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TABLE OF CONTENTS

1. Learning outcomes

After studying this module you shall be able to:

- To develop a basic understanding of chemical co-ordination leading to formation of minerals with various structures.
- To develop the ability to identify minerals in hand-specimen and thin section.
- To develop appreciation for the application of mineral science to everyday life.

2. Phyllosilicates

Sheet silicate minerals are known to be important and abundant in all rock types be it igneous, metamorphic or sedimentary. In terms of geologic environment they are stable at or within about 20 kms of the Earth's surface. They are of hydrous nature and the hydrogen is usually bonded to oxygen to form OH^- group. Commonly are known as Phyllosilicates based on Greek derived term "phyllon" meaning leaf owing to its flaky habit. Many prefer to call them as "layer silicates" as well.

The structure of sheet silicates consists of two different sheets O (octahedral sheets) and T (Tetrahedral sheets). Octahedral and Tetrahedral sheets are joined together to form layers and are stacked on top of another and bonded to form the repeating unit of the mineral. The gap between the two layers is usually filled by interlayer cations and/or water or may remain vacant as well. As the bonding between the two layers is weak it gives the sheet silicates the diagnostic single perfect cleavage.

The octahedral sheets typically consist of two planes of OH^- anionic groups. Divalent cations such as Fe^{2+} and Mg^{2+} or trivalent cations such as Al^{3+} or Fe^{3+} occupies the octahedral sites formed between the OH^- anionic groups. Based on this if the cations are divalent three out of three octahedral sites gets filled, forming **trioctahedral sheet**. If the cations are trivalent only two of the three octahedral sites are occupied due to charge balance requirement resulting in **dioctahedral sheets**. The net charge on both dioctahedral and trioctahedral sheets is zero, the net cation charge being +6 in both the cases.

Site occupancy has a direct bearing on the unit cell size, hence in the dioctahedral sheet silicates, the b unit cell dimension is about 9 Ǻ whereas in the triocathedral sheets b unit cell dimesion is about 9.2 Ǻ.

Tetrahedral sheets consist of sheets of tetarhedrally coordinated cations whose composition can be represented by the general formula T_2O_5, where T represents cations, usually Si^{4+}, Al^{3+} or less commonly Fe^{3+}.The tetrahedra are arranged in a mesh of 6 fold rings with three O^{2-} on each tetrahedra gets shared with the adjacent tetrahedra and are known as basal oxygens. The fourth unshared oxygen is known as the apical oxygen. So, a tetrahedral sheet has the chemical formula $Si_2O_5^{2-}$. Sometimes Al^{3+} and Fe^{3+} substitutes for Si^{4+}, increasing the net negative charge on the tetrahedral sheet. The unbounded tetrahedral apices of the sheet all point in the same direction. These apices connect the tetrahedral sheet, the apical O atoms of the tetrahedra shared with an O atom or OH^- anion from the octahedral sheet. Different stacking combinations of the two connected basic tetrahedral and octahedral sheet results in the phyllosilicate structures.

3. Structure and classification

The phyllosilicate are classified by the way in which the layers are built up of tetrahedral and octahedral sheets and by the way they are stacked relative to each other.

Three main groups of layer silicates are known to occur.

In the 1:1, the layers are made up from one sheet of SiO_4 tetrahedra, combined with one octahedral sheet. These layers are charge balanced and weak bonds are known to hold successive layers together in the stack.

In the 2:1 phyllosilicates, an octahedral sheet is sandwiched between the apices of two tetrahedral sheets. The tetrahedral-octahedral-tetrahedral layers are held together by weak van der Walls force, if they are neutral or may have cations between them, if substitutions in either of the sheets results residual charge.

In the 2:1:1 layer silicates an additional octahedral sheet is found sandwiched between each T-O-T layer.

- **1:1 Phyllosicates**

The combination of one tetrahedral and an octahedral sheet is called 1:1 layer or a T-O phyllosilicate. **(Fig. 1)** The combination can be represented as below to form a dioctahedral T-O layer

1T sheet +1 O sheet = T-O layer + Hydroxyl

$Si_2O_5^{2-}$+ $Al_2(OH)_6$ =$Al_2Si_2O_5(OH)_4$+2$(OH)^-$

The equivalent trioctahedral TO layer is $Mg_3Si_2O_5(OH)_4$.

Example of dioctahedral variety is Kaolinite and that of triocthedral variety is Serpentine.

All 1:1 layer silicates are soft as the bonding between the layers are of weak electrostatic nature. The repeat distance from one layer to the other is about 7Å, so the unit cell dimension is either about 7 or 14 Å depending on the number of layers in the structure.

