

## **SLM 301 Introductions to Soil Mineralogy**

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### **SLM 301: Introduction to Soil Mineralogy (2 Units)**

Soil components; silicate mineral structure, characteristics and classification of minerals; clay mineral structures/types and their properties; relationship of mineralogy to agriculture, engineering, and other environmental sciences, use of TEM, SEM, XRD, TGA and other analytical equipment in mineral identification of soil minerals

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## Study Units

The course is divided into fifteen (15) units. The following are the study units contained in this course:

### Module 1

Unit 1	Principles, aim and scope
Unit 2	Elements, chemical reactions, chemical compounds and minerals
Unit 3	Relationship of Mineralogy to Agriculture, Engineering and other Environmental Sciences
Unit 4	Soil components
Unit 5	Classification of Minerals

### Module 2

Unit 1	Silicate and non-silicate Mineral Structure
Unit 2	Framework Silicates
Unit 3	Chain Silicates
Unit 4	Sheet Silicates
Unit 5	Ortho- and Ring Silicates

### Module 3

Unit 1	Physical properties of minerals
Unit 2	Chemical properties of minerals
Unit 3	Optical properties of minerals
Unit 4	Methods of soil Mineral Identification
Unit 5	Use of other non-conventional methods in Mineral Identification

## INTRODUCTION

Welcome to *Introduction to Soil Mineralogy (SLM 301)*. This is one semester course of two credits. It is designed for students in agricultural sciences. This course has 8 study units and presents the fundamental concepts of soil and clay mineralogy that are important to agriculture, environment, geology and toxicology. The lectures are devoted to introduction of crystal structures of major minerals, mineral formation conditions, mineral surface properties, and reactions of minerals with heavy metals, nutrients, organics, and biologic molecules; and the importance of minerals in natural environments as well as their domestic, industrial, and environmental applications.

This course material is equipped with worked examples and tutor-marked assignments. Also, it is designed to give you a brief description of the content of the course, the work to be done and the materials that you need. There is also a list of relevant textbooks that could be consulted by you for further learning.

Assignments and exercises were meant to acquaint students with examinations and make them pass with excellent grades. If you take you take your assignments and practical serious I am sure you will all excel without casualties.

### **WHAT YOU WILL LEARN IN THIS COURSE**

The overall aim of this course is to introduce you to the basic concepts of soil and clay mineralogy. In this course, you will:

- be able to apply the principles learned in the class to solve mineralogy-related problems or to develop applications in environmental, agricultural, engineering, and geological areas;
- understand the principles of common soil mineral analysis methods and instruments;
- be able to design mineralogy experiments that are tailored to your specific research objectives;

### **COURSE AIM**

The purpose of the course is to take you through the basic principles in soil and clay mineralogy. However, the aim of the course (SLM 301), an introductory teaching to assist you in better understanding of the basic concepts and processes of soil and clay mineralogy as it relates to agriculture, environment, geology and toxicology

The aim of the course will be achieved by:

- Learning the mineralogy of soil minerals and clay.
- Understanding the composition of soil solid phase.
- Learning the various methods of soil mineral analysis

### **COURSE OBJECTIVES**

The objective of this course is to give you to an introduction to soil and clay mineralogy. To achieve the aims mentioned above, the course has overall objectives. In addition, each unit has also specific objectives. The unit objectives are given at the beginning of a unit; you should read them before you start working through the unit. You may refer to them in the course of your study of the unit, so as to check on your performance and understanding. Go through the unit objectives after completing a unit, so as to be sure that you have done what is required of you by the unit. At the end of the course, you should be able to:

- be able to identify and quantify common minerals in soils, clays, and sediments;

- understand the principles of common soil mineral analysis methods and instruments, know the advantages and limitations of each method and instrument;
- be able to design mineralogy experiments that are tailored to your specific research objectives;

### **WORKING THROUGH THE COURSE**

To complete this course, you are expected to read the study units, as well as other related materials. Pay attention to the objective of each unit and allow it to guide you through. Each unit contains self -assessment exercises, and you are required to submit assignment for assessment purposes (tutor-marked assignment) when needed to. At the end, you are expected to write a final examination. The study material has a marking scheme to enable you assess your performance after going through the assignment questions. Below is a list of all the components of the course, what you have to do and how you should allocate your time to studying this course. Final examination time will be communicated to you.

### **STUDY UNITS**

Each study unit is a week's work and it is introduced by the objective which you are expected to study before going through the unit. In each study unit or after a group of related units, you also have the reading materials and the self-assessment exercises. The tutor - marked assignments; the study units, the tutorials, and the marking scheme all put together, will help you to achieve the stated objective for this course. There are three modules and 8 units in this course and they are as follows:

Module 1. The first unit defines soil mineralogy, its importance in agriculture and its relationship to other fields of science. Unit 2 will introduce us to origin of minerals and their relationship with chemical elements in the earth crust.

Unit 3 will take us through relationship of soil mineralogy to agriculture and other field of sciences. Units 4 and 5 deals with soil composition with emphasis on the soil solid phase and classification of soil minerals and their structures

Module 2. This deals with more details of soil mineralogy. It contains 5 units and deals with the structure of soil silicate and non-silicate clay minerals as well as methods of soil mineral analysis, their advantages and disadvantages.

Module 3. In this module, properties of soil silicate and non-silicate clay minerals as well as methods of soil mineral analysis, their advantages and disadvantages will be discussed extensively and it has 5 units.

Each unit includes specific objective and summaries of key issues and ideas. There are lists of recommended text books and references to provide additional information. You can also go online to get the desired information needed.

### **SET TEXTBOOKS**

Each unit has a list of recommended textbooks and materials. Go through the recommended textbooks and materials for necessary assistance while going through the unit and before

attempting the exercises. Where you think you cannot find the necessary references that have been quoted in any of the units, just go on-line and type in the name of the author on Google, and from there you can find all relevant materials needed.

### **ASSESSMENT**

You will be assessed in two ways in this course – the tutor- marked assignments and a written examination. You are expected to do the assignments and submit them to your tutorial facilitator for formal assessment in accordance with the stated deadlines in the presentation schedule and the assignment file. Your tutor-marked assignments will account for 30% of the total course mark.

