

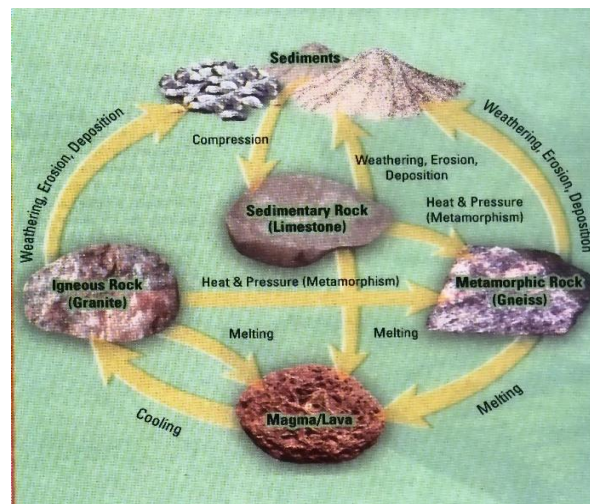
## Rocks and minerals

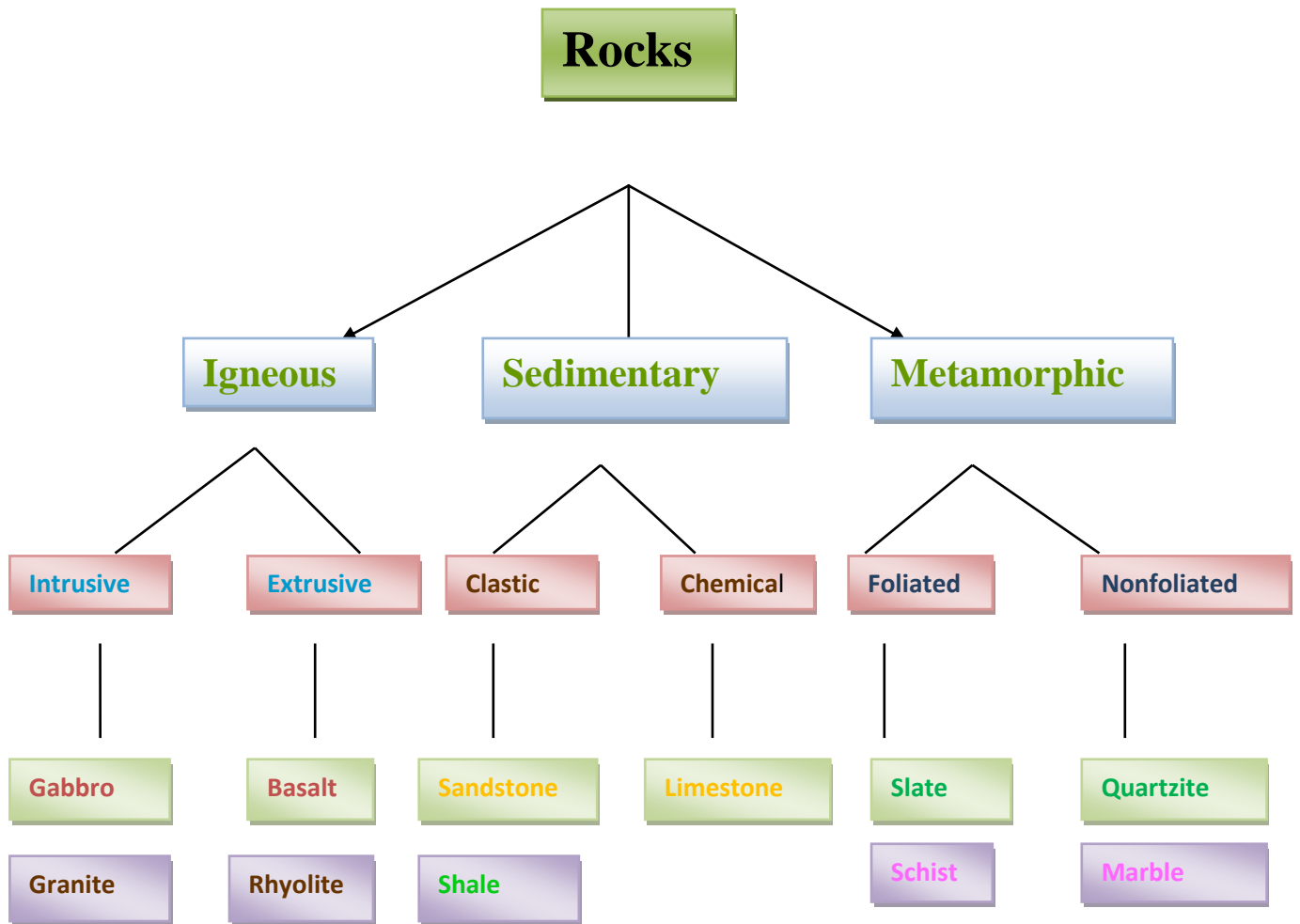
### What is Rocks?

Rocks are the materials that form the essential part of the Earth's solid crust. "Rocks are hard mass of mineral matter comprising one or more rock forming minerals". Rocks are formed from the molten material known as **magma**. The study of rocks is called **Petrology** (in Greek, petra means rock, logos means science). Petrology deals with the description of rocks; petrogenesis is the study of the origin of rocks.