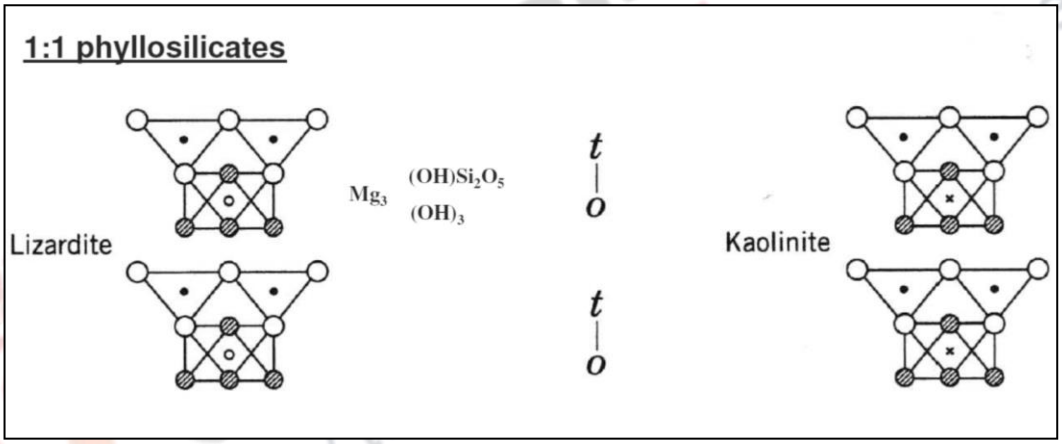

Fig. 1 Schematic diagram of structure of 1:1 phyllosilicates.

❖ 2:1 Phyllosilicates

The 2:1 layer silicates are constructed of repeating T-O-T layers (**Fig. 2**). Depending on whether the T-O-T layers have a net negative charge and what is placed between interlayer sites, decides the varieties of 2:1 layer silicates.

(i) **With no interlayer sites**: In the general 2:1 layer silicates the dioctahedral and trioctahedral T-O-T layers are electrically neutral. The bonding between the adjacent layers is also weak van der Waals and hydrogen bonds. Talc represents the triocathedral variety and pyrophyllite represents the dioctahedral variety of phyllosilicates from this group. Weak interlayer bonding results in the soft waxy feel of both talc and pyrophyllite. The repeat distance between the layers are between 9 and 9.5 Å or multiple of it depending on the number of layers in the unit cell.

(ii) **With cations (e.g. K^+) in inter layer sites:** The structure consists of T-O-T layers wherein some tetrahedral sites are occupied by Al^{3+} rather than Si^{4+}. Common minerals which are included in this group are micas and the brittle micas.

In the micas, the ratio of Al^{3+} to Si^{4+} in tetrahedral site is 1:3. In the dioctahedral T-O-T layer the general formula is $Al_2(AlSi_3O_{10})(OH)_2^{1-}$ and for the trioctahedral T-O-T layer the general formula is $Mg_3(AlSi_3O_{10})(OH)_2^{1-}$.

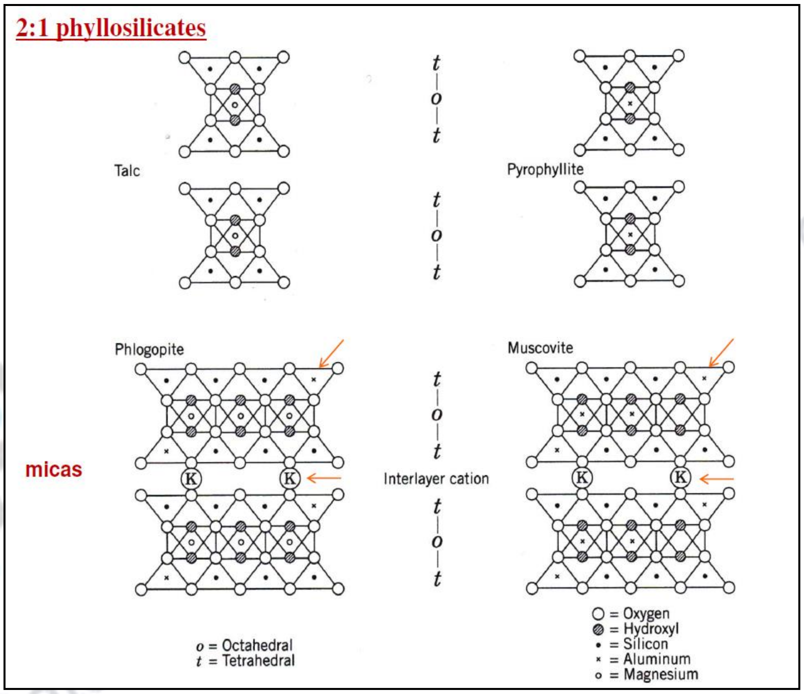

Fig. 2 Schematic diagram of structure of 2:1 phyllosilicates.