### **TUTOR- MARKED ASSIGNMENT**

There are tutor-marked assignments at the end of every unit which you are expected to do. You are expected to go through the study units very carefully so that you can attempt the self-assessment exercises. You will be assessed on the different aspects of the course but only three of them will be selected for continuous assessment. Send the completed assignments (when due) together with the tutor-marked assignment form to your tutorial facilitator. Make sure you send in your assignment before the stated deadline.

### **FINAL EXAMINATION AND GRADING**

The modalities for the final examination for SLM 301 will be determined by NOUN. The pattern of the questions will not be too different from those you have responded to in the tutor - marked exercises. However, as the university has commenced online examinations, you may have to adjust to whatever format is made available to you at any point in time. Nonetheless, you can be assured of the content validity of the examinations. You will only be examined strictly on the content of the course, no matter the form the examination takes. It is thus advisable that you revise the different kinds of sections of the course properly before the examination date.

### **HOW TO GET THE BEST FROM THE COURSE**

The study units in this course have been written in such a way that you can easily go through them without the lecturer being physically around and this is what happens in distance learning. Each study unit is for one week. The study units will introduce you to the topic for that week; give you the objective for the unit and what you are expected to be able to do at the end of the unit.

Follow these religiously and do the exercises that follow. In addition to the above, unlike other courses where you just read and jot notes, SLM 301 has a lot of basic principles and practical applications to learn. You therefore need a lot of concentration while going through the course.

### **TUTORS AND TUTORIALS**

There are 6 tutorial hours for this course. The dates, times and location of these tutorials will be communicated to you as well as the name and phone number of your tutorial facilitator. You will also be notified of your tutorial group. As you relate with your tutorial facilitator, he/she will mark and correct your assignments and also keep a close watch on your

performance in the tutor-marked assignments and attendance at tutorials. Feel free to contact your tutorial facilitator by phone or e-mail if you have any problem with the contents of any of the study units.

### COURSE MARKING SCHEMES

The following table lays out how the actual marking scheme is broken.

**Table 1: Course Marking Scheme**

<b>Assessment</b>	<b>Marks</b>
Assignments (1-6)	6 assignments count for 30 % of the overall course marks (5 % each)
Final Examination	70 % of the overall course marks
<b>Total</b>	<b>100 % of course marks</b>

### COURSE OVERVIEW

This Table brings together the units, the number of weeks you should take to complete them and the assignment that follows them.

**Table 2. Course Schedule**

<b>Unit</b>	<b>Title of Work</b>	<b>Weeks Activity</b>	<b>Assignment (End of Unit)</b>
<b>Module 1: Soil Mineralogy and its relation to other fields of Sciences</b>			
1	Definition and meaning of soil mineralogy	1	Assignment 1
2	Elements - chemical reactions - chemical compounds – minerals	1	Assignment 1
3	Relationship between soil mineralogy, soil fertility, soil chemistry, pedology and other field of sciences	1	Assignment 1
4	Soil composition; soil air, soil water and the soil solid phase	1	Assignment 1
5	Clay mineral types and their classification: 1:1 clay minerals; 2:1 clay minerals; 2:1:1 or 2:2 clay	1	Assignment 1

	minerals; non-silicate clay minerals		
<b>Module 2: Structural Chemistry of Silicate and non-silicate minerals</b>			
6	The unit cell and crystal lattice of silicate clays	1	Assignment 1
7,8	The kaolinite group (1:1 layer clays); The Smectite group (Expanding 2:1 layer clays); The Illite group (Non-expanding 2:1 layer clays); Vermiculites; Chlorites (2:1:1 layer clays)	1	Assignment 1
9.	Mixed layer Clays Silica minerals Iron and aluminum oxides, hydroxide and oxyhydroxides	1	Assignment 1
10.	Framework silicates Chain silicate Sheet silicates Ortho- and Ring Silicates`	1	Assignment 1
<b>Module 3: Properties and identification of Silicate and non-silicate minerals</b>			
11.	Chemical properties of minerals	1	Assignment 1
12	Physical properties of minerals	1	Assignment 1
13	Optical properties of minerals	1	Assignment 1
14, 15	Identification of clay minerals using the following: Differential thermal analysis X-Ray diffraction analysis Infrared spectroscopy	1	Assignment 1

## **SUMMARY**

SLM 301 is designed to introduce you to the principles of soil and clay mineralogy. The course is to assist you in better understanding of the basic concepts and processes of soil mineral formation, their composition and structure at the School of Agricultural Sciences, National Open University (NOUN). Soils are complex heterogeneous medium that reflects/shows various physical, chemical and biological conditions of soil. This course is an introduction to the mineralogy of soil, the importance of the soil mineral constituents to soil fertility, plant growth and soil development. You will be able to answer these key questions:

- What do you understand by the term soil mineralogy?
- What is the importance of soil mineralogy in agriculture?
- What are the various components of the soil?
- What are the basic classifications of soil silicate and non-silicate clay minerals?
- How you can identify different various minerals in the soil.

The list of questions you can answer is not limited to the above. To gain a lot from this course, you should try to apply the principles learnt especially to agricultural production.

We wish you the best and hope that you will find the course interesting and useful. I wish you the best and outstanding success as you go through this course.

## **MODULE 1                      SOIL MINERALOGY AND ITS RELATION TO**

### **OTHER FIELDS OF SCIENCE**

- |        |   |
|--------|---|
| Unit 1 | Meaning of Soil Mineralogy  |
| Unit 2 | Relationship of Mineralogy to Agriculture, Engineering and other Environmental Sciences |

## **UNIT 1                      MEANING OF SOIL MINERALOGY**



## **CONTENTS**

- 1.0 Introduction
- 2.0 Objective
- 3.0 Main Content
  - 3.1 Definition and Meaning
  - 3.2 Soil Mineralogy and Plant Nutrition
  - 3.3 Soil Mineralogy, Soil Chemistry and Soil Formation
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Reading

### **1.0 INTRODUCTION**

Soil minerals play a significant role in dictating the suitability and behavior of soil for various land uses. They provide physical support for plants, contribute to soil structural formation, are sources of many soil nutrients, and can act as sorbents of several environmental pollutants. Therefore, understanding soil mineralogy is essential to understanding many facets of land use and is often a key to solving specific agricultural and environmental problems.