### Formation of rocks

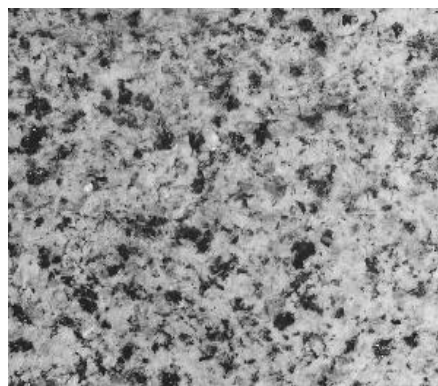
1. Cooling and consolidation of molten magma within or on the surface of earth = Igneous or **Primary rocks**
2. Transportation and cementation of primary rocks = **Sedimentary or Secondary rocks**
3. Alteration of the existing primary and secondary rocks = **Metamorphic rocks**





### 1. Igneous rocks (primary or massive rocks)

These are first formed in the earth crust due to the solidification of molten magma. Based on the mode of formation, they are further classified as extrusive and intrusive rocks



### Extrusive rocks or volcanic rocks

These rocks are formed due to the consolidation of magma on the surface of the earth. The magma, when it flows on the Earth surface is called LAVA. E.g. Basalt.

### Intrusive rocks or plutonic rocks

These rocks are produced due to solidification of magma below the surface of the earth. Plutonic – intrusive rocks solidifies at greater depth and Hypabassal rocks solidifies at shallow depth from the surface. E.g. Granite, syenite, diorite, Gabbro *etc.* Rocks formed in vertical cracks are called dykes and in horizontal cracks are called sills.

**Vesicular rocks:** Molten magma cools on the surface. Steam of water is entrapped into rocks and forms vesicles.

**Based on the silica content,** rocks are also classified as

1. Acid rocks : >65% SiO<sub>2</sub> (Granite, Rhyolite)
2. Intermediate : 56 to 65% SiO<sub>2</sub>  
(Sub acid rocks 60 to 65% SiO<sub>2</sub> (Syenite and Trachyte))  
(Sub basic rocks 56 to 60 % SiO<sub>2</sub> (Diorite and Andesite))
3. Basic rocks : 40 to 55% (Gabbro, basalt)

### Igneous rocks

| S.No | Rocks   | Origin                   | Essential minerals           | Common minerals                | Average specific gravity | Remarks                         |
|------|---------|--------------------------|------------------------------|--------------------------------|--------------------------|---------------------------------|
| i.   | Granite | Plutonic holocrystalline | Quartz (20 to 30%)           | Hornblende, magnetite, mica    | 2.64                     | Light coloured white or reddish |
| ii.  | Syenite | Plutonic Holocrystalline | Quartz, orthoclase           | Hornblende, magnetite, biotite | 2.80                     | Light coloured white or reddish |
| iii. | Diorite | Plutonic Holocrystalline | Quartz                       | Hornblende, magnetite, biotite | 2.85                     | Darker                          |
| iv   | Gabbro  | Plutonic Holocrystalline | Labradorite, augite, olivine | Hornblende, ilmenite           | 3.0                      | Blakish                         |

|     |          |   |                                    |                         |     |         |
|-----|----------|---|------------------------------------|-------------------------|-----|---------|
| v.  | Dolerite | Hypabasal                                   | Labradorite,<br>augite,<br>olivine | Hornblende,<br>ilmenite | 3.0 | Blakish |
| vi. | Basalt   | Volcanic<br>crystalline with<br>glassy mass | Labradorite,<br>augite,<br>olivine | Hornblende,<br>ilmenite | 3.0 |         |

## 2. Sedimentary rocks

These rocks are formed from the consolidation of sediments accumulated through wind or water action at the surface of the earth. Many are deposited in layer or formed through chemical reactions as precipitates from aqueous solutions. Sediments may contain various size particles cemented together by substances like  $\text{SiO}_2$ ,  $\text{Fe}_2\text{O}_3$  or lime. These rocks are also called as clastic rocks.

**Based on the origin, the sedimentary rocks are classified as**

1. Residual : Laterite
2. Transported
  - a. Deposited as solids in suspension : Sandstone, shale
  - b. Deposited by chemical precipitation : Limestone, ironstone
  - c. Deposited through agency of organic matter: Peat, Phosphatic deposits

**Based on the grain size, sedimentary rocks are classified as**

1. Rocks with boulder pebbles sized minerals (Rudaceous) : Conglomerate
2. Rocks with sand size particles (Arenaceous) : Sandstone
3. Rocks with silt size particles (silt rocks) : Siltstone
4. Rocks with clay size particles (Argillaceous) : Shale

