually have ribbon like layers and may have shiny crystals.
- **Examples**: Gneiss and Marble.

Gneiss

Marble

How are rocks redistributed?

The core, mantle, and crust are one giant rock recycling machine



Igneous Rocks

- "Ignis"=Latin for "fire"
- Formed from the cooling of either magma or lava
- The most abundant type of rock
- Classified according to their origin

ORIGIN — where igneous rocks are formed

Below ground = from magma (intrusive igneous rock)

- Usually have LARGE crystal grains (they
- Some have large &small crystals (called **porphyritic)**

Porphyritic

Above ground = from lava (extrusive igneous rock)

- Usually have small or NO crystals
- They cooled very quickly

Obsidian

Pumice

- Intrusive (Plutonic) rocks form inside the Earth (underground) when magma cools slowly to create large crystals.
- (Intrusive = Inside)
- Extrusive (Volcanic) rocks form on the Earth's surface (above ground) when lava cools quickly to create small crystals.
- (Extrusive = Exit/outside)

Types of Magma

There are two types of magma

- Felsic = Light color, high in silica, viscous (thick and slow), low in iron, calcium or magnesium
- Felsic = Feldspar + Silica
- Mafic = Dark color, low in silica, not viscous (thin and watery), high in iron, calcium and magnesium
- Mafic = Magnesium + Iron (Fe)

Texture refers to the crystal size.

- Textures are divided into two main types:
- **Fine-grained** = crystals are too small to see (basalt)
- **Coarse-grained** = crystals are easily visible (granite)

Other types of textures:

- A glassy texture occurs when rock freezes instantly.
- There are no crystals (Example: Obsidian).
- A porphyritic texture is a rock with large crystals surrounded by fine-grained crystals (Example: Rhyolite).
- A vesicular texture is a rock that has many holes in it (Example: Pumice).

Volcanic - crystallize at or near the surface. Quickly cooled, therefore fine grained or **aphanitic** texture (typically <1 mm). Form from **lava** (magma at the surface). Sometimes produce volcanic glass (**obsidian**), a quenched lava.

Plutonic - crystallize at depth. Slowly cooled, therefore coarse grained or phaneritic texture (typically >1 mm).

Classification of Igneous rocks

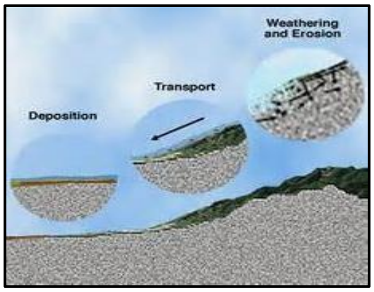
Igneous rocks are classified on the basis of texture and composition. Giving a rock a name is important. It communicates a lot of information about a rock. It's more than just a name.

COMPOSITION				
TEXTURE		FE-MG-CA-RICH DARK COLORED HI-T; OL, PYX		K-AL-SI-RICH LIGHT COLORED LO-T; QTZ, K-FELD
	APHANITIC/ VOLCANIC	**BASALT**	**ANDESITE**	**RHYOLITE**
	PHANERITIC/ PLUTONIC	**GABBRO**	**DIORITE**	**GRANITE**

Sedimentary Rocks

Rivers, oceans, winds, and rain carry the eroded particles of rocks.

- Detritus, fragments of rocks and minerals.



If the transporting current is not strong, the particles drop out in the process of sedimentation. This type of deposition is clastic sedimentation.

When material is dissolved, and chemically precipitates from the water, this type is called chemical sedimentation.

- When living organisms extract ions dissolved in water to make shells and bones, this type of sedimentation is called biochemical sedimentation.
- The accumulation of plant matter, such as at the bottom of a swamp, is referred to as organic sedimentation.

There are 4 major types of sedimentary rocks:

1. Clastic Sedimentary Rocks
2. Chemical Sedimentary Rocks
3. Biochemical Sedimentary Rocks
4. Organic Sedimentary Rocks.

The formation of a clastic sediment and sedimentary rocks involves five processes:

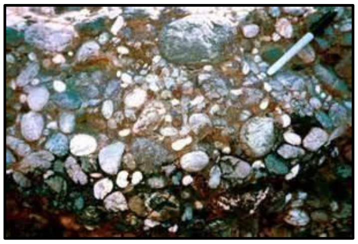
- **Weathering** - The first step is transforming solid rock into smaller fragments or dissolved ions by physical and chemical weathering.
- **Erosion** - Erosion is many processes which act together to lower the surface of the earth. It begins the transportation process by moving the weathered products. This can take place by gravity (slides or rock falls), by running water, by wind, or by moving ice. Erosion overlaps with transportation.
- **Transportation** - by sliding down slopes, or by running water in streams, rivers, or ocean currents. The transportation distance and the energy of the transporting medium leave clues that tell us about the mode of transportation.

- **Deposition**- Sediment is deposited when the energy of the transporting medium becomes too low to continue. If the transportation velocity becomes low, the sediment will fall out and become deposited. The final sediment reflects the energy of the transporting medium.
- **Lithification (Diagenesis)** - is the process that turns sediment into rock. The first stage of the process is compaction when the weight of the overlying material increases. Compaction forces the grains closer together, reducing pore space and eliminating some of the contained water. Some of this water may carry mineral components in solution, and these constituents may later precipitate as new minerals in the pore spaces. This causes cementation, which will bind the particles together.

Clastic Sedimentary Rocks

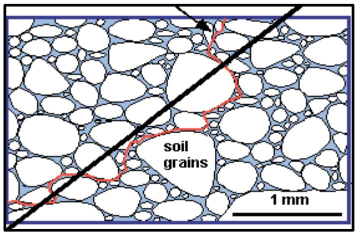
Coarse-grained rocks

- Conglomerates have rounded, gravel-sized particles.
- Breccias are composed of angular, gravel-sized particles.



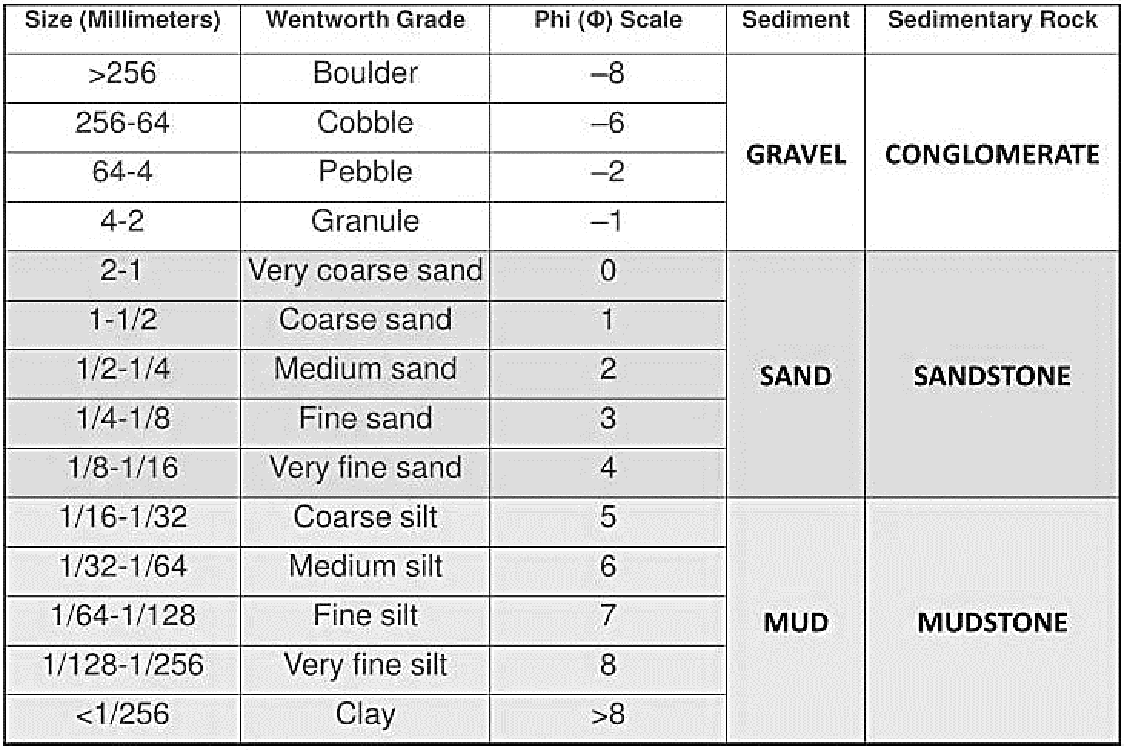
Medium-grained rocks

- Contain sand-sized rock and mineral fragments
- Porosity is the percentage of open spaces between grains in a material, such as rock.
- When open spaces between grains are connected, fluids can move through porous rock such as sandstone.
- Sandstone layers can be valuable as underground reservoirs of oil, natural gas, and groundwater.



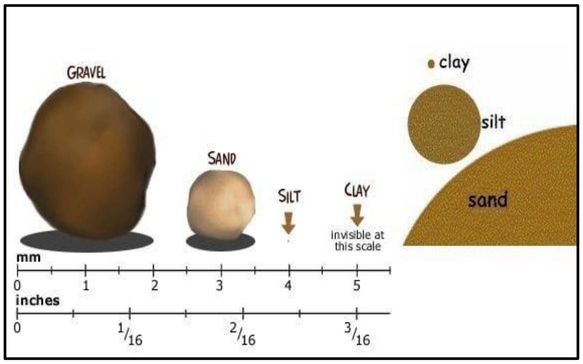
Fine-grained rocks

- Consisting of silt- and clay-sized particles are called fine-grained rocks.
- Low porosity and often forms barriers that hinder the movement of groundwater and oil.