In this unit you will learn about meaning of soil mineralogy and how it relates with other field of science and importance of minerals in natural environments as well as their domestic, industrial, and environmental applications.

### **2.0 OBJECTIVE**

At the end of this unit, you should be able to:

- define and explain soil mineralogy
- explain how soil mineralogy relates with other scientific fields.

### **3.0 MAIN CONTENT**

#### **3.1. Definition and meaning:**

Soil mineralogy is the study of the composition of the solid inorganic phases that control the physical and chemical processes in soils. It is one of the principal soil forming factors (Jenny, 1941) and therefore a key determinant of basic soil functional properties. Soil mineralogy has a profound influence on the dynamic behavior of soils namely the gains, losses, transformation and translocation of inorganic and organic substances. Therefore understanding soil mineralogy is important for assessing functional soil properties, such as interactions with nutrients, nutrient quantity (stock) and availability (intensity or strength of retention by soil), sorption of metals,

organics and nutrients to mineral surfaces, fertilizer response, water storage, erosion susceptibility, and provision of sites for microbial and faunal activities. These properties in turn determine soil agricultural, environmental and engineering qualities.

### **3.2 Soil Mineralogy and Plant Nutrition**

Soil clay minerals interact with elements most of which are plant nutrients, organics and biological molecules. These interactions may affect the availability of a nutrient to plants. For example phosphorus (P) can undergo fixation when it interact with iron and/or aluminum oxide (non-silicate clay minerals) especially at low pH. This element can also undergo precipitation with apatite at high pH. Soil mineralogy can therefore regulate the availability of essential and non-essential elements like P and heavy metals.

### **3.3 Soil Mineralogy, soil chemistry and soil formation**

The origin of soil minerals, the crystal structures of major minerals and their formation conditions. Pedogenic transformation of primary minerals to secondary minerals and properties of mineral surface, reactions of minerals with other soil nutrients and heavy metals, organics, and biologic molecules. An integral part of soil mineralogical studies also include the importance of minerals in natural environments, their domestic, industrial and environmental applications.

### **SELF-ASSESSMENT EXERCISE**

What is the meaning of the term “mineralogy”?

### **4.0 CONCLUSION**

Soil mineralogy is very essential in the field agriculture, environmental science and related fields.

### **5.0 SUMMARY**

Soil mineralogy studies the nature and occurrence of soil minerals chemical elements in the soil system in organic and inorganic combinations. It also studies the inter-relationship between these chemical elements and how they relate with three states of matter. It is central to many scientific fields.

### **6.0 TUTOR-MARKED ASSIGNMENT**

1. Define soil mineralogy?
2. List four scientific fields that is closely related to soil mineralogy

### **7.0 REFERENCES/FURTHER READING**

Dixon, J. B., and Weed, S. B. (eds.), 1977. Minerals in Soil Environments. Madison,

Wisconsin: Soil Science Society of America, 948p.

Grim, R.E., 1968. "Clay Mineralogy", 2nd Ed, McGraw Hill, NY, 596p

Joe B. Dixon and Darrell G. Schulze (ed.) 2012. Soil Mineralogy with Environmental Applications. Soil Science Society of America

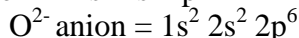
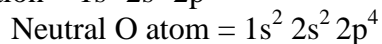
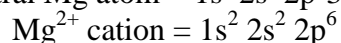
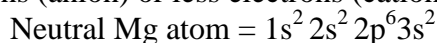
## **UNIT 2 ELEMENTS - CHEMICAL REACTIONS -CHEMICAL COMPOUNDS - MINERALS**

### **CONTENTS**

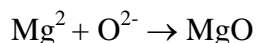
- 1.0 Introduction
- 2.0 Objective
- 3.0 Main Content
  - 3.1 Crystallization
  - 3.2 Crystal growth
  - 3.3 Solid chemical compound versus mineral
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Reading

### **1.0 INTRODUCTION**

Atoms of an element contain a dense nucleus of protons (p<sup>+</sup>) and neutrons (no charge; n<sup>0</sup>). These particles in the nucleus are held together by the strong force that acts over only at very short distance scale. The atomic nucleus is surrounded by electron (e<sup>-</sup>) cloud. These electrons are in different orbitals (s, p, d, f) around the nucleus, in a neutral atom, the number of electrons equals to the number of protons. However, most atoms can exist in ionized states where there are more electrons (anion) or less electrons (cations) than the protons.



These two ions are stable because both have a noble gas configuration of Ne (1s<sup>2</sup> 2s<sup>2</sup> 2p<sup>6</sup>). But when they come together they explosively interact forming a chemical reaction and a chemical compound:



The chemical so produced is a magnesium oxide that is electrically neutral. The chemical compound is solid at surface conditions, ie., at low pressure and temperature (P & T). At temperature of 2820°C it melts to form a liquid phase of same composition. At still higher temperature 3600°C it is vapourized to form a gas phase. The reverse process from vapour to liquid to solid state is known as crystallization or solidification.

### 3.0 MAIN CONTENT

#### 3.1 CRYSTALLIZATION

Crystals are formed from solutions, melts and vapours. The atoms in these **Disordered states** have a random distribution. With changing temperature, pressure and concentration, atoms may join in an ordered solid arrangement → **Crystalline State**.

**Crystallization from solutions:** During **evaporation** water molecules evaporate from NaCl solution, and the solution contains more and more  $\text{Na}^+$  &  $\text{Cl}^-$  per unit volume. Ultimately when the remaining water cannot hold all the salt in the soln the solid salt begins to precipitate.

Slow evaporation → few centers of crystallization → big crystals with common orientation.

Rapid evaporation → many centers of crystallization → randomly oriented small crystals.

As higher pressure or temperature (**P** or **T**) dissolve more salt into solvent by forcing solvent into crystal structure and increasing thermal vibrations and hence breaking ionic bonds. Thus lowering **P** or **T** of a saturated soln → **Supersaturation** → crystallization.

**Crystallization from melt:** Much the same process as crystallization from a soln. In a rock melt or **Magma** many of the ions are in uncombined state, although there is considerable cross-linking of ions or **ionic** groups  $[\text{SiO}_4]^{4-}$ . These ions are free to move in any direction in the molten state. In the cooling magma there are two opposing tendencies:

- (1) Thermal vibrations tends to destroy the nuclei of potential minerals,
- (2) Attractive forces tend to aggregate ions into crystal structure.