### Sedimentary rocks

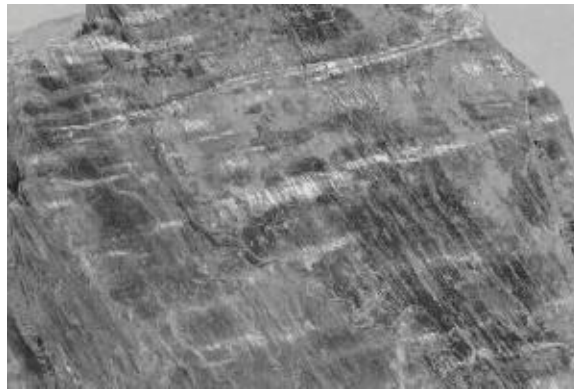
| S.No | Rock      | Mineral composition  | Colour and structure                           |
|------|-----------|--|--|
| 1.   | Sandstone | Mainly quartz with some $\text{CaCO}_3$ , iron oxides and clay                     | Light to red, granular                         |
| 2.   | Shale     | Clay minerals, quartz and some organic matter                                      | Light to dark thinly laminated                 |
| 3.   | Limestone | Mainly calcite with some dolomite, iron oxides, clay, phosphate and organic matter | Light grey to yellow, fine grained and compact |



### 3. Metamorphic rocks

These are formed from igneous and sedimentary rocks under the influence of heat, pressure, chemically active liquids and gases. Change may occur in mineral composition or texture or both. The changes due to water is called **hydro metamorphosis** and due to pressure is called **dynamo metamorphosis**

|            |                      |
|------------|----------------------|
| Sand stone | : Quartzite          |
| Shale      | : Slate/mica, schist |
| Lime stone | : Marble             |
| Granite    | : granite gneiss     |
| Dolerite   | : Hornblende gneiss  |



### Metamorphic rocks

| S.No. | Rock      | Mineral composition         | Colour and structure                                    |
|-------|-----------|-----------------------------|---|
| 1.    | Gneiss    | Formed from granite         | Alternating light and dark colours, banded and foliated |
| 2.    | Schist    | Formed from basalt or shale | As original rock, foliated                              |
| 3.    | Quartzite | Formed from                 | Light or brown, compact and uniform texture,            |

|    |        |                        |   |
|----|--------|------------------------|---|
|    |        | sandstone              | foliated structure  |
| 4. | Slate  | Formed from shale      | Grey to black, compact and uniform texture, foliated structure              |
| 5. | Marble | Formed from lime stone | Light red, green, black, compact fine to coarse texture, foliated structure |

## Brief description of important rocks-Mineralogical composition

### Sedimentary rocks

Formed through the agency of water. Also called as **aqueous rocks**. Formed from sediments brought by water. The sediment may contain various types of substances and sizes of particles. The particles are cemented by silica, iron oxide or lime to give a consolidated form. The rocks are mostly deposited in layers or strata – so called as **stratified rocks**. Sometimes they are formed by cooling, evaporation or by direct chemical precipitation. Anyway they are of secondary origin.



### Sedimentary rocks divided into six groups as follows

1. **Arenaceous:** Formed of the deposits of coarse grained particles. They are composed of siliceous material derived from the disintegration of older rocks. The fragmental material so derived is deposited in beds of varying thickness through the agency of water. Depending upon the nature of cementing material present, some arenaceous rocks are hard and refractory, but most are loose and fall away very easily. E.g. Sandstone, grit, conglomerate and breccia.
2. **Argillaceous rocks:** Consist of small sized particles known as clay. They are composed of hydrated silica of alumina in admixture with sand, various other silicates and calcareous matter. When clay is deposited mainly of silicate of alumina, it is known as kaolin or China clay. E.g. clay, mudstone, shale and fuller's earth.

**3. Calcareous rocks:** Consists of carbonate of lime or lime and magnesia. They may be of sedimentary origin or formed by chemical precipitation or by organic agency. When, they are of organic agency, they are composed mainly of debris from plant and animal life. They are formed either by growth and decay of organisms in situ or by the transport and subsequent accumulation of their remains. The rocks so formed are found in layers, which vary considerably in depth of thickness.

When formed by chemical precipitation, the calcareous material is deposited in the form of layers/sheets from waters containing calcium carbonate in solution. The precipitate when first formed is usually soft and chalky, but soon acquires a hard, compact structure and crystalline texture. The important calcareous rocks of aqueous origin are limestone, chalk, magnesian, ferruginous limestones, dolomite, marks of various varieties and coral.

**4. Carbonaceous rocks:** Formed from decomposing vegetation under anaerobic conditions. When plants undergo decomposition under restricted air supply, a greater portion of the carbonaceous matter is retained and the material is slowly converted into coal. E.g. peat, lignite, coal, anthracite.

**5. Siliceous rocks:** Siliceous rocks of organic origin formed from parts of minute plants and animals like diatoms, radiolaria etc, some are soft and friable and crumble to powder very easily. Others like flint and chert are hard and compact.

**6. Precipitated salts:** Consist mainly of deposits formed as rock masses either by cooling, evaporation or by chemical precipitation. Water charged with acid or alkaline material, acting under pressure as it does under subterranean regions, dissolves various mineral substances from rocks with which it comes in contact. The salts thus formed deposit as rocks and such rocks vary in composition. They are

- i. Oxides: e.g. hematite, limonite, bauxite and quartz.
- ii. Carbonates: e.g. stalactite, stalagmite, magnetite and limestone.
- iii. Sulphates: e.g. gypsum and anhydrite
- iv. Phosphates: e.g. phosphorite
- v. Chlorides: e.g. rock salt.