Size (Millimeters)	Wentworth Grade	Phi (Φ) Scale	Sediment	Sedimentary Rock
>256	Boulder	–8	GRAVEL	CONGLOMERATE
256-64	Cobble	–6		
64-4	Pebble	–2		
4-2	Granule	–1		
2-1	Very coarse sand	0	SAND	SANDSTONE
1-1/2	Coarse sand	1		
1/2-1/4	Medium sand	2		
1/4-1/8	Fine sand	3		
1/8-1/16	Very fine sand	4		
1/16-1/32	Coarse silt	5	MUD	MUDSTONE
1/32-1/64	Medium silt	6		
1/64-1/128	Fine silt	7		
1/128-1/256	Very fine silt	8		
<1/256	Clay	>8		

- A **boulder** is big and difficult to lift. No upper limit to the size of boulder.
- A **cobble** will fit in one hand, a large one in two hands.
- A **pebble** is something that you could throw quite easily. The smaller ones—known as granules—are gravel size, but still you could throw one.
- **Sand** ranges from 2 millimeters down to 0.063 millimeters,
- **Silt** is essentially too small for Individual grains to be visible.
- **Clay** is so fine that it feels smooth even in your mouth.



Chemical Sedimentary Rocks

- Clastic rocks are dominated by components that were transported as solid clasts (clay, silt, sand, etc.)
- Chemical rocks are dominated by components that were transported as ions in solution (Na+, Ca2+, HCO3−, etc.).
- Almost all clastic rocks contain cement formed from dissolved ions, and many chemical sedimentary rocks include some clasts.
- Since ions can stay in solution for years, and can travel for thousands of kilometers, it is impossible to relate chemical sediments back to their source rocks.

The most common chemical sedimentary rock, is **limestone**.

- Others include **chert**, **banded iron formation,** and **evaporites**.
- Biological processes are important in the formation of some chemical sedimentary rocks.
- Limestone is made up of fragments of marine organisms that manufacture calcite for their shells.
- Most chert includes at least some of the silica tests (shells) of tiny marine organisms (such as diatoms).

Limestone

- Almost all limestone forms in the oceans, and most of that forms on the shallow continental shelves.
- Reefs are highly populated by a wide range of organisms, which use calcium and bicarbonate ions in seawater to make carbonate minerals (especially calcite) for their shells.

Dolomite: CaMg(CO3)$_2$ is another carbonate mineral,

- *Dolomite* is also the name for a rock composed of the mineral dolomite.

- All of the dolomite found in ancient rocks has been formed through magnesium replacing some of the calcium in the calcite in carbonate muds and sands.
- This process is known as ***dolomitization***.

Evaporites

- Composed of minerals precipitated from evaporating seawater or lakes. Common evaporites are halite, gypsum, borates, potassium salts, and magnesium salts.
- When water becomes increasingly concentrated with dissolved salts, some of these salts reach saturation levels and start to crystallize.
- Gypsum ($CaSO4 \cdot H2O$) precipitates at about 20% of the original volume and halite ($NaCl$) precipitates at 10%.

Metamorphic Rocks

Metamorphism

- The word "***Metamorphism***" comes from the Greek: Meta = after, morph = form, so metamorphism means the after form.
- In geology this refers to the changes in mineral assemblage and texture that result from subjecting a rock to conditions such pressures, temperatures, and chemical environments different from those under which the rock originally formed.

Contact Metamorphism

- Occurs adjacent to igneous intrusions and results from high temperatures associated with the intrusion**.**
- Since only a small area surrounding the intrusion is heated by the magma, metamorphism is restricted to the zone surrounding the intrusion, called a ***metamorphic*** or ***contact aureole***.
- Outside of the contact aureole, rocks are not affected.

TYPES OF METAMORPHISM

Contact Metamorphism

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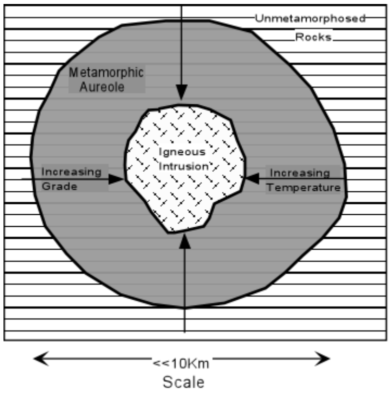
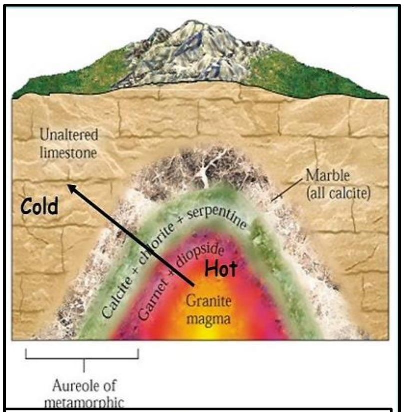


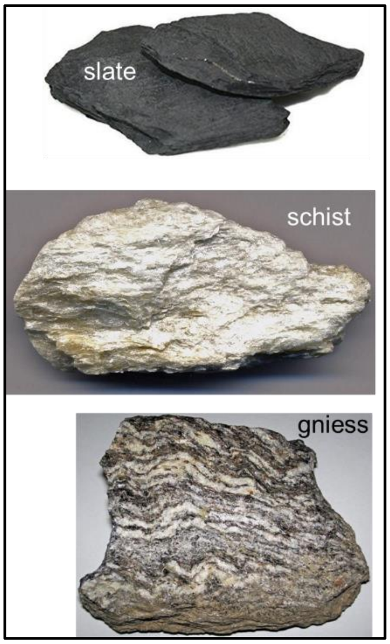
Contact Metamorphism



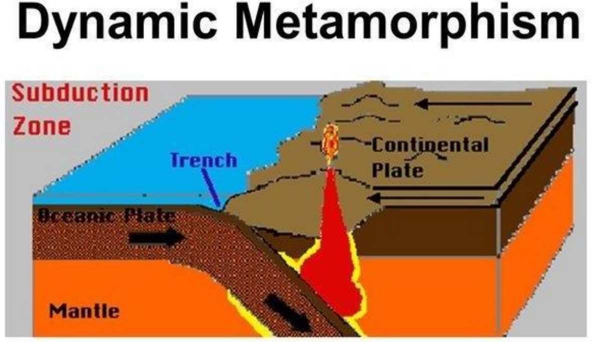
- The grade of metamorphism increases in all directions toward the intrusion.
- As the temperature contrast between the surrounding rock and the intruded magma is larger at shallow levels in the crust where pressure is low, contact metamorphism is often referred to as high temperature, low pressure metamorphism.
- The rock produced is often a fine-grained rock that shows no foliation, called a Hornfels.

Regional Metamorphism

- Occurs over large areas and does not show relationship to igneous bodies.
- Usually results in forming metamorphic rocks that are strongly foliated, such as slates, schists, and gneisses.
- The differential stress causing this metamorphism usually results from tectonic forces that produce compressional stresses in the rocks, such as when two continental masses collide.
- Regionally metamorphosed rocks occur in the cores of fold/thrust mountain belts or in eroded mountain ranges.
- Compressive stresses result in folding of rock and thickening of the crust, which tends to push rocks to deeper levels where they are subjected to higher temperatures and pressures.



Cataclastic Metamorphism



Dynamic Metamorphism also occurs because of mountain-building.

- Occurs as a result of mechanical deformation, like when two bodies of rock slide past one another along a fault zone.
- Heat is generated by the friction of sliding along such a shear zone, and the rocks are mechanically deformed, being crushed due to the shearing.
- It is not very common and is restricted to a narrow zone along which the shearing occurred.

Cataclastic Metamorphism

- Cataclastic metamorphism is generally localized along fault planes (areas of detachment where rocks slide past one another)
- Cataclastic Metamorphism produces sheared, highly deformed rocks called mylonites.

Hydrothermal Metamorphism

Rocks that are altered at high temperatures and moderate pressures by hydrothermal fluids are hydrothermally metamorphosed.

- This is common in basaltic rocks that generally lack hydrous minerals.
- The hydrothermal metamorphism results in alteration to Mg-Fe rich hydrous minerals as talc, chlorite, serpentine, and clay minerals.
- Rich ore deposits are often formed as a result of hydrothermal metamorphism.

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Links

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PART III: ECONOMIC GEOLOGY

Economic geology

Economic geology is concerned with earth materials that can be used for economic and industrial purposes. These materials include precious and base metals, nonmetallic minerals, construction-grade stone, petroleum, natural gas, coal, and water. Economic geology is a sub discipline of the geosciences and it is “the application of geology to serve society”. The term commonly refers to metallic mineral deposits and mineral resources.

One of the most important branches of the economic geology is the **science of mineral deposits**. This science deals with the minerals of an economic importance and how they form in the Earth's crust and where they found and the conditions of their occurrence. This helps in finding the best ways to explore and mine them.

Let us revise our understanding of some common terminology to explain and establish the mutual relationship between minerals, mineral deposits, the host rocks that bear specific mineral or group of minerals within it under certain physicochemical conditions, classification systems based on various characteristic features, and their origin.