As **T** and **P** falls in a "**wet**" melt or **T** falls and **P** rises in a "**dry**" melt the destructive effect of (1) diminishes which allows the attractive effect of (2) to dominate → crystallization.

**Crystallization from vapour phase:** Solid crystals are formed without the intervening liquid phase from vapours, eg. sublimates of S formed near volcanic vents.

#### 3.2 CRYSTAL GROWTH

First stage during crystal growth is **Nucleation**. Crystal growth can start only after a nucleus has been formed. In the beginning there is a random formation of large number of potential nuclei. They are unstable → have high **surface energy=surface area/volume**. Small nuclei have high surface area where there are many atoms on the outer surface with unsatisfied bonds. Thus, in saturated soln most nuclei redissolve. For a nucleus is to survive, it must grow rapidly enough to reduce its surface energy or increase its volume where most of the internal atoms have completely satisfied bonds. After rapidly reaching a critical size the nucleus survives and grows at a relatively diminished rate.

In ionically bonded crystals, during crystal growth ordered accretion of ions occur where the surface energy is greatest (max. unsatisfied bonds at corners; -at edges, intermediate number - surface, min.). Thus, **dendrites** are common during crystallization, eg. snow flakes.

In nonionically bonded crystals, atoms accrete on the outer surface as clumps of atoms providing 'steps' along which new outer layer of crystal can be built up.

### 3.3 SOLID CHEMICAL COMPOUND VERSUS MINERAL

A **MINERAL** is a naturally occurring, homogeneous solid with a definite (not fixed) chemical composition, and a highly ordered atomic arrangement usually formed by inorganic processes.

### 4.0 CONCLUSION

From the above we can deduce the following:

(a) distinguishes man-made substances from mineral, - ie., synthetic material (eg. synthetic diamond) is not a mineral.

(b) means that it consists of a single, solid substance that can not be divided into chemical compounds. The qualification solid excludes gases and liquids. Thus H<sub>2</sub>O as **Ice** in a glacier is a mineral, but water is not. However, liquid Hg present in some ore deposits is called **Mineraloid**.

(c) implies that minerals have specific but variable chemical formula, ie. **Dolomite** CaMg(CO<sub>3</sub>)<sub>2</sub>, but generally Mg $\leftrightarrow$ Fe, Mn; thus, Ca(Mg<sub>0.6</sub>Fe<sub>0.3</sub>Mn<sub>0.1</sub>)(CO<sub>3</sub>)<sub>2</sub>. However, **Opal** having indefinite chemical composition SiO<sub>2</sub>.nH<sub>2</sub>O is a **Mineraloid**.

(d) indicates an internal structural framework of atoms (or ions) arranged in a regular geometric pattern  $\equiv$  **Crystalline Solid**. In the crystalline structure atoms are in order and shows repeated patterns in 3-D. The position of an atom in the structure is definite and is predictable. Solids that lack an ordered atomic arrangement are called **Amorphous**, eg. volcanic glass, **Limonite** and **Metamict minerals** where original crystallinity is destroyed by radiation from radio active elements present in the original structure (ie. U and Th in **Zircon** destroys **Biotite** structure).

(e) generally inorganic in origin but some biogenically produced inorganic compounds such as **Aragonite** in shell and pearl, and also **Opa**, **Mat** (Magnetite), **Fluorite**, some phosphates, sulphates and Mn oxides, **Pyt** (Pyrite) and elemental **S** of bacterial origin are included. However, organic compounds of petroleum and coal (**macerals**) are excluded.

### 5.0 SUMMARY

All of the minerals are the subject of **MINERALOGY**, which is composed of Latin word **MINERA** (from the Earth crust) and Greek word **LOGOS** (knowledge). More than 2500 minerals are known but 200 are the most common and abundant.

### 6.0 TUTOR-MARKED ASSIGNMENT

Define the following:

- Crystallization
- Nucleation
- Mineral

### 7.0 REFERENCES/FURTHER READING

Dixon, J. B., and Weed, S. B. (eds.), 1977. Minerals in Soil Environments. Madison, Wisconsin: Soil Science Society of America, 948p.

Grim, R.E., 1968. "Clay Mineralogy", 2nd Ed, McGraw Hill, NY, 596p

Joe B. Dixon and Darrell G. Schulze (ed.) 2012. Soil Mineralogy with Environmental Applications. Soil Science Society of America

### **UNIT 3. Relationship of Mineralogy to Agriculture, Engineering and other Environmental Sciences**

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- 1.0 Introduction
- 2.0 Objective
- 3.0 Main Content
  - 3.1 Soil Mineralogy and Soil Chemistry
  - 3.2 Soil Mineralogy and Toxicology
  - 3.3 Soil Mineralogy and Engineering
  - 3.4 Significance of Soil Mineralogy
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Reading

#### **1.0 INTRODUCTION**

This unit is a continuation of the previous one. It seeks to elucidate the link between soil mineralogy and some other scientific fields of study.

#### **2.0 OBJECTIVE**

At the end of this unit, you should be able to:

- explain how soil mineralogy relates with soil chemistry, toxicology and engineering.

#### **3.0 MAIN CONTENT**

##### **3.1 Soil Mineralogy and Soil Chemistry**

Most reactions in the soil occur in the soil-solution interface and the soil solid phase is made up of the soil colloid and exchangeable ions which make up the soil exchange complex. The properties the soil colloids that determine the reactivity of the soil are determined through mineralogy of the clay soil fraction. The most reactive components of the soil are the sesquioxides (Fe, Al and Mn oxides) and their properties can only be determined through mineralogical analysis.

### **3.2 Soil Mineralogy and Toxicology**

The soil is an excellent sorbent for a variety of organic and inorganic pollutants. The fate of these pollutants is very critical to ecosystem health. The soil acts as a sorbent through the adsorption of these pollutants onto soil minerals. The fate of pollutants from manures, sewage sludge, pesticides and herbicides is determined by the mineralogy of the soil clay fraction. The ability of the soil to render pollutants ineffective is a function of its mineralogical properties.

