

# DEFINITION OF ROCKS AND MINERALS

PREPARED BY

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## ROCKS AND MINERALS

### 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.

They are crystalline and known as **Crystalline rocks**. Also called as massive rocks as they occur in masses. Igneous rocks mainly consist of primary minerals of which quartz, feldspar, amphiboles, pyroxenes and micas are the most common.

Based on the mode of formation, they are further classified as extrusive and intrusive rocks

##### a. 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

##### b. 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 : >66 % SiO<sub>2</sub> (e.g. Granite, Rhyolite)
- 2. Intermediate : 56 to 65 % SiO<sub>2</sub>
  - i. (Sub acid rocks 60 to 66 % SiO<sub>2</sub> e.g. Syenite and Trachyte)
  - ii. (Sub basic rocks 56 to 60 % SiO<sub>2</sub> e.g. Diorite and Andesite))
- 3. Basic rocks : 40 to 55 % (e.g. 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, augite, olivine	Hornblende, ilmenite	3.0	Blakish
vi.	Basalt	Volcanic crystalline with glassy mass	Labradorite, augite, olivine	Hornblende, ilmenite	3.0	



## **Fig. Igneous rocks**

### **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, aqueous, stratified rocks.

#### **SEDIMENTARY ROCK FORMATION**

Four stages

Weathering, Transportation, Deposition or sedimentation, Diagenesis (Compaction and Cementation)

#### **i) Based on the origin, the sedimentary rocks are classified as**

1. Residual : Laterite

2. Transported

- Deposited as solids in suspension : Sandstone, shale
- Deposited by chemical precipitation : Limestone, ironstone
- Deposited through agency of organic matter : Peat, Phosphatic deposits

#### **ii) 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

#### **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.

E.g. Sandstone, grit and conglomerate.

#### **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

**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 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.

E.g. limestone, chalk, magnesia, ferruginous limestones, dolomite and coral.

**Carbonaceous rocks:**

Formed from decomposing vegetation under anaerobic conditions. When plants undergo decomposition under restricted air supply, is greater portion of the carbonaceous matter is retained and the material is slowly converted into coal.

E.g. peat, lignite, coal, anthracite.

**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.

**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.

**Sedimentary rocks**

S.No	Rock	Mineral composition	Colour and structure
1.	Sandstone	Mainly quartz with some CaCO <sub>2</sub> , 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,	Light grey to yellow, fine

	clay, phosphate and organic matter	grained and compact
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### 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 *hydrometamorphosis* and due to pressure is called *dynamometamorphosis*

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

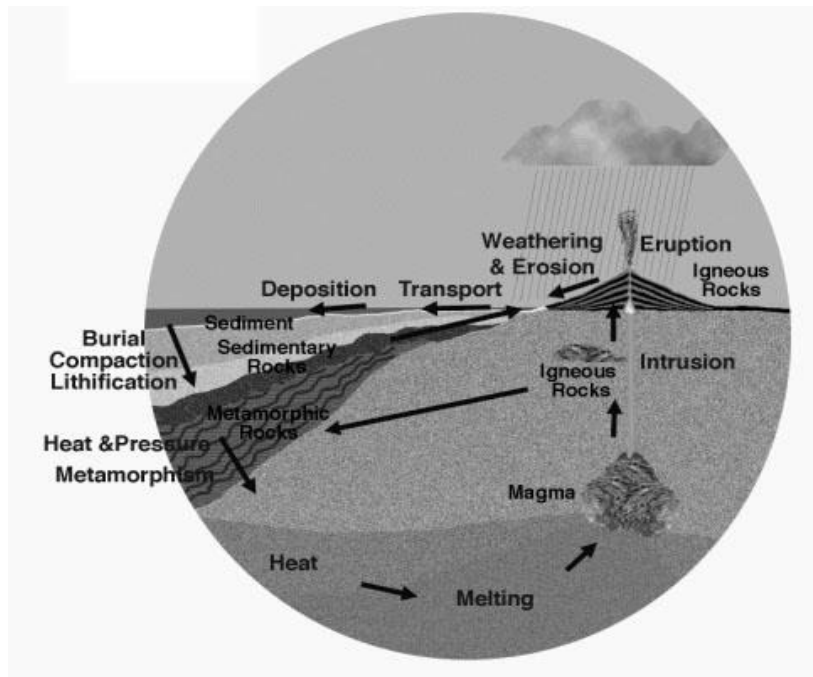
#### Metamorphic rocks

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 sandstone	Light ot brown, compact and uniform texture, 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

#### Percentages of rock types at land surface.

- **Sedimentary rocks -74%**
- 52% Shale
- 15% Sandstone
- 7% Limestone & Dolomites
- **Igneous rocks - 18%**
- 15% Granite
- 3% Basalt

- 8% others



### 1.3 SOIL FORMING MINERALS

#### 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"*

#### Formation

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. (SiO<sub>2</sub>). 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.*

#### Classification of minerals

Quantity	Mode of origin	Specific gravity	Chemical composition
Essential Minerals	Primary Minerals	Light minerals	Native elements

Accessory Minerals	Secondary Minerals	Heavy minerals	Oxides & OH, SO <sub>4</sub> ,CO <sub>3</sub> , Halides & Silicates
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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*).