The net negative charge of these layers is balanced by inserting monovalent cations such as K^+ between the layers to form muscovite (dioctahedral). Phlogopite is the trioctahedral equivalent of this. The interlayer cations are situated in the centers of the tetrahedral rings in the centers of the tetrahedral sheets. The repeat distance between the layers are slightly increased due to the addition of inter layer cations to 9.5 to 10Å than for the T-O-T structure. As both ionic and van der Waals bonds are involved to bind the adjacent T-O-T layers and the interlayer cations, micas show a hardness between 2 and 3.

For the brittle micas structure is same except that more tetrahedral are occupied by Al^{3+}.

In the dioctahedral mica margarite, half of the tetrahedral sites are occupied by Al^{3+} so the T-O-T layers are $Al_2(Al_2Si_2O_{10})(OH)_{22}$. The net negative charge of 2^- is balanced by insertion of Ca^{2+} in the interlayer site. The trioctahedral variety of brittle mica is clintonite, $\sim CaMg_3Al(Al_3SiO_{10})(OH)_2$. In this structure 1/3 rd of the octahedral sites contain Al^{3+}, the excess charge being balanced by substitution of additional Al^{3+} for Si^{4+} in tetrahedral site.

❖ 2:1:1 Phyllosilicates

This structure is can be derived by adding an octahedral sheet between the T-O-T layers (**Fig. 3**). The most common representative of this type is the chlorite group of minerals.

Talc like layer + brucite like layer = chlorite unit structure

$Mg_3Si_4O_{10}(OH)_2 + Mg_3(OH)_6 = Mg_3Si_4O_{10}(OH)_2Mg_3(OH)_6$

The repeat distance of the unit cell is about 14Å. The Al^{3+} substitutes for about a third of the Si^{4+} in the tetrahedral site, this gives the T-O-T layers a net negative charge. However the interlayer octahedral sheet has a positive charge produced by substitution of Al^{3+} and Fe^{3+} for octahedrally coordinated divalent cations. The net negative charge on the T-O-T layer is balanced by the net positive charge on the interlayer O sheet.

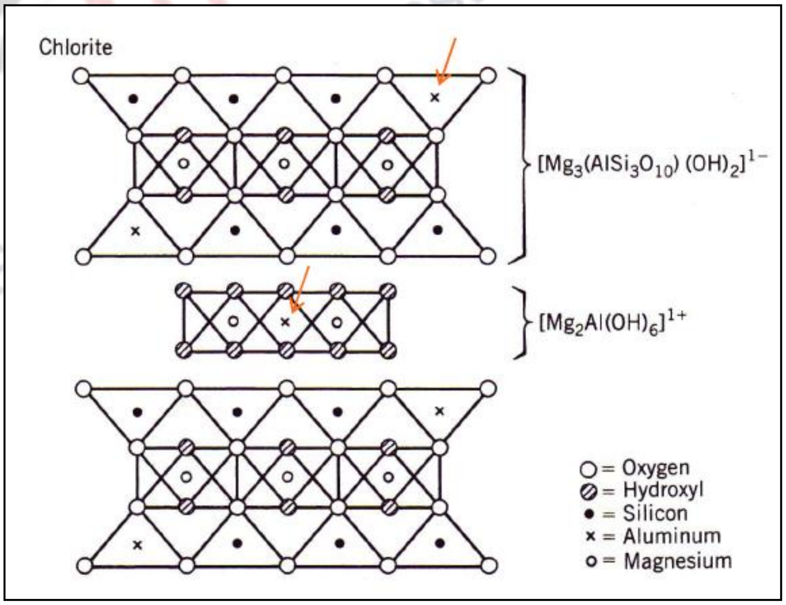

Fig. 3 Schematic diagram of structure of 2:1:1 phyllosilicates.

4. Tetrahedral_Octahedral mismatch in the layer silicates

In the dioctahedral kaolinite structure Al occupies two thirds of the octahedral sites which results in the mesh size of the Al octahedral sheet being smaller than that of the tetrahedral sheet. A better fit is achieved when the [SiO_4] tetrahedra rotate by about 9º about an axis normal to the sheet, with adjacent tetrahedral rotating in opposite senses.

In other 1:1 phyllosilicates the degree of mismatch depends on the cations occupying the tetrahedral and octahedral layers. The rotation of the tetrahedra needed to link the two sheets increases by replacement of Si^{4+} by the smaller Al^{3+} ion in the tetrahedral layer and decreases by replacing the Al^{3+} ion by the larger Mg^{2+} ion in the octahedral layer. This type of mismatch is well exemplified by three forms of serpentine minerals namely lizardite, chrysotile and antigorite. Each reflecting a different attempt at coping with this tetrahedral-octahedral mismatch.