### **3.3 Soil Mineralogy and Engineering**

Soil mechanical properties that are important for many engineering decisions such as road construction and earthworks also determine structural stability and tillage properties of soils. Properties such as atterberg limits, linear shrinkage tests, and hygroscopic water content are very important for determining suitability of a soil for engineering purposes. The atterberg limits are used to estimate the strength and settlement characteristics of soils. They characterize and define the behavior of soil by measuring shrinkage limit, liquid limit and plastic limit. The limits are also linked to erodibility of the soil and their properties depend on the amount of clay, silt, organic matter and type of minerals present in the soil.

### **3.4 Significance of Soil Mineralogy**

Soil minerals play a very important role in soil fertility evaluation and the suitability of soil for various land uses. They provide anchorage for plants, contribute to soil structural formation, are sources of many soil nutrients, and can act as sorbents of several environmental pollutants. Therefore, understanding soil mineralogy is essential to understanding many facets of land use and is very essential in solving specific agricultural and environmental problems.

## **4.0 CONCLUSION**

Soil Mineralogy is fundamental to all soil processes that affect the use of soil in agriculture, pollution control and engineering making it at the center of soil and environmental sciences. The significance of soil mineralogy cut across its importance in determining soil fertility status, soil chemical reactions, fate of pollutants in the soil and in the use of soil for construction purposes.

## **SELF-ASSESSMENT EXERCISE**

How do soil mineralogy control the availability of soil nutrients and render pollutants ineffective in the environment?

## **5.0 SUMMARY**

Soil mineralogy, soil chemistry, pollution control and engineering are much related.

## **6.0 TUTOR-MARKED ASSIGNMENT**

1. How do soil minerals affect nutrient availability?
2. What soil component affects pollutant movement?
3. What is the importance of the knowledge of soil mineralogy?

## **7.0 REFERENCES/ FURTHER READING**

Dixon, J. B., and Weed, S. B. (eds.), 1977. *Minerals in Soil Environments*. Madison, Wisconsin: Soil Science Society of America, 948p.

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## **UNIT 3 SOIL COMPONENTS**

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- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1. The Solid Phase
  - 3.2. The Solution or Liquid Phase
  - 3.3. The Gas Phase



- 4.0. Conclusion
- 5.0. Summary
- 6.0. Tutor-Marked Assignment
- 7.0. References/Further Reading

## **1.0 INTRODUCTION**

Soil is a major component of the ecosystem; it is the storehouse of all anthropogenic activities and a sink for soil nutrients for crop production and pollutants from different sources. The soil is composed of some basic constituents, some which are visible to naked eyes while others are very small and cannot be seen by the ordinary eyes (microscopic). This unit deals with the basic components of the soil and their importance in agriculture.

## **2.0 OBJECTIVES**

At the end of this unit, you should be able to:

- identify the components of soil
- mention the factors that affect the composition of the soil.

## **3.0 MAIN CONTENT**

Soil may be defined as material of variable depth with a substantial solid content at the Earth's surface which is undergoing change as a consequence of chemistry, physics and biology processes.

Soil essentially consists of three phases; a solid phase, a liquid or solution phase and a gas phase.

### **3.1 The Solid Phase**

The soil solid phase is a complex mixture of mineral matter, originating from parent material and organic debris under the influence of biogeochemical activities. Solid phase occupies about 50% of the soil's volume. It is composed more than 90% inorganic materials except in Histosols that has about 50% organic material. This soil phase comprises of the primary and secondary minerals. The primary minerals are derived from the parent rock while the secondary minerals are derived as a result of pedogenic transformation of the primary minerals. The mineral particles in the soil vary in size. The size ranges from sand particles with 2.0-0.05 mm size range; silt (0.05 – 0.002 mm) and clay (less than 0.002mm. Sand particle can be seen with the naked eyes and feel gritty when rubbed between the fingers and its major composition is the Si-O units. The particles do not adhere to one another; therefore sands do not feel sticky. Silt particles are too small to be seen without a microscope or to feel individually, so silt feels smooth but not sticky, even when wet. Clay particles are the smallest of the three particles, they adhere together when wet to form a sticky mass and also forms a hard clod when dry. One major composition of the soil solid phase is the soil organic matter. It is often referred to as the life blood of the soil.

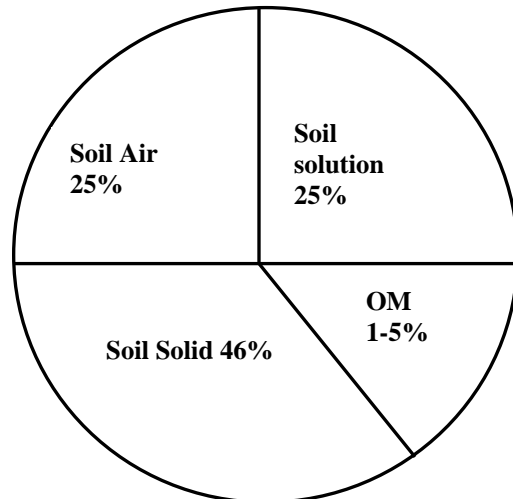
### 3.2 The Solution or Liquid Phase

This phase is in constant equilibrium with the solid phase. It is where all soil chemical processes like adsorption-desorption, precipitation-dissolution, complexation, oxidation-reduction, ion exchange etc reactions take place. Soil water is a repository for dissolved solids and gases, and for this reason is referred to as the *soil solution*. With respect to dissolved solids, those that dissociate into ions (*electrolytes*) in the soil solution are most important to the chemistry of soils. The soil solution originates from water infiltrating the soil from rainfall, dew, snow, fog etc or from rising water or water moving laterally (pools of water in the soil, this could be water from the ground source etc). The chemical composition of the soil solution depends on:

- i. anthropogenic activities
- ii. adsorption-desorption reactions
- iii. solute movement
- iv. ion exchange reaction
- v. oxidation-reduction reaction
- vi. biological activities in the soil

### 3.3 The Gas Phase

This phase together with the liquid phase constitutes one to two-third of the soil volume. Its composition is mainly oxygen and other atmospheric gases such as CO<sub>2</sub> (3-4%), H<sub>2</sub>, NO, N<sub>2</sub>O, NH<sub>3</sub>, CH<sub>4</sub>, and H<sub>2</sub>S. Most of these gases are produced under oxygen deficiency and microbial mediation. It is responsible for soil microbial respiration.