### Primary minerals

<b>Primary minerals</b>		
<i>Ferro magnesium minerals</i>		
Ortho-ino silicates		16.8
Olivine	Fe, Mg	
Pyroxenes	Ca, Na, Fe, Mg	
Amphiboles	Ca, Na, Fe, Mg, Al, OH	
<i>Phyllo Silicates</i>		3.6
Biotite	K, Fe, Mg, Al, OH	
Muscovite	K, Al, OH	
<i>Non-Ferro Magnesium</i>		
<i>Tecto Silicates</i>		
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
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### Secondary 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)

### Non-silicate minerals

Oxides: Haematite ( $\text{Fe}_2\text{O}_3$ )

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

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

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

The red, yellow or brown colours in soils are due to the presence of goethite and haematite, 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)

### Percentages of minerals at land surface.

- 30% Feldspar
- 28% Quartz
- 18% Clay minerals and mica
- 9% Calcite and dolomite
- 4% Iron oxides



- 1% Pyroxene and amphibole
- 10% others

### **SILICATE MINERALS (Primary minerals)**

- ❖ Neosilicates/ortho
- ❖ Inosilicates
- ❖ Phyllosilicates
- ❖ Tectosilicates

### **ISOLATED SILICATES [Neosilicates]**

Silicon tetrahedra share no oxygen anions with other tetrahedra, and so have an excess negative charge of 4-. In the mineral olivine, this is balanced by the insertion of a pair of divalent cations in the crystal structure, either or both of  $Mg^{2+}$  and  $Fe^{2+}$ . The chemical formula for olivine is written  $(Mg,Fe)_2SiO_4$ , which tells us that for every silicon, there are four oxygen and two cations, either or both of Mg and Fe.

### **SINGLE CHAIN SILICATES [Inosilicates]**

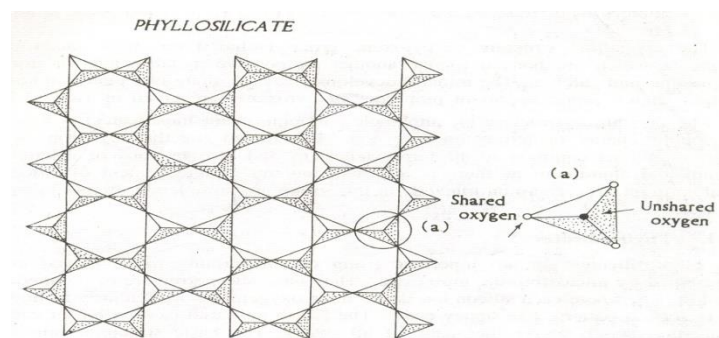
Each silicon tetrahedron shares two oxygen anions, one with neighbouring tetrahedron, and one with another, to produce long, strongly bonded chains. For each silicon tetrahedron, the excess negative charge is only 2<sup>-</sup>, which still requires insertion of cations in the crystal structure.

Ex. Pyroxene

### **DOUBLE CHAIN SILICATES [Inosilicates]**

As with single chain silicates, chains are constructed by sharing of two oxygen for each silicon tetrahedron. The double chains are constructed by having every second silicon along the chain share a third oxygen with a silicon from the facing chain. The net result is that on average, each silicon shares 2 ½ oxygen, so the excess negative charge per silicon is reduced to 1 ½. Ex: Amphibole

### **SHEET SILICATES [Phyllosilicates]**



In this group, each silicon tetrahedron shares three oxygen anions with neighbouring tetrahedra, so that the net negative charge per silicon is now  $1^-$ . This produces a kind of hexagonal honeycomb sheet, in which all tetrahedra point in the same direction. This enables these layers to bond with layers of cations at the centres

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.

Ex. For Sheet Silicates- Mica Group (Muscovite, Biotite) and Clay minerals

### FRAMEWORK SILICATES - Tectosilicates

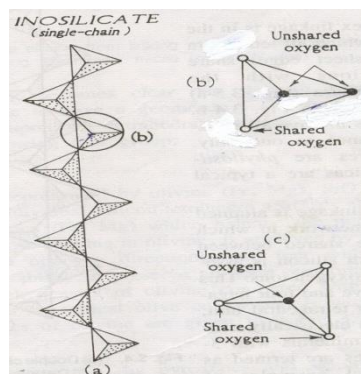
All four oxygen are shared, each one with a different silicon tetrahedron, which eliminates the excess negative charge, given the basic formula  $\text{SiO}_2$  (the two oxygen are in effect four  $\frac{1}{2}$  oxygen, each being shared). One might therefore expect the framework silicates to be the simplest group to deal with, but complexity is introduced in the feldspar group. 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. The relative degree of close packing of atoms in their structural frame work may be the reason for such a 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.