In the 2:1 phyllosilicates curvature of the layers on any macroscopic scale is not seen. However in Talc this fit is achieved by a tetrahedral rotation of about 3.5º and in pyrophyllite the tetrahedral rotation is about 10º. In cases where the octahedral sheet is too large for the tetrahedral sheet, it gets more difficult to stretch the tetrahedral sheet to fit in, in such cases the octahedral sheet has to split into ribbons to reduce the strain e.g. sepiolite and palygorskite.

5. Representative minerals

5.1 Kaolinite Group

Structure and composition: It is a type of dioctahedral clay with a 1:1 layer with no interlayer cation and a composition of $Al_2Si_2O_5(OH)_4$. Dickite, halloysite and nacrite are polymorphs of it.

Crystallographic properties: It belongs to triclinic system, Point group 1 and Space group P1. Unit cell parameters are a = 5.15Ǻ, b = 8.95Ǻ and c = 7.39Ǻ and α = 9.18º, β = 104.5-105º, γ = 90º, z = 2.

Physical properties: Usually shows white to tan colour but may be variously coloured due to presence of impurities. Rarely occur as crystals. Thin platy or stacked to 2mm. More commonly occur as microscopic pseudohexagonal plates and cluster of plates. Cleavage perfect on {001}. Hardness varies from 2 to 2.5. Specific gravity varies between 2.61-2.68. It gives a streak of white colour and is non-pleochroic. Lusture varies from pearly to dull earthy.

Optical properties: In thin section appears as fine grained brown to grey earthy aggregates. It is biaxial negative in character, optic orientation X^c = -13º to -10º, Y^a = 1º-4º, n_α = 1.503-1.563, n_β = 1.559, n_γ = 1.560-1.570. 2V = 24º-50º, has low to moderate positive relief in thin section.

Occurrence: Found in association with quartz, feldspar and muscovite. They all primarily form by weathering or hydrothermal alteration of feldspars. It is also a common constituent of the clay size fraction of sediments where it forms by direct precipitation.

Use: Used as drilling mud additive, used for ceramics, as filler Material, used in cosmetics, used in refractory and building products, used in manufacture of Portland cement, used as absorbents and also in pharmaceuticals.

5.2 Serpentine Group

Structure and composition: All the three varieties of serpentine group of minerals $Mg_3Si_2O_5(OH)_4$ namely chrysotile, lizardite and antigorite are trioctahedral 1:1 layer phyllosilicates.

The lateral dimensions of the tetrahedral and octahedral layers in an ideal 1: 1 layer are different which results in a misfit. The three varieties of Serpentine minerals results due to different attempts at coping with this tetrahedral octahedral misfit.

In lizardite the tetrahedral rotation is around 3.5º.

In chrysotile the tetrahedral are slightly tilted so that their apices no longer lie in a flat plane. The increased distance between the apices to achieve a fit with octahedral mesh results in curvature of the whole layer. Continued growth of crystal results in rolled up layers.

In antigorite, the curvature of the layers is accompanied by periodic switching of the direction of the tetrahedral layer.

Mostly are close to the ideal composition but substitution of Al^{3+} for Si^{4+} or Al^{3+}, Fe^{3+} or Fe^{2+} for Mg^{2+} may occur.

Crystallographic properties: Chrysotile (Orthorhombic or Monoclinic), Lizardite (Hexagonal or monoclinic) and Antigorite (Monoclinic), Point Group - 2/m, Space Group - P31m. Lizardite a~5.3Ǻ, c~7.25Ǻ; Antigorite a~33-51Ǻ, b~ 9.25Ǻ, c~7.25Ǻ, β=91.4º; Chrysotile a~5.3Ǻ, b~9.25Ǻ, c~14.6Ǻ, β =93.3° or 90°.

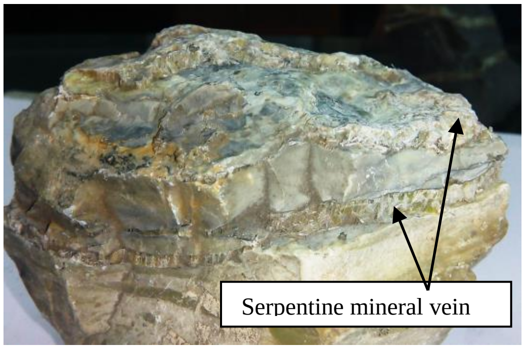

Fig. 4. Serpentine mineral bearing veins in calc silicate rock from north western India. Note worthy is the fibrous nature of the veins

Physical properties: Usually occurs in shades of green, yellowish green, white or grey. It gives white streak. Silky, greasy or waxy lusture is common. Shows perfect cleavage on {001}. Chrysotile forms fibers, lizardite occur as fine grained masses whereas antigorite can form scaly or foliated masses. Twins are uncommon. May show weak pleochroism in rare cases. Lizardite: Density ~2.55 Hardness 2 ½; Antigorite Density ~2.6 Hardness 2 ½ -31/2 and Chrysotile: Density ~2.55 Hardness 2.½. (**Fig. 4**)