Minerals, rocks, ores and mineral deposits:

Mineral is a naturally occurring homogeneous substance, usually inorganic, and symbolized by unique atomic structure and chemical formula with minor deviation (addition or subtraction) of certain basic compositional elements. It is habitually in solid form, other than a few like mercury, natural water, and fossil fuel (oil and gas). The minerals of solid form are stable at normal temperature and pressure.

Minerals are different from rocks. **Rock** is an assemblage of minerals formed under natural process of igneous, sedimentary, and metamorphic origin. The rocks do not have a specific chemical composition.

Mineral deposits are aggregate of mineral or group of minerals in an unusually high concentration. The mineral deposits must have three-dimensional configuration that includes shape in plan and sectional view, continuity in strike and depth to represent volume, and size with average characteristics. The rock bodies can similarly be outlined by shape, size, and continuity and defined as deposit with commercial values. The rock deposits can serve as raw material sources for industry such as the limestone deposits of Egypt for preparation of lime, mortar, and cement.

The rock deposits can directly be used after cutting, shaping, and polishing in road and building construction such limestone in “The Great Pyramid” at Giza, Egypt.

Mineral deposits are divided into:

1- Metallic mineral deposits: such as iron, copper, gold and silver deposits.
2- Non-metallic mineral deposits: such as sulfur, shale and limestone deposits.
3- Fuel deposits: these are the deposits which are used as energy sources such as coal and oil (which are not considered minerals by definition). These deposits also include radioactive minerals such as uranium and thorium deposits which are used as nuclear fuel.

Not all minerals are considered economic. A mineral deposit is considered economic when the extracted materials are more expensive than the cost of their extraction. This is depending on three factors:

1. Geologic factors: such as the concentration of the mineral within the deposit, its size and its depth beneath the ground.
2. Geographic factors: such as how close is the mineral deposit extraction site to the market, transportation and climate conditions.
3. Economic factors: such as the prices of the extracted materials and how monopoly affect these materials.

Metallic mineral deposits occur as single element such as gold, silver and copper, or occurred as compounds of more than one element known as **ore minerals**.

An **ore** is a naturally occurring accumulation or deposit of one or more minerals of economic value (more or less mixed with gangue) that can be exploited at a profit. The term is usually restricted to the description of mineral deposits that are of value for their metal content. This mixture of the ore and gangue minerals is known as **ore body** and the rock containing this mixture is called **the host rock**. Important examples of the ore minerals are galena (PbS) that is composed of sulfur and lead, and the iron oxides such as hematite and magnetite.

Gangue minerals are the commercially worthless minerals that surround, or are closely mixed with, ore deposit. Most of these minerals are nonmetallic such as the quartz and calcite. These minerals can be used as rock fragments in paving roads and constructions.

CLASSIFICATION OF MINERALS AND MINERAL DEPOSITS

Minerals and mineral deposits can be classified in various formats based on the type and chemistry of minerals, geographic distribution, depth of occurrence, morphology, relation to host rocks, nature of mineralization, structural control, genetic model, economic gradation fitting with the overall characteristics, and perspective. The most important classifications are those based on the chemical composition of the minerals, depth of occurrence and nature of mineralization.

Mineral Classification System Based on Chemical Composition:

The most common mineral classification system is based on the type and chemical composition of individual mineral. Minerals occur in various forms such as native elements to complex compounds and in this classification, they can be grouped into be 10 categories or class following Gaines et al.(1997) as in the following table:

Class	**Forms**	
01	Native elements	Copper (Cu), gold (Au), silver (Ag), sulfur (S)
02	Sulfides and sulfosalts	Chalcopyrite ($CuFeS_2$), sphalerite (ZnS), galena (PbS).
03	Oxide and hydroxides	Quartz and amethyst (SiO_2), hematite (Fe_2O_3), cassiterite (SnO_2)
04	Halides	Fluorite (CaF_2), halite (NaCl).
05	Carbonates	Calcite ($CaCO_3$), magnesite ($MgCO_3$), dolomite ($CaMg\ (CO_3)_2$)
06	Borates	Howlite ($Ca_2B_5SiO_9(OH)_5$) and kernite $Na_2B_4O_6(OH)_2\$3(H_2O)$
07	Sulfates	Barites ($BaSO_4\ 2H_2O$), Gypsum ($CaSO_4$), anglesite ($PbSO_4$)
08	Phosphates	Apatite ($Ca_5\ (PO_4)_3\ (F,Cl,OH)$) and berlinite ($AlPO_4$).
09	Silicates	Andalusite-kyanite-sillimanite (Al_2SiO_5), beryl ($Be_3Al_2Si_6O_{18}$)
10	Organic minerals	Fossil-bearing limestone, coal, and oil shale

Depth of Occurrence:

Type	**Description**
Exposed to surface	Mineral deposits like iron ore, bauxite, chromite, copper, limestone, and magnesite are exposed to the surface and easy to explore.
Shallow depth	Deposits like base metals, coal, and gypsum are covered by altered oxidized capping or exist at shallow depth or under thick overburden of bed rock.
Deep-seated hidden deposits	Igneous intrusive deposits are often deep seated and hidden at greater depth posing difficulties in discovery, exploration, and extraction.

Nature of mineralization:

Mineral deposits can be classified based on the nature of their appearances in situ as described in the following table:

Type	Description	Example
Disseminated	Disseminated types of mineralization are formed by crystallization of deep-seated magma. The valuable minerals are sparsely disseminated or scattered as fine grains throughout or part of the host rock.	Diamond and copper.
Massive	Massive deposits are formed as large mass; bulky and heavy.	Zinc, lead and silver deposits.
Veins	Veins, fissure, and lodes are tabular deposit formed by deposition of minerals in open spaces within faults and fractures	Chromite and magnesite deposit

Stringers/fibers	Stringers are large numbers of thin, tiny, and closely spaced mineralized veins originating from the main mineral body and often described as “stringer zone”	Zinc-lead deposit body
Stock work/network	Stock is a large mass of rock impregnated by dense interlacing network of variously oriented irregular metal-bearing veins.	Platinum and chromite deposits
Ladder veins	Ladder veins are regularly spaced, short, and transverse nearly fractures confined wall to wall within compact rock mass for considerable distance. Fractures filled with quartz or valuable minerals forming economic deposit	Gold veins
Layered		Chromite and hematite
Lenses		Chromite

Magma and mineral deposits

The formation of the mineral deposits:

The economic mineral deposits are formed by the same processes by which the host rock is formed. These processes are:

1. Igneous processes: when molten rock (magma or lava) cools and solidifies forming igneous rocks.
2. Sedimentary processes: when particles settle out of water or air, or by precipitation of minerals from water. The sedimentary rocks accumulate in layers.
3. Metamorphic processes: when existing rocks are changed by heat, pressure, or reactive fluids, such as hot, mineral-laden water.

Most rocks are made of minerals containing silicon and oxygen, the most abundant elements in the Earth’s crust. It is noted that the magma forms the source of all rocks on the Earth, and thus is the source of all mineral deposits.

What is magma?

Magma is a molten and semi-molten rock mixture found under the surface of the Earth. This mixture is usually made up of four parts: a hot liquid base, called the melt; minerals crystallized by the melt; solid rocks incorporated into the melt from the surrounding confines; and dissolved gases. Magma is extremely hot—between 700° and 1,300° Celsius. This heat makes magma a very fluid and dynamic substance, able to create new landforms and engage physical and chemical transformations in a variety of different environments.

How Magma Forms

Earth is divided into three general layers. The core is the superheated center, the mantle is the thick, middle layer, and the crust is the top layer on which we live.

Magma originates in the lower part of the Earth's crust and in the upper portion of the mantle. Differences in temperature, pressure, and structural formations in the mantle and crust cause magma to migrate upwards to be stored in magma chambers. magma chambers sit far beneath the surface of the Earth.

The magma may solidify deep underground in the magmatic chamber or in the subsurface sedimentary layers, to form an **intrusion.** This forms plutonic igneous rocks. When magma is ejected by a volcano or other vent, the material is called **lava.** Lava is cooled into a volcanic igneous rock (Figure 1).

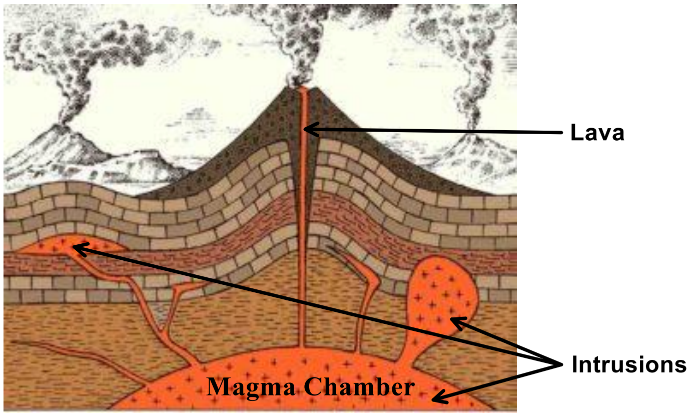


Figure 1: The magma formed in the magmatic chamber is cooled and some of it intruded in the subsurface layers forming intrusions. other parts of the magma are extruded on the surface to form lava.