**Composition of the Soil**

### 4.0 CONCLUSION

Soil is made up of solid, liquid and gaseous phases.

### 5.0 SUMMARY

The soil is made up of the three states of matter. The constituent of the soil has a large effect on soil properties and its functionality.

## **SELF-ASSESSMENT EXERCISE**

What is the determinant of the composition of the soil gaseous phase?

### **6.0 TUTOR-MARKED ASSIGNMENT**

1. List four determinants of the composition of the soil liquid phase.
2. List five types of gases in the soil.
3. List two sources of the soil solid materials.

### **7.0 REFERENCES/FURTHER READING**

Brady, N. C. & Weil, R. R. (1999). *The Nature and Properties of Soils*. (12th ed.). New Jersey: Prentice-Hall.

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## **UNIT 4**

## **CLASSIFICATION OF MINERALS**

1.0 Introduction

2.0 Objectives

3.0 Main Content

3.1. General classification of minerals

3.2. Primary minerals

3.3. Secondary minerals

3.3.1 Classification secondary minerals

- 4.0. Conclusion
- 5.0. Summary
- 6.0. Tutor-Marked Assignment
- 7.0. References/Further Reading

## 1.0 Introduction

The soil solid phase is divided into organic and inorganic components; the inorganic component is further categorized into crystalline and non-crystalline. Crystalline soil components are categorized. The Earth crust is made of various rocks which are classified as:

1. Igneous (Plutonic, Volcanic and Hypabyssal), formed from **melts** at high temperature in liquid state.
2. Sedimentary, formed at surface conditions of low temperature and pressure mostly from aqueous solutions
3. Metamorphic; formed at depth at higher temperature and pressure, due to physical and chemical changes of source material, in solid state.

## 2.0 OBJECTIVES

At the end of this unit, students should be able to

- Classify minerals into primary and secondary
- Differentiate primary minerals from secondary minerals

## 3.0 MAIN CONTENT

### 3.1 GENERAL CLASSIFICATION OF MINERALS

These rocks consist of various minerals which are called, **Rock Forming Minerals**. Some of them are useful for industry (eg. **Feldspar** → Ceramics, and Glass industry, or Diatomite, a sedimentary rock → Sugar industry) and are called **Industrial Minerals and Rocks**. Some minerals have high concentrations of metallic elements (eg. **Cpy** (Chalcopyrite)-Cu; **Cinnabar**-Hg), from which metals and valuable elements are extracted, which are called **Ore Minerals**. Some minerals are used for decorative purposes (eg. **Diamond**; **Corundum**, **Ruby**, **Sapphire**; and **Beryl**, **Aquamarine**, **Emerald**) which are called **Gemstones**.

When **HT/HP** rocks consisting of **Primary minerals** are brought to surface (**LT/LP** conditions) by tectonic forces rock forming minerals are decomposed and altered to **Secondary minerals**, which may be grouped as **Clay minerals**, **Serpentine minerals** etc. If clay minerals are mixed with organic material they produce fertile soils.

Meteorites originated from space consist of pure elements, minerals or rocks. Their compositions are Fe, FeS (**Troilite**) and silicates which may be named as **Meteoroids**. Asteroids and other inner terrestrial planets and their satellites also consist of minerals and rocks. Crust of inner planets are made of silicate rock. However, the far-out satellites of the giant gaseous planets of the Solar System are made of generally sulphur minerals, ice, methane and nitrogen minerals.

**Minerals are named** on the basis of

- physical property, magnetic → Magnetite, **Mat** (Fe<sub>3</sub>O<sub>4</sub>)
- predominant element, Cr → **Chromite** (FeCr<sub>2</sub>O<sub>4</sub>)

Ba → **Barite** (BaSO<sub>4</sub>)

- locality, Franklin, New Jersey → **Franklinite** (ZnFe<sub>2</sub>O<sub>4</sub>)

Panderma (Bandırma) → **Pandermite** (Ca<sub>4</sub>B<sub>10</sub>O<sub>19</sub>.7H<sub>2</sub>O)

- colour, Albus (**L.** white) → **Albite** (NaAlSi<sub>3</sub>O<sub>8</sub>)

Rhodon (**G.** rose) → **Rhodonite** (MnSiO<sub>3</sub>)

### 3.2 Primary Minerals

Primary silicates appear in soils as a result of deposition processes and from the physical disintegration of parent rock material. The weathering of primary silicates contributes to the native fertility and electrolyte content of soils. Among the major decomposition products of these minerals are the soluble metal cation species Na<sup>+</sup>, Mg<sup>2+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mn<sup>2+</sup>, and Fe<sup>2+</sup> in the soil solution. The metal cations Co<sup>2+</sup>, Cu<sup>2+</sup>, and Zn<sup>2+</sup> occur as trace elements in primary silicates and thus are also released to the soil solution by weathering. The names and chemical formulas of primary silicate minerals important to soils are listed in Table 4.1. The fundamental building block in the atomic structures of these minerals is the silica tetrahedron: SiO<sub>4</sub><sup>4-</sup>. Silica tetrahedral can occur as isolated units, in single or double chains linked together by shared oxygen corners, in sheets, or in full three-dimensional frameworks. Each mode of occurrence defines a class of primary silicate.

The *olivines* comprise individual silica tetrahedra in a structure held together with bivalent metal cations like Mg<sup>2+</sup>, Fe<sup>2+</sup>, Ca<sup>2+</sup>, and Mn<sup>2+</sup> in octahedral coordination. The *pyroxenes* and *amphiboles* contain either single or double chains of silica tetrahedra that form the repeating unit Si<sub>2</sub>O<sub>4</sub><sup>-6</sup> or Si<sub>4</sub>O<sub>6</sub><sup>-11</sup>, respectively.

Table 4.1 Names and chemical formulas of primary silicates found in soils.