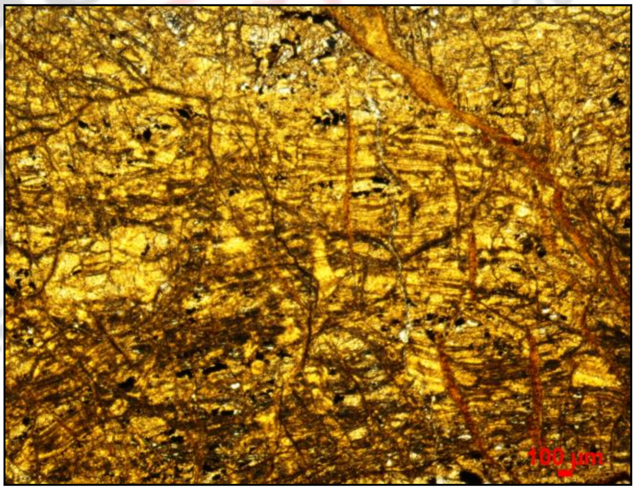

Fig. 5 Photomicrograph of a serpentinite from the Andaman Ophiolite belt.

Optical properties: Colourless to pale green or yellow green in thin sections. Shows moderate relief and are biaxial negative. n_α =1.529-1.595, n_β=1.530-1,603, n_γ=1.537-1.604. 2V= 20º-50º, optic orientation α ~ parallel to Z, γ= Y. (**Fig. 5**)

Occurrence: Usually forms by hydrothermal alteration of mafic and ultramafic rocks. Chrysotile is stable at < 260ºC whereas antigorite stable upto ~600ºC. The associated minerals may include calcite, brucite, chlorite, magnetite and chromite. Occurs in association with calcite, dolomite, forsterite, magnesite and calc-silicate minerals in contact metamorphosed carbonate rocks. The serpentine rich rock is known as serpentinite.

Use: Low thermal conductivity and incombustibility makes it a valuable industrial mineral. Used as asbestos and also finds use in automobile industry as brake shoe and clutch facings. It is also used in fireproof insulators and in construction materials.

5.3 Talc

Structure and composition: It is a trioctahedral 2:1 layer silicate with a composition of $Mg_3Si_4O_{10}(OH)_2$. The composition is usually close to the ideal formula. Minor substitution of Fe, Mn or other cations for Mg in the octahedral sites and Al for Si in the tetrahedral site occurs. Fe bearing variety of talc Minnesotaite[$Fe_3Si_4O_{10}(OH)_2$] is found in metamorphic iron formations.

Crystallographic properties: Belongs to Triclinic or Monoclinic class, Point group -1, 1 or 2/m. Space group C-1, C2/c, Unit cell parameters a = 5.290Ǻ, b = 9.173 Ǻ c = 9.460 Ǻ, $\alpha = 90.46^\circ$, $\beta = 98.68^\circ$, $\gamma = 90.09^\circ$, z = 4.

Fig. 6 Hand sample of Talc. Noteworthy is its pearly lusture. Soapy touch is its diagnostic property.

Physical properties: Usually shows white, light to dark green or brown colour. It occurs as foliated radiating or randomly oriented aggregates of irregular flakes or fibers. Talc has a soapy feel and is sectile. Cleavage is perfect {001}. Gives white streak and pearly lusture. Shows no pleochroism and twinning. Hardness is diagnostic 1, Specific gravity varies from 2.58-2.83. (**Fig. 6**)

Optical properties: In thin section it appears colourless with a low to moderate positive relief. Biaxial (-ve), n_α = 1.538-1.554, n_β = 1.575-1.599, n_γ = 1.575-1.602. 2V = 0º-30º, optic orientation X^c ≈ +10º, Y ≈ b, Z ≈ a and Optic plane (010).

Occurrence: In metamorphic environment talc is formed due to metamorphism of siliceous dolomite where it is found associated with calcite, dolomite, tremolite and other calc-silicate minerals. Talc also forms due to metamorphism of mafic igneous rocks or mafic volcaniclastic sedimentary rocks associated with magnetite, tremolite, chlorite, anthophyllite or serpentine.

Talc is also found in hydrothermally altered mafic and ultramafic rocks in association with serpentine, magnesite and relict grains of olivine and pyroxene.

Use: It is used as a filler and colorant in paint, rubber etc and as a lubricant. It finds widespread use in cosmetic products.

5.4 Pyrophyllite

Structure and composition: It is a dioctahedral layer silicate and consists of two T-O-T layers in monoclinic unit cell and one layer T-O-T in the triclinic polytype. The ideal composition is $Al_2(Si_4O1_0)(OH)_2$. Common substitutions are Al^{3+} for Si^{4+} and Mg^{2+}, Fe^{2+}, Fe^{3+} or Ti^{4+} for Al^{3+}. Minor Ca^{2+}, Na^+ or K^+ may be present in interlayer sites.