Chemical composition of magma

Magmas are composed of three components:

1. Major Constituents
    - O, Si, Al, Mg, Fe, Ca, Fe and K.
2. Trace constituents**:**
    - Rest of the elements in the periodic table.
3. Volatile constituents**:**
    - Gases and liquids such as CO_2 and H_2O.

Types of Magma

All magma contains gases and a mixture of simple elements. Being that oxygen and silicon are the most abundant elements in magma, geologists define magma types in terms of their silica content, expressed as SiO2. These differences in chemical composition are directly related to differences in gas content, temperature, and viscosity.

1- Mafic or basaltic Magma:

Mafic magma is characterized by:

- relatively low silica content, roughly 50%, and higher contents in iron and magnesium.
- low gas content
- low viscosity, or resistance to flow
- high density
- high mean temperatures, between 1000o and 2000o Celsius, which contributes to its lower viscosity.

Low viscosity means that mafic magma is the most fluid of magma types. It erupts non-explosively and moves very quickly when it reaches Earth's surface as lava. This lava cools into basalt, a rock that is heavy and dark in color due to its higher iron and magnesium levels.

2- Granitic or felsic magma:

Felsic or granitic magma is characterized by:

- high silica content, between 65-70%., and rich in Si, Al, Ca, Na, and K oxides
- high gas content
- high viscosity,
- low density
- low mean temperatures, between 650° and 800° Celsius.

Magma development stages:

Magma is developed to its final form as rocks and minerals in five stages (Figure 2):

1. Early Magmatic Stage
2. Late Magmatic Stage
3. Pegmatitic Stage
4. Pneumatolytic Stage
5. Hydrothermal Stage

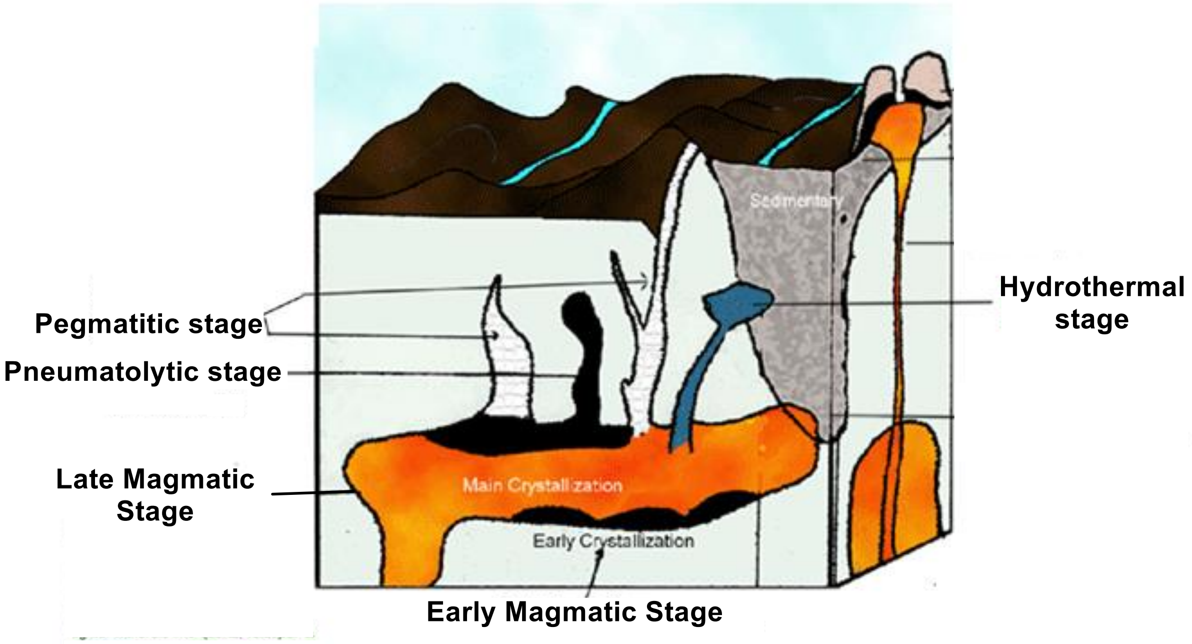


Figure 2: Magmatic development stages

1- The Early magmatic stage:

This stage begins when magma is formed under very high temperature and pressure in great depths. Crystallization of minerals from the magna is very slow. Minerals with heavy weights such as chromite and zircon are formed and settled down in the magma chamber. Metals such as diamond and chrome are also formed.

2- Late magmatic stage:

In this stage, Silicate minerals such as olivine and pyroxene began to form. Also, in this stage the process of magmatic differentiation occurs, where part of the magma crystalized and form sedimentary rocks, and the other part forms the residual liquid which is different in composition from the original magma. In the mafic magma, the residual liquid is rich of iron and titanium, while in granitic magma, it is rich of silicon, sodium, potassium and volatiles. In both cases, the residual liquid becomes the source of many important mineral deposits in later stages.

3- Pegmatitic stage:

In the granitic magma, the residual fluid is sufficiently enriched in volatile materials and intrudes in surrounding rock to permit the formation of coarse-grained rocks (pegmatite) in the form of sills and veins. A pegmatite is an igneous rock that is formed and is showing a very coarse texture, with large interlocking crystals. Pegmatite rocks contain important minerals such as lithium and radioactive minerals.

4- Pneumatolytic stage:

This stage only occurred in the granitic magma where gases and water that were left after the residual liquid formed pegmatites, penetrate through cracks and fractures in surrounding rocks. They chemically interact with the fracture walls causing alteration of the rock materials in these walls. They also precipitate minerals in these cracks and fractures. Some of the water and gases are consumed before reaching the surface. While, in some cases some are reaching the surface and form hot springs for the next stage of development.

5- Hydrothermal stage:

In this final stage, the gases and water remain after the pneumatolytic stage explode on the surface as hot springs. Hot springs are natural water emanations from the subsurface of the earth, with very high temperature. This temperature affects the rock, where the hot springs formed in two ways:

1- Contact metasomatism: is the mineral alterations occurred in the surrounding rocks due to the effect of the temperature.
2- Contact metasomatism: is the chemical and mineral alterations occurred in the surrounding rocks due to the effect of the temperature.

Origin of ores and mineral deposits

The origin of the mineral deposits refers to the geologic processes by which the mineral deposits form. According to their origin, mineral deposits are subdivided into:

A) **Syngenetic mineral deposits**: which formed at the same time with the host rocks.
B) **Epigenetic mineral deposits**: which formed later, by introduction into pre-existing rocks.

The geologic processes by which mineral deposits are formed includes:

a. **Endogenic processes**: are the geologic processes that is formed or occurring beneath the surface of the Earth. These processes include:
   i. Magmatic concentration
   ii. Hydrothermal processes
   iii. Contact metasomatism
   iv. Metamorphism

b. **Exogenic processes:** include geological processes that originate externally to the Earth’s surface.
   i. Sedimentation and evaporation
   ii. Mechanical concentration

c. **Volcanic-sedimentary processes**

The following is a detailed explanation of these processes and how they form mineral deposits.

Endogenic processes:

1-Magmatic concentration:

Magmatic deposits that are genetically linked with the evolution of magma are called magmatic mineral deposits. Magmatic mineral deposits are those which are formed during crystallization of a magma, deep underground. The host rock for the mineralization can range from ultramafic to felsic. The deposit can consist of massive ores in some cases, and disseminations of rare minerals in others. In the case of more massive ores, there are three primary means of concentrating minerals of value during the formation of these deposits:

A) Gravitational settling
B) Differentiation
C) Immiscible separations

a- Gravitational settling:

The process of gravitational settling causes early-formed heavy minerals to sink to the bottom of a magma chamber. This process is best exemplified in magmas with ultramafic and mafic compositions, and the best examples are chromite deposits. Chromite is a very high temperature mineral which is also quite heavy. As a result, in some situations it will tend to sink and form layers of massive ore in the bottom of a magma chamber.

b- Magmatic differentiation:

Magmatic differentiation is a complex process whereby magma can produce a wide variety of different igneous rocks. In this process, the magma is differentiated into a rock and residual liquid. Differentiation causes a concentrating effect resulting in a concentration of selected elements in the residual magma. These elements are the ones which did not fit well inside of common rock forming minerals. Instead, they become included in the final liquid present, which forms "pegmatite". Pegmatites are very coarse-grained rocks and form at the very last stage of crystallization. The final fluids tend to have a very high-water content, which also contributes to forming large crystals. Pegmatites also contain accessory minerals of special interest because they trap the rare elements in their crystal structure. Because of the rarity of some of these elements, the accessory minerals in the pegmatite can be quite valuable and constitute an ore deposit.

c- Immiscible separation:

Immiscible separation is an important magmatic differentiation process. It consists of the separation of an initially homogeneous magma liquid into two compositionally distinct liquid phases. These two magma liquids have entirely different compositions. Like oil and water, the two magmas will not mix (i.e., they are immiscible). Immiscible melts form irregular shaped segregations or may be injected as a dike into previously crystallized material.

Iron sulfide is the principal constituent of most immiscible magmas. Immiscible sulfide drops can become segregated and form immiscible magma layers in a magma chamber and when layers of sulfide magma cool and crystallize, the result is a deposit of ore minerals of copper, nickel, and platinum-group metals in a gangue of an iron sulfide mineral.