## **Metamorphic rocks**

The igneous and sedimentary rocks after they were first formed sometimes undergo a change. When the change is considerable, the rock is said to have undergone metamorphosis and the new rock is known as a metamorphic rock. The metamorphism is brought about by the action of water, heat or pressure or by the combined action of any one of these or all. The change brought about by water is hydro-metamorphism. The change brought about by heat is thermo-metamorphism. The change brought about by pressure is

dynamo- metamorphism. The changes that are brought about are both physical and chemical in character. In some cases the metamorphism is so pronounced that the new rock looks quite different from the original.

The action of water tends to remove some material or introduce new materials. By the introduction of a cementing material like silica, lime or iron oxide, loose sand may be turned into sandstone or sandstone into a quartzite. By the removal of certain constituents by percolating waters, basalt or granite may be converted into a laterite.

The action of heat hardens the rock and develops new crystals in it. Crystalline marble is produced this way from amorphous limestone by the action of heat and pressure. Due to pressure, the crystals of the original rock get pressed or flattened and the new rock is foliated. When foliation is slight, the layers are inseparable and it is called as gneiss. If foliation is complete with distinct and separable layers it is called as schist.

#### Mineralogical composition of important rocks

| SI. No                   | Rocks        | Grain size                 | Essential minerals  | Most common accessory minerals | Average specific gravity | Remarks                          |
|--------------------------|--------------|----------------------------|---|--------------------------------|--------------------------|----------------------------------|
| <b>(i) Igneous rocks</b> |              |                            |   |                                |                          |                                  |
| 1.                       | Granite      | Plutonic Holocrystalline   | Predominant quartz 20-35 orthoclase                               | Hornblende mica, magnetite     | 2.64                     | Light coloured, White or reddish |
| 2.                       | Syenite      | - do -                     | Predominance quartz 100% plus of orthoclase, nepheline and albite | Hornblende, biotite, magnetite | 2.08                     | - do -                           |
| 3.                       | Granodiorite | - do -                     | Intermediate quartz plagioclase exceeds orthoclase                | - do -                         | 2.07                     | Medium coloured reddish          |
| 4.                       | Diorite      | - do -                     | Intermediate quartz absent plagioclase                            | - do -                         | 2.85                     | Darker                           |
| 5.                       | Gabbro       | - do -                     | Labradorite augite + olivine                                      | Hornblende, ilmenite           | 3.00                     | Blackish                         |
| 6.                       | Dolerite     | Hypabyssal ophitic texture | - do -  | - do -                         | 3.00                     | - do -                           |



|    |        |   |        |        |      |        |
|----|--------|---|--------|--------|------|--------|
| 7. | Basalt | Volcanic micro crystalline with glassy mass | - do - | - do - | 3.00 | - do - |
|----|--------|---|--------|--------|------|--------|

| SI.No | Name of the type         | Mineral composition  | Colour and structure  |
|-------|--------------------------|--|---|
| (ii)  | <b>Sedimentary rocks</b> |  |   |
| 1.    | Sandstone                | Mainly quartz with same contents, such as calcium carbonate, iron oxides and clays               | Light to red, usually granular in structure                       |
| 2.    | Shale                    | Clay minerals, quartz and some organic matter  | Light to dark thinly laminated structure                          |
| 3.    | Limestone                | Mainly calcite or calcite and dolomite with some iron oxides, clay, phosphate and organic matter | Usually light grey to yellow usually fine grained and compact     |
| (iii) | <b>Metamorphic rocks</b> |  |   |
| 1.    | Gneiss                   | Formed from granite, mineral composition like that of granite                                    | Alternating light and dark colours. Banded and foliated structure |
| 2.    | Schist                   | Formed from basalt or shales. Mineral composition much as that of original rock                  | Much as original rock, foliated structure                         |
| 3.    | Quartzite                | Formed from sandstone and of same composition  | Light to brown. Compact and uniform texture, foliated structure   |
| 4.    | Slate                    | Formed from shale and of same composition  | Grey to black, compact, and uniform texture                       |

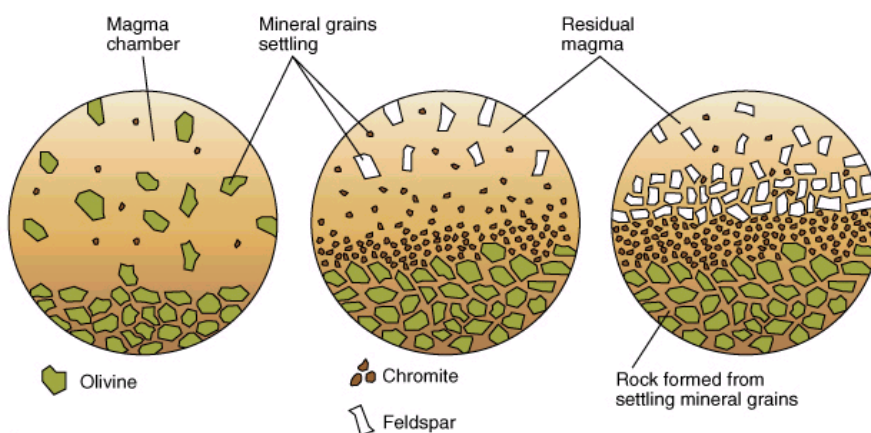
|    |        |                       |  |
|----|--------|-----------------------|--|
|    |        |                       | foliated structure   |
| 5. | Marble | Formed from limestone | Light red, green, black, compact, fine to coarse texture, non-foliated structure |

## Minerals

Minerals are naturally occurring solids with a definite chemical composition and crystal structure. "Solid substances composed of atoms having an orderly and regular arrangement"

When molten magma solidifies, different elements present in them freely arrange in accordance with the attractive forces and geometric form. Silica tetrahedron is the fundamental building blocks for the formation of different minerals. ( $\text{SiO}_2$ ). Different silicate minerals are ortho silicates, ino-silicates, phyllosilicates and tectosilicates. There are non-silicate minerals also. These are different oxides, carbonates, sulphates, phosphates etc.