Name	Chemical formula	Mineral group
Forsterite	Mg <sub>2</sub> SiO <sub>4</sub>	Olivine
Fayalite	Fe <sub>2</sub> SiO <sub>4</sub>	Olivine
Chrysolite	Mg <sub>1.8</sub> Fe <sub>0.2</sub> SiO <sub>4</sub>	Olivine
Enstatite	MgSiO <sub>3</sub>	Pyroxene
Orthoferrosilite	FeSiO <sub>3</sub>	Pyroxene
Diopside	CaMgSi <sub>2</sub> O <sub>6</sub>	Pyroxene
Tremolite	Ca <sub>2</sub> Mg <sub>5</sub> Si <sub>8</sub> O <sub>22</sub> (OH) <sub>2</sub>	Amphibole
Actinolite	Ca <sub>2</sub> Mg <sub>4</sub> FeSi <sub>8</sub> O <sub>22</sub> (OH) <sub>2</sub>	Amphibole
Hornblende	NaCa <sub>2</sub> Mg <sub>5</sub> Fe <sub>2</sub> AlSi <sub>7</sub> O <sub>22</sub> (OH)	Amphibole

Muscovite	$K_2[Si_6Al_2]Al_4O_{20}(OH)_4$	Mica
Biotite	$K_2[Si_6Al_2]Mg_4Fe_2O_{20}(OH)_4$	Mica
Phlogopite	$K_2[Si_6Al_2]Mg_6O_{20}(OH)_4$	Mica
Orthoclase	$KAlSi_3O_8$	Feldspar
Albite	$NaAlSi_3O_8$	Feldspar
Anorthite	$CaAl_2Si_2O_8$	Feldspar
Quartz	$SiO_2$	Silica

### 3.3 Secondary Minerals

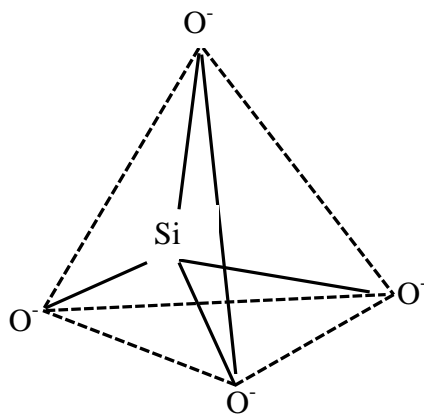
Secondary minerals are a result of pedogenic transformation of primary minerals. In other words, they are primary minerals that have undergone extensive weathering.

#### 3.3.1 Classification of secondary minerals

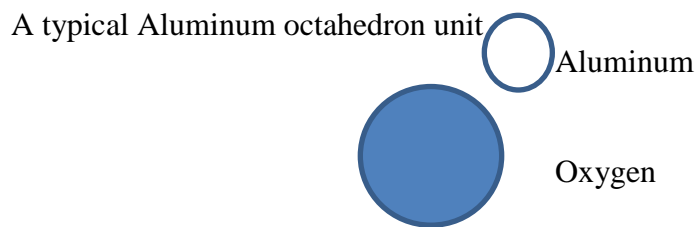
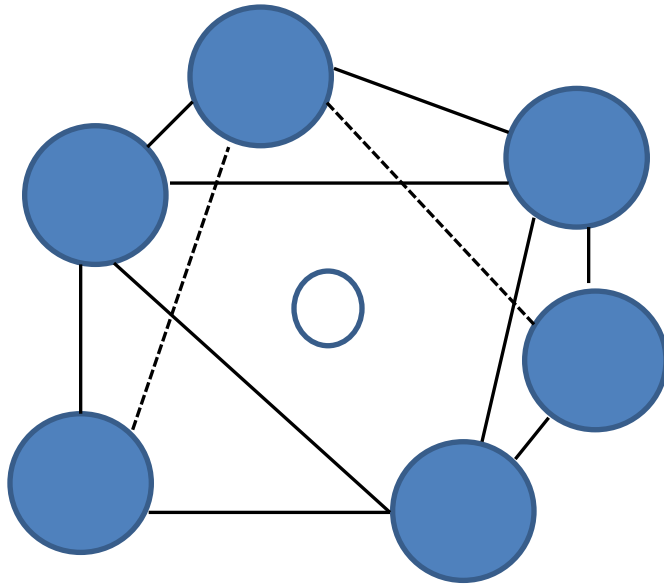
##### 3.3.1.1. Classification based on the mineralogical composition

1. Secondary minerals are classified into silicate clay minerals and non-silicate clay minerals. Silicate Clay minerals are layer-type aluminosilicates that predominate in the clay fractions of soils at the intermediate to advanced stages of weathering. These minerals, like the micas, are sandwiches of tetrahedral and octahedral sheet structures. This bonding together of the tetrahedral and octahedral sheets occurs through the apical oxygen ions in the tetrahedral sheet and produces a distortion of the anion arrangement in the final layer structure formed. The major building blocks of silicate clay minerals are the silicon tetrahedral unit and aluminum octahedral units.

Silicon tetrahedral unit comprises of a central Silicon (Si) atom surrounded by four oxygen (O) atoms while aluminum octahedral unit comprises of a central aluminum (Al) atoms surrounded by six oxygen (O) atoms.



A typical Silicon tetrahedron



2. Non-silicate clay minerals comprises of metal oxides, oxyhydroxides, and hydroxides. Because of their great abundance in the lithosphere, aluminum, iron, manganese, and titanium form the important oxide, oxyhydroxide, and hydroxide minerals in soils. They represent the *climax mineralogy* of soils. The most significant of these minerals, all of which are characterized by small particle size and low solubility in the normal range of soil pH values, are indicated in Table 4.2.

Table 4.2 Metal oxides, oxyhydroxides, and hydroxides found commonly in soils.