Another important deposit formed by immiscible separation is “diamond-bearing kimberlite”. Kimberlites are rocks of ultramafic composition which are generally fine-grained. Diamonds occur as accessory minerals in the kimberlite, which is frequently highly altered. Kimberlites are thought to represent mantle rocks emplace near the surface by forceful, possibly explosive, intrusion. The shapes are often like a vertical pipe. The world’s most famous diamond-bearing kimberlite deposits occur in South Africa.

2- Hydrothermal processes:

Hydrothermal solutions are hot, aqueous, metal-saturated fluids that react chemically with crustal rocks. In this case, the metallic minerals formed by the precipitation from these solutions are called hydrothermal mineral deposits. These hydrothermal solutions are effective solvents of many sulfide and oxide ore minerals, and they are even capable of dissolving and transporting native metals such as gold and silver.

The water in a hydrothermal solution can come from any of several sources. It may arise as residual watery fluids derived during the later stages of magma crystallization; it can be expelled from a mass of rock undergoing metamorphism; or it may originate at Earth’s surface as rainwater, groundwater or seawater and then trickle down to great depths through fractures and porous rocks, where it will be heated, react with adjacent rocks, and become a hydrothermal solution. Regardless of the origin and initial composition of the water, the final compositions of all hydrothermal solutions tend to converge, owing to reactions between solutions and the rocks they encounter.

The ore constituents (Cu, Pb, Au, etc.) are dissolved in the hydrothermal solution along with other deposit constituents such as Si, S, and Fe. The metallic elements are deposited to form the ore and gangue, in response to a change in the solution and very sharp decrease in temperature when the solution move into cooler areas in the crust.

Hydrothermal deposits are classified in 3 groups:

A) Hypothermal deposits:
These deposits are formed at great depths and high temperature (300-600^{o}C) and they form close to the magmatic body. An example of the ore minerals which belong to these deposits are gold, copper and lead.

B) Mesothermal deposits
They are formed at intermediate depths and temperature (200-300^{o}C) and they form some distance away of the magmatic body. Example of this group is galena.

C) Epithermal deposits
They are formed at the shallowest depths and low temperature (50-200^{o}C) and they form far away from the magmatic body. Example of these deposits is pyrite.

Mineral deposits are formed by hydrothermal solutions by two processes: cavity filling and replacement.

A- <u>Cavity filling:</u>

Cavity fillings are ore deposits that get deposited from hydrothermal solutions in rock openings (cavities). Epithermal deposits are of this type. The precipitated mineral deposits are mostly in the shape of veins and are known as hydrothermal vein deposits. Hypothermal deposits such as gold, silver, copper, lead and zinc are of this type. When the hydrothermal solution interacts with carbonate rocks such as limestone, they dissolve the rock forming caves with different sizes and shapes (Figure 1). In some cases, they can modify pre-existing openings in the carbonate rocks such as caves and fissures. The hydrothermal solution precipitates the mineral deposits in these caves whether they are modification of pre-existing openings or formed by dissolution. These minerals are called solution cavity fillings, such as barite.

Figure 3: Caves in limestone formed by dissolution by hydrothermal solutions.

Mineral deposits formed by cavity fillings also occur as layered deposits known as stratabound deposits. These deposits are formed when the dissolved minerals in a hydrothermal fluid precipitate in the pore spaces of unconsolidated sediments on the bottom of a lake or ocean. Such minerals may contain economic concentrations of lead, zinc and copper, usually in sulfide form like galena, sphalerite and chalcopyrite.

B- Replacement:

In replacement process, the minerals dissolved in hydrothermal solutions are substituted for one or more earlier formed minerals in the encountered rocks. This is a dominating process in mesothermal and hypothermal deposits.

3- Metamorphism:

Metamorphic mineral deposits are transformed alteration product of preexisting igneous or sedimentary materials. The reconstruction occurs under increasing pressure and temperature caused by igneous intrusive body or by tectonic events. There are two types of metamorphism: contact and regional metamorphism.

Contact metamorphism is a type of metamorphism where rock minerals and texture are changed, mainly by heat, due to contact with magma. The heat from a body of magma in the upper crust can create a very dynamic situation with geologically interesting and economically important implications. The main process is heat transfer from the pluton to the surrounding rock, creating a zone of contact metamorphism (Figure 2).

Regional metamorphism is occurred under increasing both temperature and pressure under great depths below the Earth's surface.

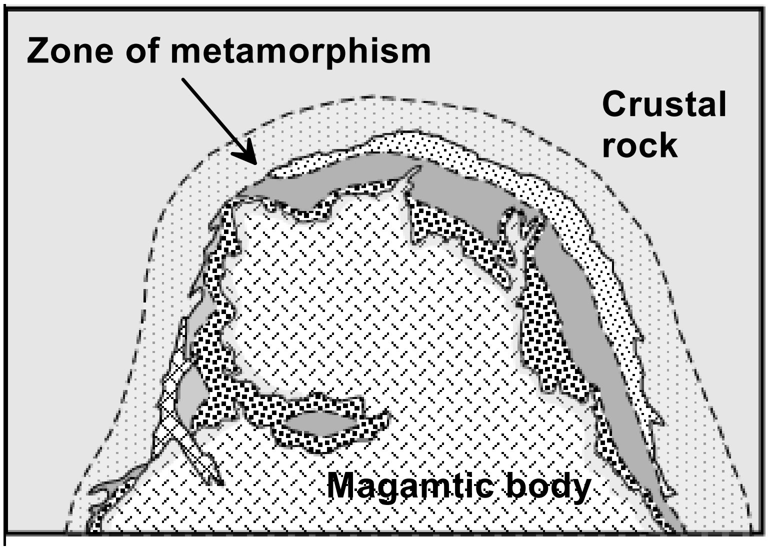


Figure 4: An illustration of contact metamorphism.

<u>**Formation of mineral deposits by metamorphism:**</u>

In both types of metamorphism, the mineral deposits are formed when the temperature and pressure conditions changed. When these conditions changed for a certain pre-existing igneous or sedimentary rock, its minerals became unstable. So, these minerals re-arrange themselves to form new minerals that are stable in the new temperature and pressure conditions. And if these conditions changed again, other new minerals are formed. For every change in the temperature and pressure conditions new minerals are formed instead of the older unstable ones. For example, chlorite mineral in clay rocks is stable at low temperature and pressure. When the temperature and pressure increased, chlorite became unstable and it changed to biotite mineral which is more stable in the new conditions. With increasing metamorphism, biotite is changed into garnet and kaynite and so on. Minerals like garnet, kyanite, sillimanite, wollastonite, graphite, and andalusite are end products of metamorphic process.

Examples of metamorphic mineral deposits:

1. *Asbestos minerals:*

Asbestos is a generic term referring to six types of naturally occurring minerals that are in the form of fibers. These fibers are easily separated, flexible, and resistant to high temperature and acids. These asbestos fiber minerals are divided into two mineral groups: serpentine asbestos and amphibole asbestos.

The serpentine group contains a single fiber mineral called: chrysotile. Chrysotile fibers are longer, strong, flexible to be spun and can be easily separated from each others. They are used in manufacturing fire-resistant clothes and robes. It occurred as veins and mass fiber deposits (Figure 3) in serpentinite rocks which are formed by metamorphism of ultra-mafic igneous rocks. The amphibole asbestos group include five minerals: anthophyllite asbestos, grunerite asbestos (amosite), riebeckite asbestos (crocidolite), tremolite asbestos, and actinolite asbestos. The fibers of these minerals are shorter and less strong than the serpentine asbestos fibers. They are resistant to acids and burning chemicals, thus they are used in manufacturing insulating and resistant materials. They are occurred in schist and slate rocks.

Figure 5: Chrysotile mass fibers

2. *Graphite deposits:*

Graphite, pure carbon, has a simple composition and a quite simple layered structure. However, interesting physical properties such as low density and high electrical conductivity make graphite a very important industrial mineral with many applications including a group of new and developing technologies such as lithium-ion batteries, nuclear, wind and solar power, fuel cells, semi-conductors, or even graphene.

Graphite deposits result from the contact or regional metamorphism of sedimentary rocks rich in carbonaceous matter such as coal seams. In the beginning of metamorphism, organic substances are converted into carbon and oil and natural gas are released. This stage is called carbonization. Then, at higher temperatures and pressures, carbon is converted into graphite and this process is called graphitization.

The graphite deposits occur in schist rocks in layered form and as lenses.

4- Metasomatism:

Metasomatism is the process of altering the composition of a rock, either by the addition or subtraction of chemical elements. Deposits are developed due to replacement, alteration, and contact metasomatism of the surrounding country rocks by ore-bearing solutions and emerging gases adjacent to mafic, ultramafic, or granitic-intrusive body. It is most often developed at the contact of intrusive plutons and carbonate country rocks; thus, it is usually accompanying contact metamorphism.

Formation of mineral deposits by metasomatism:

All the granitic magmas contain volatile components (gases) which are dissolved in the magma liquid before crystallization. When the magma rises and intrudes in the crust rocks, the gaseous components form bubbles which increases in size when more gases flow. These bubbles contain many metals in gas forms. So, when these bubbles rise upward in the magma, they chemically interact with the surrounding rocks. These chemical reactions cause some alterations in the parts of the rock where they occurred as the gas components partially or totally replace parts of these rocks, forming mineral deposits. These alterations include the following processes:

1- **Greizenization:**

Greizenization is a metasomatic process where feldspars minerals are partially replaced by quartz, with the formation of white mica. This is leading to the formation of a rock called greisen. Greisen is a medium-temperature metasomatic rock characterized by the presence of quartz and white mica, commonly with topaz, fluorite, tourmaline.