Minerals that are original components of rocks are called **primary minerals**. (feldspar, mica, etc.). Minerals that are formed from changes in primary minerals and rocks are called **secondary minerals** (clay minerals). Those minerals that are chief constituents of rocks are called as **essential minerals** (Feldspars, pyroxenes micas etc) and those which are present in small quantities, whose presence or absence will not alter the properties of rocks are called **accessory minerals** (tourmaline, magnetite etc).



**Of the >2000 known minerals, only few occur in abundance in the Earth crust.**

| Minerals (arranged in the order of their crystallization) | Important constituents | Percent distribution |
|---|------------------------|----------------------|
| <b>Primary minerals</b>                                   |                        |                      |
| <b>Ferro magnesium minerals</b>                           |                        |                      |
| Ortho-ino silicates                                       |                        | 16.8                 |
| Olivine   | Fe, Mg                 |                      |
| Pyroxenes   | Ca, Na, Fe, Mg         |                      |
| Amphiboles  | Ca, Na, Fe, Mg, Al, OH |                      |
| Phyllo Silicates  |                        | 3.6                  |
| Biotite   | K, Fe, Mg, Al, OH      |                      |
| Muscovite   | K, Al, OH              |                      |
| <b>Non-Ferro Magnesium</b>                                |                        |                      |
| Tecto Silicates   |                        |                      |
| Feldspars   |                        | 61.0                 |
| Anorthite   | Ca, Al                 |                      |
| Albite  | Na, Al                 |                      |
| Orthoclase  | K, Al                  |                      |
| Quartz  |                        |                      |
| <b>Secondary clay minerals</b>                            |                        |                      |
| Minerals  | Na, K, Ca              | 11.6                 |
| Others  | Mg, Fe, Al, OH         | 6.0                  |

### **Ferro magnesium minerals**

**Pyroxenes and amphiboles:** The pyroxenes and amphiboles are two groups of ferromagnesian minerals (heavy group) the structure of which consists of long chains of linked silica tetrahedral. The pyroxenes consist of a single chain (2 oxygen shared in each tetrahedron) whereas amphiboles consist of a double chains (alternately 2 and 3 oxygen atoms shared successive tetrahedral). These chain silicates are sometimes referred to inosilicates. The pyroxene group of minerals comprised of different minerals namely enstatite, hypersthene, diopside and augite, of which **augite** is the most important minerals in soils and it is found in basic rocks. The amphibole group of minerals are common in acidic rocks and it can be represented by the isomorphous series between tremolite actinolite olivine and hornblende. Hornblende weathers fairly rapidly. Olivine (olive-green) minerals from an isomorphous series between forsterite ( $\text{Mg}_2\text{SiO}_4$ ) and fayalite ( $\text{Fe}_2\text{SiO}_4$ ).

Pyroxenes are more basic in character and therefore it weathers more rapidly than amphiboles.

**Micas:** Micas occur extensively in soils. They are primarily originated from the parent rock from which the soil is derived. Generally soils are inherited from well-ordered and imperfectly ordered micas. Well-ordered micas are derived from sedimentary rocks. The most common well ordered micas are muscovite, paragonite, biotite and phlogopite (trioctahedral). The imperfectly ordered micas contain less potassium and more water as compared to well-ordered micas and this type of micas are most abundant in the clay fraction of soils. Among the ordered micas, biotite weathers more rapidly than muscovite. In imperfectly ordered micas, many of the illite-type specimens as well as the disordered micas of soils exhibits some mixed-layering with phases of vermiculite, smectite group of minerals, chlorite and intergrades of several of these species.

### Non-ferromagnesium minerals

**Feldspars:** Feldspars are anhydrous aluminosilicates of K, Na and Ca and occasionally of other large cations such as Ba. The feldspar structure consists of tetrahedral which are attracted by sharing each oxygen atom between neighbouring tetrahedron. The tetrahedral contain mainly Silicons with sufficient Al substitution. It belongs to the group of minerals that are light in weight. There are two groups of feldspars: **(i) potassium feldspars** ( $\text{KA1Si}_3\text{O}_8$ ) include orthoclase, microcline, adularia and **sanidine**. **Orthoclase and microcline are more common in the plutonic and metamorphic rocks.** The potassium feldspars occur commonly in the silts and sands of soils and also abundant in clay-size, **(ii) plagioclase feldspars**- a series consisting of a solid solution of albite ( $\text{NaA1Si}_3\text{O}_8$ ) high in sodium and **anorthite** ( $\text{CaA1}_2\text{Si}_2\text{O}_8$ ) high in calcium. Plagioclase weathers more rapidly than orthoclase.