Crystallographic properties: Crystallizes in both monoclinic and triclinic system. Point group 2/m and -1; space group C2/c or C-1. Cell parameters for monoclinic unit cell a= ~5.17Ǻ, b=~8.96Ǻ, c= ~18.68Ǻ; parameters for triclinic unit cell a= ~5.16Ǻ, b=~8.96Ǻ, c= ~9.35Ǻ; α=~91º, β= ~100º, γ= ~90º, z = 2.

Physical properties: It occurs as foliated columnar radiating masses or as massive aggregates. It also shows fibrous habit. It shows dull to pearly lusture. It is usually of white, pale blue or brownish green colour. It gives white streak. It shows no twinning and is sectile. Shows perfect {001} cleavage. Hardness varies from 1 to 2, specific gravity varies from 2.65-2.90.

Optical properties: It is colourless in thin section. It shows low to moderate positive relief.

Biaxial negative, n_α = 1.552-1.556, n_β = 1.586-1.589, n_γ = 1.596-1.601. 2V = 53º-62º, optic orientation X^c ≈ 10º, Y = a, Z = b.

Occurrence: It is usually found in low grade Al-rich metapellites, metabauxite, or metaquartzite formed due to hydrothermal alteration of aluminous minerals such as feldspars, muscovite and aluminium silicates.

Use: It finds most common use as refractory line in kilns, furnaces and ladles in foundries. Also used in ceramic industry, as filler in paints, cements and as construction material.

5.4 Micas

✓ **Muscovite**

Structure and composition: It consists of a unit cell of two T-O-T layers and may also have a unit cell one T-O-T layer thick. They represent 2M1 and 1M polytypes respectively. The ideal composition is $KAl_2(AlSi_3O_{10})(OH)_2$. The common substitutions are F and Cl for (OH), Mg, Fe $^{2+}$, Fe $^{3+}$, Mn, Li, Cr, Ti and V for Al^{vi} and Na, Rb, Cs, Ca and Ba for K and $AlSi_3$ to $Al_{0.5}$ $Si_{3.5}$ in tetrahedral site.

Paragonite [$NaAl_2(AlSi_3O_{10})(OH)_2$] is the sodium analog of muscovite. Muscovites also show phengitic substitution in which Si:Al ratio is greater than 3:1 and Mg^{2+} or Fe^{2+} substitutes for Al^{3+} to compensate for the higher charge of the Si.

Crystallographic properties: Crystallizes in monoclinic system. Point group 2/m, space group C2/c. Cell parameters for Monoclinic unit cell a = 5.19Å, b = 9.04Å, c = 20.08Å, β = 95.8º, z = 4.

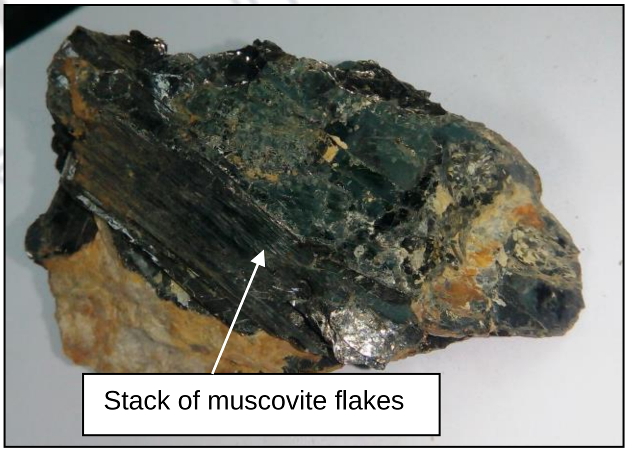

Fig. 7 Book mica associated with a late stage aplitic vein from Dumka area of Jharkhand.

Physical properties: It occurs mostly as flakes or in tabular form **(Fig. 7).** Usually colorless or may be green red or brown. It has a vitreous lusture. It gives white streak. Perfect cleavage on

{001} and twining present with twin axis being. [310]. It has a hardness of 2 ½ on cleavage plane and ~4 at right angles to cleavage plane. Specific gravity varies from 2.77-2.88.

Optical properties: It is colourless in thin section. It moderate positive relief (Fig. 8). Biaxial negative, n_α = 1.552-1.576, n_β = 1.582-1.615, n_γ = 1.587-1.618. $2V_x$ = 28º-47º, optic orientation X^c = +1 to +4º, Y^a =+1 to +3º Z= b. Shows no pleochroism.