2- **Albitization:**

Albitization is the partial or complete replacement of pre-existing plagioclase feldspar or alkali feldspar by albite (Na Al silicates). In this case, the whole rock is converted into a single white-colored albite mineral.

3- **Microclinization:**

In this process, the rock is converted into green colored microcline mineral accompanied with titanium.

4- **Silicification:**

This is the process where the minerals in rock is replaced by silica, generally resulting in the formation of fine-grained quartz. In this case, the resulting rock is called quartzite.

This metasomatic process occurred after a period of time when the magma intrudes in the crust rocks. The first process occurring directly after the intrusion is the contact metamorphism. This metasomatic process is controlled by the following factors:

1- The depth of the intruded magma:

At shallow depths where the pressure is low, fractures and cracks occurred in the crust in great amounts which helps the gas components to escape in the atmosphere. While at great depths below the surface, the high pressure doesn't allow the gases to escape and thus, there is a high chance to accomplish all the chemical reactions. Thus, most of the mineral deposits formed by metamorphism occur at depths of 2000-6000 m below the surface.

2- The nature of the surrounding rocks:

Calcareous rocks such as limestone and dolomites tend to react with gases more than the clay rocks. Clay rocks are solid rocks with no pores or fractures that can allow the gases to flow in. also, the clay minerals have no tendency to react with gases.

3- Geologic structures:

Geologic structures such as faults, joints and fractures present passages for the gases to flow within.

4- Chemical composition of the intruded granitic magmas:

Granitic magmas with intermediate compositions such as granodiorite contain more gas components than the other magmas, thus, they form more minerals than the others.

Examples of metasomatic mineral deposits:

The mineral deposits formed by metamorphism occur as disseminated in the host rocks, veins and massive. An example of the rocks that is mainly formed by metasomatism is skarn. **Skarn** is a metasomatic rock formed at the contact between a silicate rock and a carbonate rock such as limestones. In other words, it formed when granitic magma intruded in carbonate rocks. It consists mainly of Ca-Mg-Fe-Mn- silicates, which form as a result of alteration which occurs by the chemical interaction between the igneous body and the carbonate rock. Skarns can form layers along the contact or occur as veins crossing the carbonate and/or the silicate rocks. Skarns generally contain various metal ores such as copper, tungsten, iron, tin, molybdenum, zinc-lead, and gold.

B- Exogenic processes:

1. Sedimentation:

Mineral deposits that are formed by the process of deposition and consolidation of loose materials are called sedimentary mineral deposits. These sedimentary mineral deposits can be formed by two ways; mechanical deposition and chemical deposition.

A- Mechanical Deposition of Sedimentary Mineral Deposits:

During sedimentation, the ore mineral is not affected by breaking and removal of other minerals due to its resistance to weathering, its hardness, and weight. It is sorted out from the fragments of quartz and other resistant minerals. Thus, the ore-mineral was deposited, without being chemically changed, in a layer by itself or approximately so. Black magnetic sand illustrates this process of concentration, and if consolidated, it would form a bed of iron ore. One of the most important mineral deposits formed by the mechanical deposition are the placer deposits.

Placer deposits:

Placer deposits of gold, platinum, tinstone, monazite, etc., are natural concentrations of heavy strongly resistant economic minerals, separated from the lighter substances by the sorting action of surface weathering and running water. The placer can be an accumulation of valuable minerals formed by gravity separation during sedimentary processes.

When heavy, stable minerals are freed from their matrix by weathering processes, they are slowly washed downslope into streams that quickly remove the lighter matrix. Thus, the heavy minerals become concentrated in stream, beach, and residual gravels and constitute ore deposits. Minerals that form placer deposits have high specific gravity, are chemically resistant to weathering, and are durable; such minerals include gold, platinum, cassiterite, magnetite, chromite, ilmenite, rutile, native copper, zircon, monazite, and various gemstones.

The types of placer deposits are (Figure 4):

- **Alluvial (stream) placers** which transported by a stream or river, such as rutile.
- **colluvial placers** which are unconsolidated sediments that have been deposited at the base of hillslopes as they transported by gravity action,
- **eluvial placers** which material still at or near its point of formation,
- **beach placers** which are coarse grains deposited along the edge of large water bodies, such as monazite, ilmenite, rutile, garnet,
- **paleoplacers** which are ancient buried rock from an original loose mass of sediment.

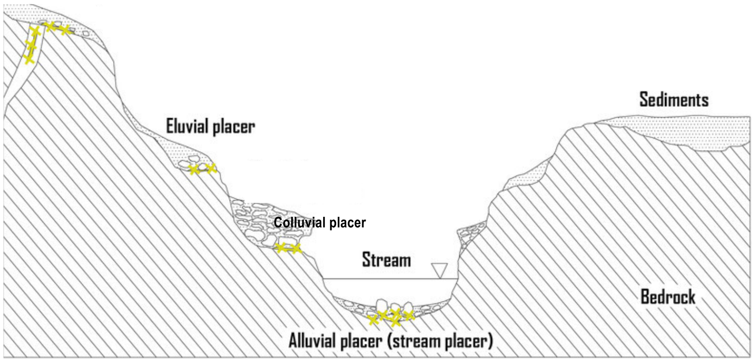


Figure 6: An illustration of three types of the placer deposits.

The placer deposits can be concentrated in many geologic environments including: below waterfalls, inside meander loops, downstream from a tributary, behind undulations on ocean floor, behind rock bars, and in rock holes (Figure 5).

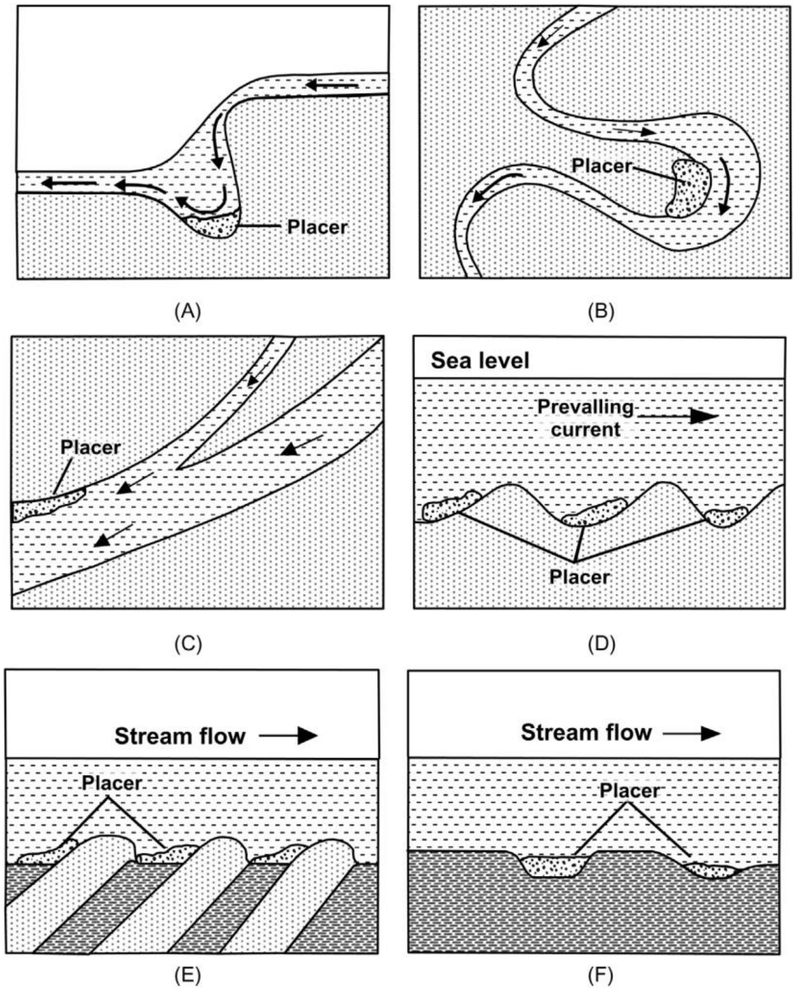


Figure 7: The loci of placers concentration (A) below waterfalls, (B) inside meander loops, (C) downstream from a tributary, (D) behind undulations on ocean floor, (E) behind rock bars, and (F) in rock holes.

B- Chemical Deposition of Sedimentary Mineral Deposits:

In the weathering of rocks, iron and manganese are dissolved as carbonates by water containing carbonic acid, and are carried down to swamps, lakes, and seas, where they have been deposited as beds of ore; under some circumstances they have been deposited as carbonates or as oxides.

In the chemical deposition of the sedimentary mineral deposits, ore body may be concentrated in two ways;

1. by the removal of valueless material so as to leave a richer ore.

2. by solution of the valuable material and re-deposition at a lower level.

1- By Removal of Valueless Material:

Ore bodies formed in this manner are called **residual deposits**. The residual deposits are formed by chemical weathering process which removes gangue minerals and enriches valuable metals in situ or at nearby location. The most important example is formation of bauxite under tropical climate where abundance of high temperature and high rainfall during chemical weathering of granitic rocks produces highly leached cover rich in aluminum.