### Ferro magnesium minerals

#### Olivine

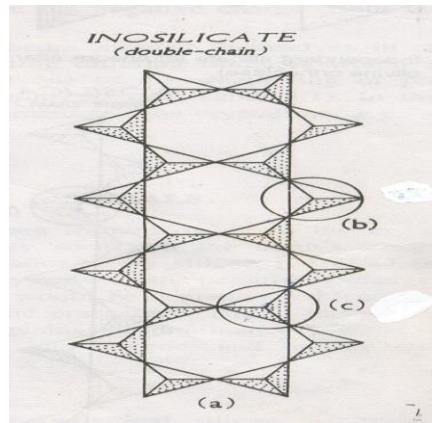
$(\text{Mg,Fe})_2\text{SiO}_4$ . Found in basic igneous rocks. First mineral to weather because of easily oxidizable Fe and soluble Mg ions. Weathers to clay minerals

#### Pyroxene



Chain like silica tetrahedral.  $\text{Ca (Mg,Fe,Al) (Al,Si)}_2\text{O}_6$ . Found in igneous and metamorphic rocks. Weathers by ion exchange and lattice alteration to clay minerals.

### **Amphibole**



Si tetrahedra in double chain.  $(\text{Mg,Fe,Ca,Na})_2 (\text{Mg,Fe}^{+2},\text{Al})_5 (\text{Si,Al})_8 \text{O}_{22}(\text{OH})_2$ . Found in igneous and metamorphic rocks. Weathers by ion exchange and lattice alteration to chlorite and clay minerals with release of bases to soil solution.

### **Non-ferro magnesium minerals**

#### **Quartz**

$\text{SiO}_2$ , silicon dioxide. Found in sandstone, igneous rocks (granites, etc.), many metamorphic rocks. Forms last, at lowest temp. Very resistant to weathering. No cleavage or fracture. In many weathering profiles the proportion of quartz increases toward the surface.

#### **Mica**

Sheet like structure.  $\text{K(Mg,Fe)}_3 \text{AlSi}_3\text{O}_{10} (\text{OH})_2$ . Found in igneous, metamorphic and sedimentary rocks. Breaks easily into flakes, soft, and attacked easily by water. Black or white in color. Weathers by ion exchange into clay minerals.

#### **Feldspar**

Al-silicates.  $(\text{K,Na}) \text{AlSi}_3\text{O}_8$ .  $(\text{Na,Ca}) \text{Al} (\text{Al,Si}) \text{Si}_2\text{O}_8$ . Common in igneous and metamorphic rocks. Uncommon in sedimentary rocks. Well defined cleavage. Often alters to kaolin.

#### **Potassium Feldspar**

In the feldspars, we see coupled ionic substitution, rather than the simple substitution exhibited by olivine. By virtue of its size,  $\text{Al}^{3+}$  fits between the oxygen anions of the tetrahedra in place of  $\text{Si}^{4+}$ . Of course, this introduces a positive charge deficiency. In the case of potassium feldspar, one out of every four tetrahedra has aluminum, and the charge deficiency is balanced by insertion of a potassium ( $\text{K}^+$ ) cation.

## Plagioclase Feldspar

The substitution of one  $\text{Al}^{3+}$  for  $\text{Si}^{4+}$  could also be balanced by  $\text{Na}^+$ . This is albite, the sodium plagioclase feldspar. If we substitute two Al for Si out of every four Si, the charge deficiency of  $2^+$  is balanced by  $\text{Ca}^{2+}$ , and we have anorthite. The ionic radii of  $\text{Na}^+$  and  $\text{Ca}^{2+}$  are almost identical, so the two freely substitute, along with  $\text{Al}^{3+}$  for  $\text{Si}^{4+}$ , to produce the plagioclase feldspar solid solution series.

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

### Secondary mineral formation

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

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, attapulgite and apatite.

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) silicon tetrahedron + 1 aluminium octahedron
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- 3) 2: 1 expanding clay mineral
  - i. Partially expanding (Vermiculite)
  - ii. Fully expanding (Montmorillonite)
- 4) 2: 2 clay mineral
  - i. (chlorite)

### 1:1 type minerals

The layers of the 1:1-type minerals are made up of one tetrahedral (silica) sheet combined with one octahedral (alumina) sheet. In soils, **kaolinite group** is the most prominent 1:1 clay mineral, which includes kaolinite, hallosite, nacrite and dickite. The tetrahedral and octahedral sheets in a layer of a kaolinite crystal are held together tightly by oxygen atoms, which are mutually shared by the silicon and aluminum cations in their respective sheets. These layers, in turn, are held together by hydrogen bonding. Consequently, the structure is fixed and no expansion ordinarily occurs between layers when the clay is wetted.