**Quartz:** It is very densely packed and occurs in a high degree of purity. It is strongly resistant to weathering as the structure is densely packed, electrically neutral and free from any substitution. It is the most abundant mineral next to feldspars. Serpentine, a hydrous magnesium silicate occurs more commonly as a secondary product. Garnets are characteristic of metamorphic rocks and are very hard and most resistant to weathering.

### Silicate minerals

#### Ortho/ Neosilicates

The minerals in this group are composed of single tetrahedral linked together by Mg or Fe. To effect a break down, it is considered sufficient to sever the weaker Mg-O or Fe-O bonds. Non-withstanding the bond energy considerations susceptibility of the minerals in this group to breakdown by weathering appears to vary considerably from one mineral to another,

e.g., zircon makes the mineral comparatively hard. On the other hand, the looser packing of oxygens in olivine makes the mineral weather faster.

### Inosilicates

The inosilicate group has in its structure single-chain (pyroxenes) and double chain (amphiboles) silica tetrahedral linked together by Ca, Mg, or Fe. Because of the presence of many weak spots provided by the Ca-O, Mg-O, or Fe-O bonds, these minerals tend to weather rapidly

### Phyllosilicates

Linkages of silica tetrahedral and Alumina octahedral sheets by mutually shared oxygen atoms form the basis for the structure of this group. Some of the minerals, e.g., biotite and muscovite, are relatively susceptible to weathering, whereas others, like clay minerals, are resistant weathering products and further breakdown of clays is difficult. Disruption of interlayer ions, or through cleavage of Al-O bonds in tetrahedral and octahedral positions.

### Tectosilicates

The minerals are considered solid solution minerals with a framework of silica tetrahedral, in which the cavities are occupied by Na, Ca, and so on. The minerals in this group may also vary considerably in their resistance to weathering, e.g., leucite and plagioclase versus potash fertilizers. The relative degree of close packing of atoms in their structural framework may be the reason for such variability in weathering. Increased substitution of Al and Si in tetrahedral of plagioclase mineral is also considered a factor that makes these minerals weaker than potash feldspars.

### Non-silicate minerals

#### Oxides:

Hematite ( $\text{Fe}_2\text{O}_3$ )

Limonite ( $\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ )

Goethite ( $\text{FeO}(\text{OH}) \cdot \text{H}_2\text{O}$ )

Gibbsite ( $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$ )

The red, yellow or brown colours in soils are due to the presence of goethite and hematite, which occur as coatings on the surface of soil particles.

#### Carbonates:

Calcite ( $\text{CaCO}_3$ )

Dolomite ( $\text{CaMgCO}_3$ )

#### Sulphates:

Gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ )

**Phosphates:** Apatite (Rock phosphate  $\text{Ca}_3(\text{PO}_4)_2$  - primary source of phosphorus)

## Physical properties of minerals

1. Color
2. Streak
3. Fracture/ cleavage
4. Hardness
5. Luster
6. Crystal form
7. Taste
8. Specific gravity
9. Magnetism
10. Effervescence (fizz)
11. Birefringence
12. Fluorescence

### Additional reading

#### Color

- Denotes the natural colour of the mineral
- The most obvious, but least reliable.
- Calcite has more colours
- Sulfur and Pyrite have same colour



#### Streak

- Refers to the colour of the powder form of the mineral When an unknown mineral is rubbed against a piece of unglazed porcelain (streak plate) it produces a colored line.
- Hematite - red
- Magnetite - Black
- Talc - white



## Fracture and Cleavage

These terms describe the way a mineral breaks. Fracture is the nature of the surface produced as a result of its breakage.

- Conchoidal - curved surface
- Uneven - Uneven surface
- Hackly - Jagged surface
- Earthy - Like chalk
- Even - Smooth

## Cleavage

Some minerals break along certain well defined planes called cleavage planes.

- Gypsum - 1 set
- Calcite - 2 sets
- Fluorite - 3 sets

## Hardness

This is how resistant a mineral is to being scratched. We use the Mohs scale to classify a given mineral's hardness. Try to scratch the unknown mineral with various items, such as a fingernail (hardness of about 2.5), a coin (3), a steel nail (5.5) and a steel file (7).

## MOHS SCALE OF HARDNESS

| Mineral  | Hardness | Mineral  | Hardness |
|----------|----------|----------|----------|
| Talc     | 1        | Feldspar | 6        |
| Gypsum   | 2        | Quartz   | 7        |
| Calcite  | 3        | Topaz    | 8        |
| Fluorite | 4        | Corundum | 9        |
| Apatite  | 5        | Diamond  | 10       |



### Luster

The way a mineral reflects light Metallic (Magnetite); sub-metallic, Vitreous (Opal), Resinous (Pyrite), Pearly, Adamantine (Diamond), silky (Asbestos) and greasy.