2. By Solution of the Valuable Material:

At the surface, where air and water are acting together, metals are oxidized, and carried down in solution. When they reach the ground water, which keeps out the air, metals are formed again and deposited. Copper pyrite is formed when sulfides are oxidized to sulphates, then copper pyrite is formed when the solution reached down to the level of the groundwater. At or below the ground-water level, the zone of enrichment may begin and continue as far down as the enrichment solutions have reached. Below this, again, the original ore will be found.

An example of the ore minerals that formed by chemical deposition is iron ores.

Iron ores:

Iron ores are rocks and minerals from which metallic iron can be economically extracted. The ores are usually rich in iron oxides and vary in color from dark grey, bright yellow, or deep purple to rusty red. The iron is usually found in the form of magnetite ($Fe3O4$, 72.4% Fe), hematite ($Fe2O3$, 69.9% Fe), goethite ($FeO(OH)$, 62.9% Fe), limonite ($FeO(OH)\cdot n(H2O)$, 55% Fe) or siderite ($FeCO3$, 48.2% Fe). There are three types of iron deposits. The first, and by far the most important, is **banded iron formations (BIFs),** so called because they are finely layered alternations of cherty silica and an iron mineral, generally hematite, magnetite, or siderite. The banded iron layers were formed in sea water as a result of cyclic variations in available oxygen, during what is known as the great oxidation event (2,400 million years ago). The oxygen in seawater released by photosynthetic bacteria is combined with dissolved iron in Earth's oceans to form insoluble iron oxides, which precipitated out, forming a thin layer on the ocean floor. This is followed by a time where no oxygen released in the water, and so silicates were precipitated on the thin iron layer. This cycle was repeated several times before oxygen prevailed on Earth, leading to the formation of the banded iron formation.

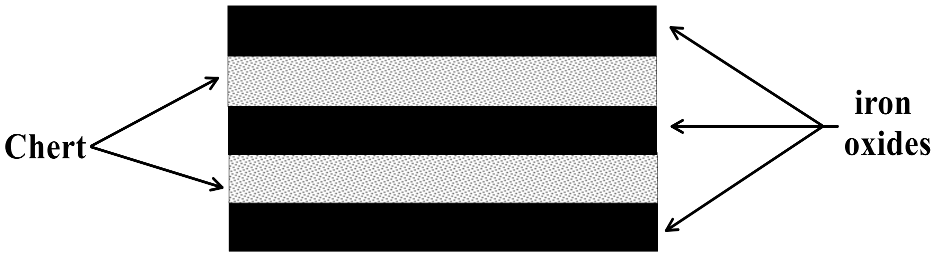


Figure 8: Sketch of banded iron formation.

The second type of the iron deposits is the **oolitic iron deposits** (also known as **ironstone**) which are chemically precipitated marine iron deposits, containing pinhead-sized ooliths (small, rounded, accretionary masses formed by repeated deposition of thin layers of an iron mineral).

The third type of the iron deposits is the **bog iron**. Bog iron is a form of impure iron deposit that develops in bogs or swamps by the chemical or biochemical oxidation of iron carried in solution. In general, bog ores consist primarily of goethite (FeO(OH)).

Mineral deposits in Egypt

Almost all types of mineral deposits are occurred in Egypt. They are generally categorized into three types; fuel deposits, metallic mineral deposits, non-metallic mineral deposits (refer to lecture 1). All the locations mentioned in the following paragraphs are shown on the map in Figure 1.

1- Fuel deposits:

Fuel deposits refer to the fossil fuel deposits such as oil and natural gas. They include:

Carbonate deposits:

- ***Coal:*** occurred in Uyun Musa (Springs of Moses) and Maghara mountain, north of Sinai. Maghara coal mine is the main producer for coal in Egypt from which the extracted coal can be used as fuel for electric power plants and cement factories.
- ***Carbonate-rich shales:*** they are shale rocks containing large amount of carbonate minerals such as calcite and dolomite. They can be used in cement manufacturing and as fuel for electric power plants. They occurred in Wadi Thura in Sinai.
- ***Oil shales:*** is an organic-rich fine-grained sedimentary rock containing kerogen (a solid mixture of organic chemical compounds) from which liquid hydrocarbons can be produced. They occurred accompanied with the phosphate rocks in the Red Sea governorates and the New Valley.

Radioactive mineral deposits:

They include the radioactive minerals such as uranium and thorium which are used as nuclear power fuel. They are occurred in many localities in both Eastern and Western Desert of Egypt. The most important occurrences are the Messikat mountain at km 70 on Qena-Safaga road and the Kattrani mountain (Western Desert, Fayium). In the Messikat mountain uranium occurred in the granite igneous rocks while in Kattrani mountain, they occurred in the shales and sandstone sedimentary rocks.

2- Metallic mineral deposits:

A. Iron Deposits

The Egyptian iron **ores** are of stratabound/stratiform type, ranging in age from early Proterozoic to Paleogene and can be chronologically categorized into: (a) Pre-Cambrian Banded Iron Formation (BIF); (b) oolitic (ironstones).

- ***Banded Iron Formations (BIF)*** occurrences are a restricted to the central segment of the Eastern Desert. Iron-formation bands range in thickness from few centimeters to one or two meters. Many of the iron-formation bands consist of iron oxide (hematite and magnetite) bands alternating commonly with chert along with silicates and rarely with carbonates. The banded iron formation that occurred in Um Nar area (Eastern Desert, north of Marsa Alam) is of Early Proterozoic age. Um Nar BIF is interpreted to be formed in a sedimentary environment. BIF also occurs in Wadi Karim area (South Quesseir City), where it is composed of iron-rich bands formed of magnetite, hematite, siderite, goethite with gangue of quartz, calcite, dolomite, and chlorite. Other important occurrences include Abu Marawat area (In the middle Eastern Desert between Qena and Safaga) and El Hadid mountain (south Eastern Desert northwest of Marsa Alam).

- ***<u>Oolitic Ironstones</u>*** are recorded in north Sinai, Wadi Qena and East Aswan. El Bahariya iron ore also is ooilitic ironstone composed mostly of laterite (iron-aluminum oxide). These lateritic iron deposits occupy local areas in El Bahariya area such as El Gedida, El Harra, and Ghorabi mine areas. Since the discovery and evaluation of El Bahariya Fe ores in the seventies of the last century, only El Gedida mine are under active operation, delivering Fe ores to the National Iron Steel Company (ISCo) near Cairo. The Fe ores in the other mines contain high amounts of harmful impurities, e.g., sulfur, phosphorous, arsenic and zinc. Thus, the other mines are out of work. East Aswan mines were the main source for iron, before the discovery of iron in El Baharya. But due to transportation expenses, work stopped in East Aswan. The oolitic ironstone in East Aswan mainly composed of hematite and goethite.

Gold:

The Eastern Desert of Egypt is well known as a gold-mining area since ancient times and more than 90 gold deposits and occurrences are spread in the basement rocks (metamorphic an igneous rocks) of Precambrian age. According to Botros (2004), Egyptian gold can be occurred as; stratabound deposits, non-stratabound deposits and placer deposits.

- ***Stratabound gold deposits:***

  This type occurs as well-defined stratigraphic unit within the BIFs in the Eastern Desert, such as Abu Marawat mountain and Um Nar area. It is also occurred within the volcanic massive sulphide deposit in the Eastern Desert include Um Samuki area.

- ***Non-stratabound gold deposits:***

  Non-stratabound gold deposits are divided into vein-type mineralization, which has constituted the main target for gold in Egypt since Pharaonic times, and disseminated-type mineralization hosted in hydrothermally altered rocks (alteration zones) which have recently been recognized as a new target for gold in Egypt. Mineralizing fluids of different sources are suggested for the formation of these deposits.

The vein-type gold is widespread in many parts of the Eastern Desert such as Abu Marawat, Sukkari areas and Atshani (South Aswan). The vein-type gold is the most-occurred form of gold in Egypt. Sukkari mine is still producing, while Atshani is old mine.

The disseminated-type gold is resulted by the alterations caused by the hydrothermal solutions. These alterations occur surrounding quartz veins. This type of gold is occurred in Sukkari and Abu Marawat areas.