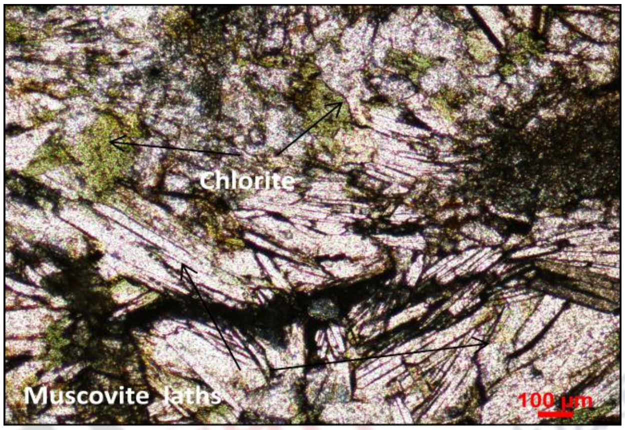

Fig. 8 Photomicrograph of a muscovite schist. Tabular habit of muscovite is evident. Also chlorite can be seen in association with Muscovite

Occurrence: Muscovite is a common constituent of metamorphic rocks like slate, phyllite, schist and gneiss. Clastic sedimentary rocks also contain muscovite. It is also a common constituent of granitic pegmatite, granite and all related felsic rocks. Phengite and paragonite are usually found in low grade regional metamorphic rocks.

Use Muscovite finds wide application in electronic industry. Used as either sheets or as ground powder in capacitors, transistors, insulators and in microwave ovens. Cosmetic products like nail paint, lipsticks and eye shadow also use muscovite in them. In industry muscovite is used as filler in plastic, paint and wall board cement and as constituents of drilling mud.

- ✓ **Biotite**

Structure and composition: Biotite structure has a one T-O-T layer thick unit cell.

Ideal composition is $K(Fe,Mg)_3AlSi_3O_{10}(OH)_2$. The compositional variation is represented by four end members $KFe_3AlSi_3O_{10}(OH)_2$ Annite - $KMg_3AlSi_3O_{10}(OH)_2$ Phlogopite - $KFe_2Al(Al_2Si_2O_{10})(OH)_2$ Siderophyllite - $KMg_2Al(Al_2Si_2O_{10})(OH)_2$ Eastonite (now discredited name). Other substitutions include Fe and Cl for OH.

Crystallographic properties: Crystallizes in monoclinic system. Point group 2/m, space group C2/c. Cell parameters for Monoclinic unit cell a = ~5.3Å, b = ~9.2Å, c = ~10.3Å, β = ~100º, z= 2.

Physical properties: It is tabular in habit and is moistly balck to dark brown in colour. It exhibits vitreous lusture and gives white to grey streak. Shows perfect basal cleavage. May show twin with {001} compositional plane. Hardness varies between 2 and 3 and specific gravity varies between 2.7-3.3. (**Fig. 9**)

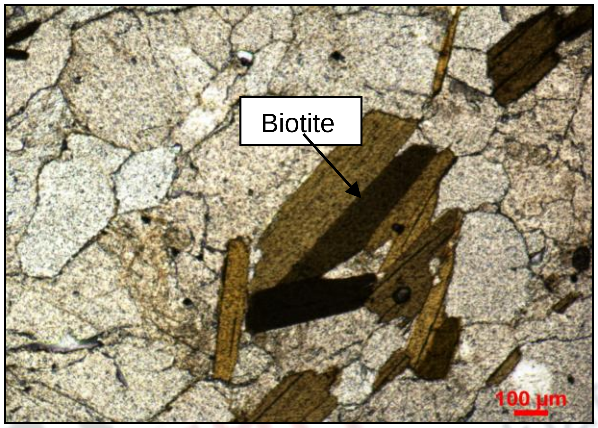

Fig. 9 Photomicrograph of Biotite flakes in plane polarized light from a biotite beraing gneiss from Himalayan terrain.

Optical properties: It is brownish, greenish brown reddish brown in thin section. It has moderate to high positive relief. Biaxial negative, $n_\alpha = 1.522-1.625$, $n_\beta = 1.548-1.696$, $n_\gamma = 1.549-1.696$. $2V_x = 0^o-25^o$, optic orientation X^c = 0 to +9º, Y = b, Z = a. Strongly pleochroic with a pleochroic scheme Z≈Y>X; Z≈Y= brown, dark red brown, X= colourless to pale brown to green.

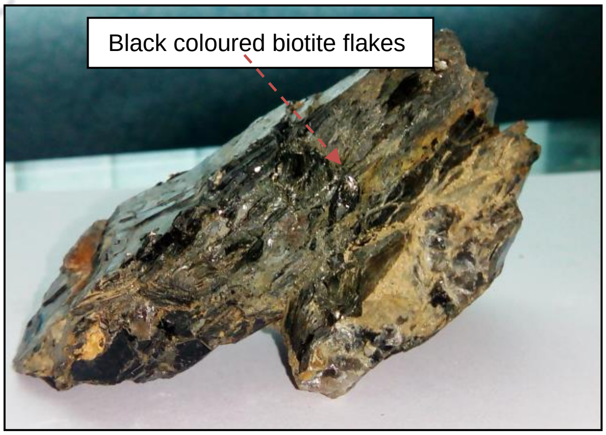

Fig. 10 Biotite schist from Himalayan terrain.