### Crystal form

Crystal structure is the result of regular grouping of atoms that are homogeneous. A crystal is a polyhedral form, which means it is a geometric solid. It has a specific set of faces, corners and edges, which is consistent with the geometric packing of the atoms

There are 6 basic crystal forms

1. Isometric
2. Tetragonal
3. Hexagonal
4. Orthorhombic
5. Monoclinic
6. Triclinic





### **Taste**

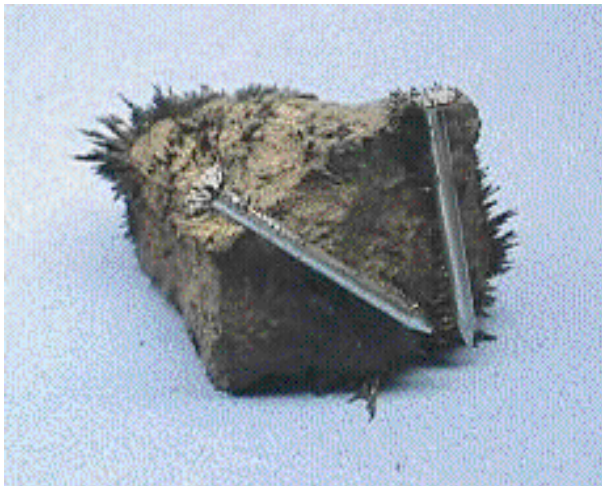
This property is used to identify the mineral halite (salt)

### **Specific Gravity**

This characteristic relates to the minerals density. If the mineral is heavy for its size, then it has a high specific gravity

### **Magnetism**

Is the mineral magnetic (try using a compass), or is it attracted by a magnet? This property is characteristic of Magnetite.



### **Effervescence**

When some minerals are exposed to acids, they begin to fizz (calcite).

### **Birefringence**

This is also known as double refraction. Birefringent minerals split the light into two different rays which gives the illusion of double vision in this Iceland Spar Calcite

### **Fluorescence**

Some minerals display the phenomenon of photoluminescence.

They "glow" when exposed to UV light.

Opal and Fluorite.

### Formation of secondary minerals, Clay minerals & Amorphous minerals

The secondary minerals are formed at the Earth's surface by weathering of the preexisting primary minerals under variable conditions of temperature and pressure. During weathering, water accompanied by  $\text{CO}_2$ , from the atmosphere plays an important role in processes, such as hydrolysis, hydration and solution. As a result the primary minerals are altered or decomposed.

#### Feldspar + water — clay mineral + cations + anions + soluble silica

Because of weathering, many elements are released into solution; a part of which may be used as a source of plant nutrients, a part may be leached out into the groundwater; still another part together with other constituents of the environment (like  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ) may recombine to form secondary minerals. The most commonly formed secondary minerals are clay minerals (e.g. illite, montmorillonite, kaolinite, etc.) and iron and aluminium oxides. Other secondary minerals observed in soils, especially in arid and semi-arid (dry) regions are gypsum, calcite, attapugite and apatite.

### SILICATES

- Clay minerals: hydrous aluminosilicates, with layer structure similar to micas, e.g. illite, montmorillonite, kaolinite, etc.

### NON-SILICATES

--Oxides, hydroxides or oxyhydrates of Si, Al and Fe

|                    |  |
|--------------------|--|
| Haematite          | $\text{Fe}_2\text{O}_3$                      |
| Goethite; Limonite | $\text{FeO}(\text{OH})_n \text{H}_2\text{O}$ |
| Gibbsite           | $\text{Al}(\text{OH})_3$                     |

### Clay Minerals

Clay minerals in soils are formed from primary minerals due to weathering processes. These clay minerals are of size  $<0.002$  mm and are considered to be the most reactive part of soil. Important soil properties like nutrient and water holding capacity are controlled by clay minerals. These minerals are layered silicates consisting of silica tetrahedron and aluminium octahedron.

- 1) 1 silicon tetrahedron + 1 aluminium octahedron = 1:1 clay mineral (Kaolinite)
- 2) 2: 1 non-expanding clay mineral
  - i. Black mica (Biotite)
  - ii. White mica (Muscovite)
  - iii. Weathered mica (illite)
- 3) 2: 1 expanding clay mineral
  - i. Partially expanding (Vermiculite)

## ii. Fully expanding (Montmorillonite)

### 4) 2: 2 clay mineral

(chlorite)

Of the naturally-occurring inorganic crystalline minerals found in the clay fraction of soils, the most commonly observed are layer silicates (illite, montmorillonite, chlorite, vermiculite, kaolinite). Besides, O, OH, Al and Si, they contain Mg, Fe and K in large amounts. They are variable in colour (white, grey, light yellow) depending on their chemical composition. In soils, the clays and oxihydrates of iron which form coatings on mineral grains impart shades of yellow, brown or red colour to soils.

The clay minerals carry a significant negative electrical charge on their surfaces and have a structure like that of mica. In some cases, the groups of sheets are not firmly bounded together and water molecules can enter in their crystal lattice. This can cause considerable swelling due to change in soil moisture content. This is the case in Vertisols (black cotton Soils) of India and NE Iraq, where deep and wide cracks on the surfaces are suggestive of the shrink-swell characteristics of soil clays.

Owing to the negative electrical charge on the clay surfaces, the cations are attracted to regions of electrical charge around the clay minerals. These cations do not get bounded permanently and can be exchanged for other cations. The amount of charge varies depending upon the type of clay mineral and it is referred to as the cation exchange capacity. Because of this exchange, there is always a balance between the concentration of cations in soil water and those adsorbed on the surfaces of the particles. Rain water percolating through the soil leaches out many meta cations (K, Na, Ca, Mg) together with the existing soil-water and replaces it with new water containing  $H^+$  ions and may render the soils acidic in reaction. The  $H^+$  concentration is expressed in terms of pH\*. A soil with high pH ( $>7$ ) is alkaline while a soil with low pH ( $<7$ ) is acidic in nature.