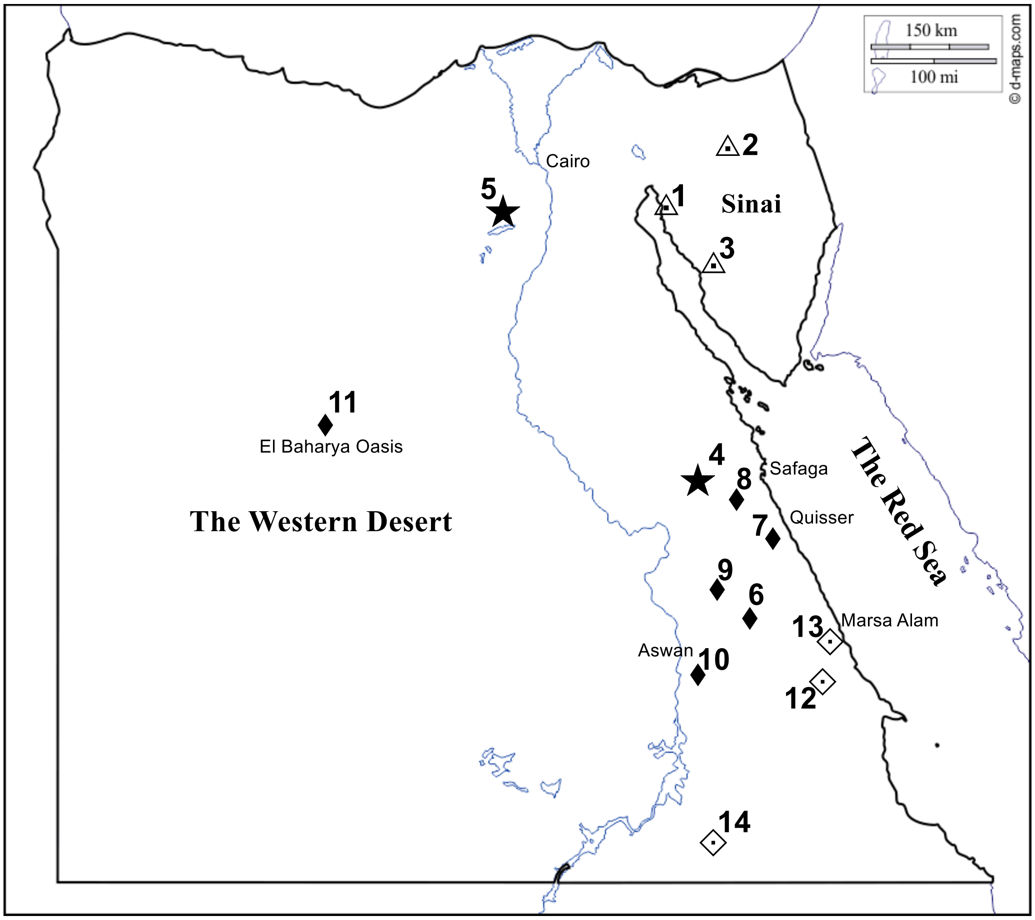
- ***Placer gold:***

Most placer gold deposits occur close to the quartz veins mostly in all over the Eastern Desert. The arid and hot climate that characterizes the Egyptian deserts results in dominantly mechanical weathering. This is the most important factor responsible for the disintegration of host rocks forming placer deposits by mechanical deposition. Gold placers in Egypt can be occurred as alluvial placers, beach placers and paleoplacers.

3- Non-metallic mineral deposits:

A. Phosphates:

Phosphate deposits (also called phosphorites) are stratified sedimentary rocks mainly composed of collophane mineral (calcium phosphates). They are usually associated with black shale, limestone, glauconite, chert, and siltstone. In Egypt, they belong to the Late Cretaceous-Paleogene time. Most of the phosphate deposits of Egypt are mainly belonged to the phosphate layer known as Duwi Phosphate Formation of the Late Cretaceous age. This phosphate layer attains maximum thickness in the central part of Egypt that extends from the Dakhla and Kharga oases in the west to the Red Sea from Qusseir to Safaga in the east. The name Duwi (phosphate) Formation was given by Youssef (1965), where the formation reaches maximum thickness (>70 m) in Duwi mountain west of Qusseir city. The distribution of phosphates in Egypt can be divided into seven domains (Fig. 2):



△ **Carbonate deposits** ★ **Radioactive minerals** ♦ **Iron deposits** ◇ **Gold deposits**

1 Uyun Musa (Springs of Moses)
2 Maghara Mountain
3 Thura
4 Messikat mountain
5 Kattrani mountain
6 Um Nar
7 Wadi Karim
8 Abu Marwat
9 El Hadid mountain
10 East Aswan
11 El Baharya Oasis
12 Um Samuki
13 Sukkari
14 Atshani

Figure 9: Map of Egypt showing the locations of the important mineral deposits.

1- The first represents the phosphorite occurrence in the Red Sea region, from Safaga in the north to Hammadat and Zug El-Bohar south of Qusseir. The phosphorite of this domain operated along half a century through underground mining. The mining activities stopped 30 years ago due to instability and the irregular structures of the phosphate beds.

2- The second domain represents the Nile Valley occurrence where phosphorite operated since about 100 years from Qena due north to Edfu due south.

3- The third domain represents the unexplored plateau at the western side of the Nile Valley, between Qena and Edfu and extending to the New Valley, where the discovery of optimistic potential resources is conceivable.

4- The fourth domain represents Abu Tartur plateau where excavation of the surface exposures and the low plateau supplies 2–3 million tons of commercial phosphorite per year. The available reserves grant consistent supply for the coming few decades.

5- The fifth domain represents the Dakhla Oasis, where the average thickness of the phosphorites varies between 1.5 and 3 m.

6- The sixth domain represents the phosphatic rocks exposed in Bahariya and Farafra Oasis and they are associated with radioactive minerals.

7- The seventh domain represents occur in north Sinai in Qabeliat mountain, Taba, Aref El-Naga, and Wadi El-Sabha.

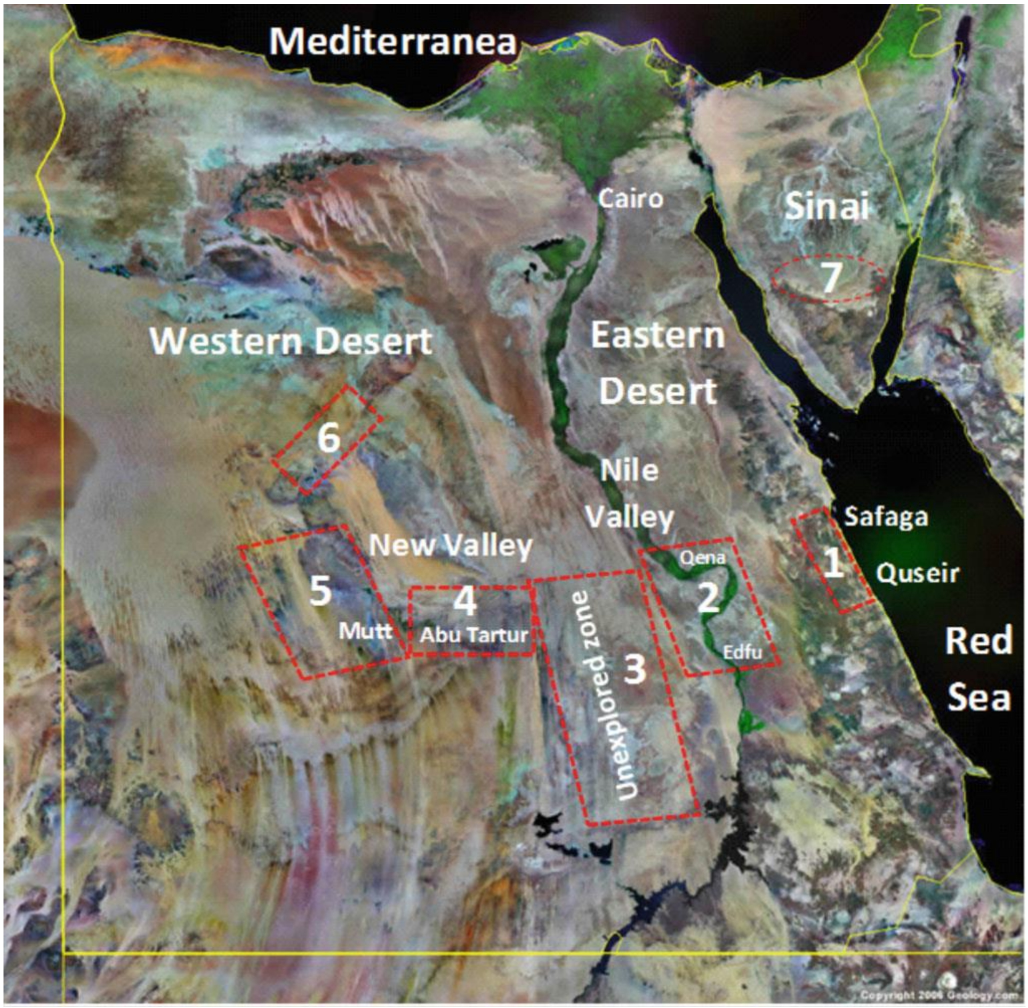


Figure 10: Satellite image of Egypt illustrating the main occurrences of the phosphate rocks.

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PART IV: PRACTICAL CLASSES

Practical classes part 1: Igneous rocks

A- Description items:

  a. Color
  b. Chemical composition
  c. Mineral composition
  d. Texture
  e. Grain size
  f. Degree of crystallinity
  g. Mode of occurrence
  h. Name of the rock

B- Rocks samples: Granite -Granodiorite – Diorite – Andesite – Rhyolite – Sphalerite – Basalt – Diabase – Gabbro – Serpentinite

Practical classes part 2: Clastic sedimentary rocks

A- Description items:

  a. Origin
  b. Mineral composition
  c. Grain size
  d. Cement
  e. Sorting
  f. Name of the rock

B- Rocks samples: Conglomerate – Breccia – Sandstone – Claystone – Mudstone - Shale

Practical classes part 3: Non-clastic sedimentary rocks

A- Description items:

  a. Origin
  b. Mineral components
  c. Cement
  d. Name of the rock

B- Rocks samples: Limestone – Chalk – Phosphorite

Practical classes part 4: Metamorphic rocks

A- Description items:

  a. Texture
  b. Type of metamorphism
  c. Agent of metamorphism
  d. Grade of metamorphism
  e. Grain size
  f. Mineral composition
  g. Parent rock
  h. Rock Name

B- Rocks samples: Slate – Quartizite – Schist – Gneiss – Megmatite - Marble