Cations and water do not enter between the structural layers of a 1:1 type mineral particle. The effective surface of kaolinite is restricted to its outer faces or to its external surface area. Also, there is little isomorphous substitution in this 1:1 type mineral. Because of low surface area and little isomorphous substitution the capacity to adsorb cations is also low.

Kaolinite crystals usually are hexagonal in shape. In comparison with other clay particles, they are large in size, ranging from 0.10 to 5  $\mu$ m across with the majority falling within the 0.2 to 2  $\mu$ m range. Because of the strong binding forces between their structural layers, kaolinite particles are not readily broken down into extremely thin plates. Kaolinite exhibits very little plasticity (capability of being molded), cohesion, shrinkage, and swelling.

### **2:1-Type Minerals**

The crystal units (layers) of these minerals are characterized by an octahedral sheet sandwiched between two tetrahedral sheets. Three general groups have this basic crystal structure.

- i. Expanding type: Smectite group and vermiculite
- ii. Non-expanding type: mica group (illite)

**Expanding Minerals:** The smectite group of minerals is noted for their interlayer expansion and swelling when wetted. The water enters the interlayer space and forces the layers apart. Montmorillonite is the most prominent member of this group in soils. Beidellite, nontronite, and saponite are also found in soils.

The flake-like crystals of smectite (e.g., **Montmorillonite**) are composed of an expanding lattice 2:1 type clay mineral. Each layer is made up of an octahedral sheet sandwiched between two tetrahedral (silica) sheets. There is little attraction between oxygen atoms in the bottom tetrahedral sheet of one unit and those in the top tetrahedral sheet of another. This permits a ready and variable space between layers, which is occupied by water and exchangeable cations. This internal surface exceeds the external surface of clay crystal. In montmorillonite, magnesium replaces aluminum in some sites of octahedral sheet.

Likewise, some silicon atoms in the tetrahedral sheet may be replaced by aluminum. These substitutions give rise to a negative charge.

These minerals show high cation exchange capacity, swelling and shrinkage properties. Wide cracks commonly form in smectite dominated soils (e.g., Vertisols) when dried. The dry aggregates or clods are very hard, making such soils difficult to till.

**Vermiculites** are also 2:1 type minerals in that an octahedral sheet occurs between two tetrahedral sheets. In most soils vermiculites, the octahedral sheet is aluminum dominated (dioctahedral), although magnesium dominated (tri-octahedral) vermiculites are also present. In the tetrahedral sheet of most vermiculite, aluminum is substituted by silicon in most of the sites. This accounts for most of the very high net negative charge associated with these minerals. Water molecules, along with magnesium and other ions, are strongly adsorbed in the interlayer space of vermiculites. They act primarily as bridges holding the units together rather than as wedges driving them apart. The degree of swelling is, therefore considerable less for vermiculites than for smectite. For this reason, vermiculites are considered limited expansion clay minerals, expanding more than kaolinite but much less than the smectite. The **cation exchange capacity** (CEC) of vermiculite is higher than all other silicate clays, including montmorillonite and other smectite because of very high negative charge in the tetrahedral sheet. Vermiculite crystals are larger than those of the smectite but much smaller than those of kaolinite.

### **2:1 Non-expanding minerals:**

Micas are the type minerals in this group. (e.g.) Muscovite and biotite. Weathered minerals similar in structure to these micas are found in the clay fraction of soils. They are called fine-grained micas. Like smectite, fine-grained micas have a 2:1 type crystal. However, the particles are much larger than those of the smectite. Also, the major source of charge is in the tetrahedral sheet where aluminum atoms occupy about 20% of the silicon sites. This results in a net negative charge in the tetrahedral sheet and the charge is higher than that found in vermiculites. To satisfy this charge, potassium ions are strongly attracted in the interlayer space and are just the right size to fit into spaces in the adjoining tetrahedral sheets. The potassium thereby acts as a binding agent, preventing expansion of the crystal. Hence, fine-grained micas are quite non-expanding.

The properties such as hydration, cation adsorption, swelling, shrinkage and plasticity are less intense in fine grained micas than in smectite but are more than kaolinite due to the presence of interstratified layers of smectite or vermiculite. Fine grained mica crystals are

intermediate in size between the smectite and kaolinite. Their specific surface area varies from 70 to 100 m<sup>2</sup> g<sup>-1</sup>, about one eighth that for the smectite.