- pH is expressed in terms of negative log to the base 10 of  $H^+$  ion concentration.

### Distribution

- While primary minerals are observed in all rocks and in sand and silt fractions of soils, the secondary minerals dominantly occur in the clay fractions of almost all soils and in sedimentary rocks, especially shales. The kind and proportion of mineral(s) observed in a soil depend on the kind of parent material and weathering intensity (to which it has been exposed.) The most common clay mineral observed is illite. Apart from illite, smectite predominates in the cracking-clay soils (of Australia, northern Iraq and central India north-east Africa), kaolinite in the highly-weathered soils of the inter tropical zones (of southern India, South America, S.E. Asia) and southern Iraq, western India). In view of their high

surface area and negative charge on them, they are considered as a source of cation adsorption and cation release which are so important in acidic soil fertility.

### **Non-Silicates**

#### **Oxides, Hydroxides or Hydrated-oxides group**

We have already seen that oxygen is present in great abundance (46.7%) in the Earth's crust. The oxide minerals are found by the direct combination of elements (present in the Earth's crust) with oxygen.

The oxides are usually harder than any other mineral, except the silicates. The most important soil-forming oxide minerals are:

|           |   |
|-----------|---|
| Haematite | : $\text{Fe}_2\text{O}_3$                           |
| Limonite  | : $\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ |
| Goethite  | : $\text{FeO}(\text{OH}) \cdot n\text{H}_2\text{O}$ |
| Gibbsite  | : $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$  |

#### **Haematite, $\text{Fe}_2\text{O}_3$**

It varies in colour from red to blackish and has reddish streak. It has a metallic luster and hardness (H) of about 5. Its presence in rocks is indicative of quick chemical change. Haematite alters to limonite, magnetite, pyrite and siderite. It occurs as coatings on sand grains and acts as a cementing agent. It swells on absorbing water to form hydrated iron oxide, i.e. limonite,  $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$  and goethite,  $\text{FeO}(\text{OH}) \cdot n\text{H}_2\text{O}$ .

#### **Limonite or Bog Iron, $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$**

It is hydrated ferric oxide, yellow to brown in colour and is of wide occurrence. It is the final product of most iron minerals and hence is resistant to any further change, except for absorption of water. It is an important colouring and cementing agent in soils, iron. Limonite is a common alteration product of pyrite, magnetite, hornblende and pyroxene. It may be present in the form of iron concentration.

#### **Goethite, $\text{FeO}(\text{OH}) \cdot n\text{H}_2\text{O}$**

Most materials, called limonite, are goethite with some adsorbed water. It is usually white but may be pink or grey in colour. Its hardness is 5.3

#### **Gibbsite (Hydrargillite), $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$**

It is the most common aluminium compound in soils. Its natural colour is white. It is abundantly observed in highly-weathered soils of the tropical environment, supporting Laterites (Oxisols). Its presence in soils suggests extreme degree of weathering and leaching under well drained conditions.

The red, yellow or brown colour in soils is due to the presence of goethite and hematite which occur as coating on the surfaces of soil particles, especially clay.

## Carbonate Group

The basic compounds, like  $\text{Mg}(\text{OH})_2$ , and  $\text{Ca}(\text{OH})_2$  combine with  $\text{CO}_2$  or carbonic acid to form carbonates as under:

### Calcite, $\text{CaCO}_3$

A white mineral, with hardness of 3, is widely distributed in sedimentary rocks, like limestone and decomposes easily to calcium bicarbonate as:



### Dolomite, $\text{Ca Mg}(\text{CO}_3)_2$

Dolomite is less-readily decomposed than calcite; it is the chief source of Mg in soils.

### Siderite, $\text{FeCO}_3$

It is an alteration product of other iron-bearing minerals, having hardness of 4 and may itself alter to hematite or limonite. It is an important mineral in waterlogged soils.

## Sulphate Group

Sulphate is a complex group formed by the combination of 1 sulphur and 4 oxygen ions, which further reacts with Ca to form calcium sulphate (anhydrite,  $\text{CaSO}_4$ ) On hydration it forms gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ )

### Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$

It is a common mineral in desert soils and in sedimentary rocks having a hardness of 2. It is slightly soluble in water and gets most-easily leached. It precipitates as very fine, powdery mycelium from ground waters rich in Ca and  $\text{SO}_4$  ions (as observed in the Mesopotamian Plain of Iraq where hyper aridic prevail). In India, it is used as an amendment to reclaim sodic soils and also acts as a source of Ca and S for plants. Under the hot, aridic climatic environments of Iraq, the presence of gypsum in high amounts is a problem, as it causes civil structures to collapse and makes sink-holes in soils, resulting in loss of irrigation water.

## Phosphate Group

### Apatite, Rock Phosphate

It is a primary source of phosphorus in soils. Its hardness is 5 in Mohs's scale. It decomposes readily under the influence of carbonic acid. It becomes immobile in calcareous soils as it readily combines with clays, with clays, Fe-Al hydrous oxides, calcium carbonate to form rock phosphate. It also precipitates under acidic environment, as Fe and/or Al-phosphate.

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