Occurrence: Biotite is a common mineral in igneous rocks like granite, granodiorite, dacite etc. It can also be a late stage magmatic product in mafic rocks like gabbro, norite and anorthosite. In the ultramafic rocks phlogopite is found. It is a common detrital mineral in immature sediments. It is a common constituent of metamorphic rocks like phyllites, schists and gneisses. (**Fig. 10**)

Use: It is mostly used as an insulation material.

5.5 Chlorite group minerals

Structure and composition:

Ideal composition is $(Mg,Fe,Al)_3$ $(Si,Al)_4O_{10}(OH)_2(Mg,Fe,Al)_3(OH)_6$**.** It consists of two T-O-T units linked together by a brucite type layer. Both the octahedral and tetrahedral sheet is trioctahedral in chlorite which means that all octhahedral sites are occupied usually by Mg, Fe or Al. In this structure major substitution is of Mg^{2+}, Fe^{2+}, Fe^{3+} and Al in octahedral sites and Si and Al in tetrahedral sites. It exhibits solid solution from Mg rich end member clinochlore to Fe rich end member chamosite. Substitution of minor amounts of Mn and Cr in octahedral sites are also common.

Crystallographic properties: Monoclinic, can also crystallize in triclinic system. Point group 2/m, Space group C2/m, C1 or C-1 is less common classes. Unit cell a = 5.3Ǻ, b = 9.2Ǻ, c = 14.3Ǻ, β = 97º, z = 2.

Physical properties: It is known to occur in various shades of green, but can also be yellow, white, pink or rose red in colour. Mostly occurs as fine grained scaly or foliated massive aggregates. Hardness is usually between 2-3 and exhibits a specific gravity of 2.6-3.3. It shows vitreous lusture and gives greenish white to white streak. Cleavage is perfect on {001}. (**Fig. 11**)

Fig. 11 Chlorite bearing Phyllite from Himalayan terrain of India.

Optical properties: Pale green coloured in thin section. Has a moderate to high positive relief. Both biaxial positive and negative, $n_{\alpha} = 1.55\text{-}1.67$, $n_{\beta} = 1.55\text{-}1.69$, $n_{\gamma} = 1.55\text{-}1.69$. $2V_x = 0^{\circ}\text{-}40^{\circ}$, $2V_z = 0^{\circ}\text{-}60^{\circ}$. Optic orientation: for optically positive variety $X \approx a$, $Y \approx b$, $Z \approx c$, trace of cleavage length fast and for optically negative variety $X \approx c$, $Y \approx b$, $Z \approx a$, trace of cleavage is length slow. Pleochroic scheme: For optically positive variety $X \approx Y > Z$: $X \approx Y$ = pale green, green, brownish green, Z= colourless, pale green and pale yellowish green. For optically negative variety $X < Y \approx Z$: X = colourless, pale green, pale yellowish green, $Y \approx Z$ = pale green. (**Fig. 12**)

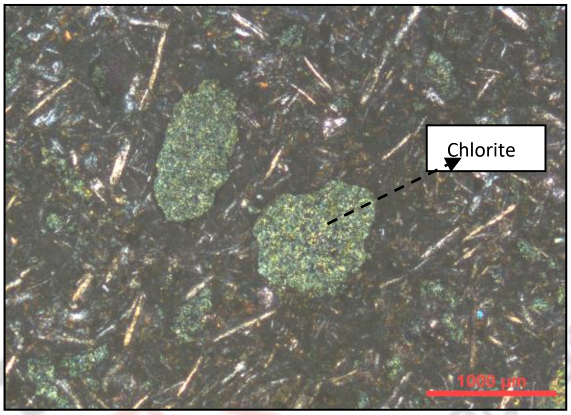

Fig. 12 Growth of secondary chlorite in vesicles of basalt from Nagaland ophiolite Belt, India.

Occurrence: It is a common mineral in igneous rocks mostly derived by alteration of primary Mg and Fe bearing minerals such as biotite and hornblende. Chlorite is common in clay bearing sediments. It is a major rock forming mineral in low and medium grade pelitic and mafic metamorphic rocks.

Use: It has no direct industrial application but chlorite schist rocks often finds use as decorative stone in construction industry.

Reference Books:

1. Klien, Cornelis and Hurlbut, Cornelius S., (1985). Manual of Mineralogy (after James D. Dana), 20th Edn. John Wiley & Sons, New York. ISBN: 0471805807, 978-0471805809.

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