Name	Chemical formula
Rutile	TiO <sub>2</sub>
Hematite	$\alpha$ -Fe <sub>2</sub> O <sub>3</sub>
Birnessite	M <sub>x</sub> Mn(IV) <sub>a</sub> Mn(III) <sub>b</sub> cOb <sub>2</sub>

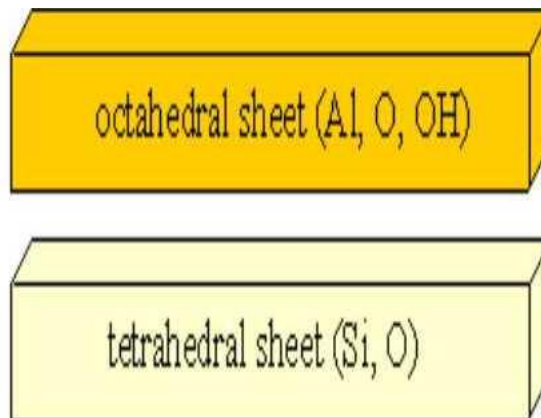
Lepidocrocite	$\gamma\text{-FeOOH}$
Ferrihydrite	$\text{Fe}_{10}\text{O}_{15} \cdot 9\text{H}_2\text{O}$
Lithiophorite	$\text{LiAl}_2(\text{OH})_6\text{Mn(IV)}_2\text{Mn(III)}\text{O}_6$
Gibbsite	$\gamma\text{-Al(OH)}_3$
Maghemite	$\gamma\text{-Fe}_2\text{O}_3$
Goethite	$\alpha\text{-FeOOH}$
Magnetite	$\text{FeFe}_2\text{O}_4$

### 3.3.1.2 Classification based on the number of silicon tetrahedral unit and aluminum octahedral units present

Secondary minerals are classified into three based on number of silicon tetrahedral unit and aluminum octahedral unit presents and their stacking arrangements.

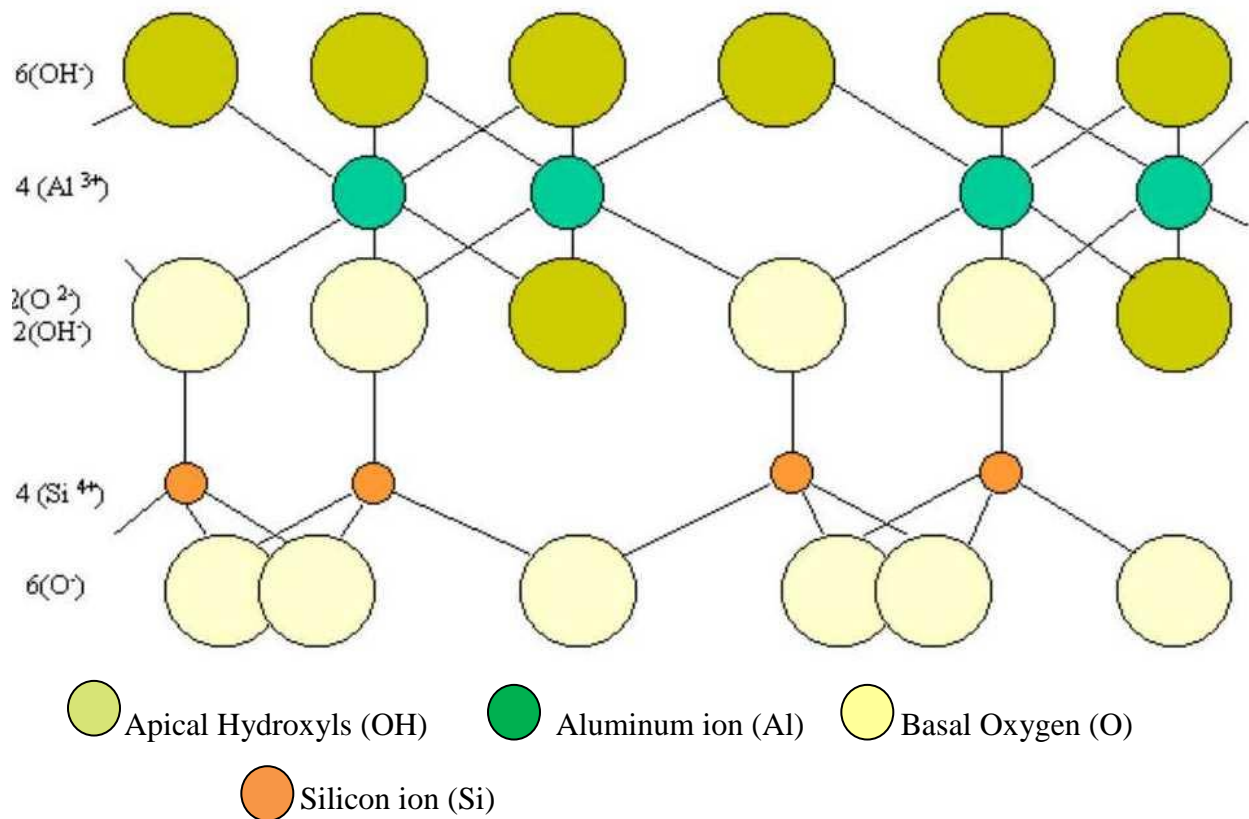
1. The 1:1 layer type: This consists of one tetrahedral and one octahedral sheet. In soil clays, it is represented by the *kaolinite group*, with the generic chemical formula  $[\text{Si}_4]\text{Al}_4\text{O}_{10}(\text{OH})_8 \cdot n\text{H}_2\text{O}$ , where the element enclosed in square brackets is in tetrahedral coordination and n is the number of moles of hydration water between layers. As is common for soil clay minerals, the octahedral sheet has two thirds of its cation sites occupied (dioctahedral sheet). Kaolinite group minerals are the most abundant clay minerals in soils worldwide, they are particularly characteristic of highly weathered soils (Ultisols, Oxisols). Other examples of 1:1 clay minerals include halloysite, dickite nacrite etc

**Kaolinite: 1 : 1 type**



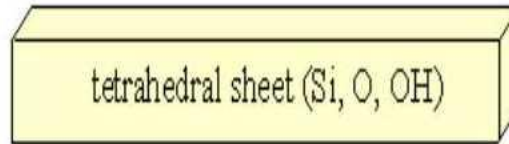


## Diagrammatic Representation of Kaolinite

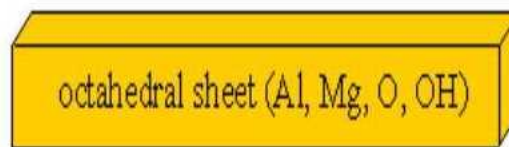
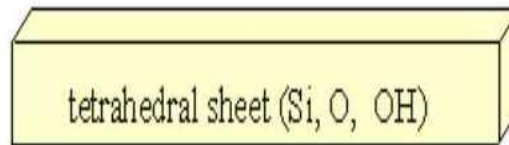


2. The 2:1 layer type: This has two tetrahedral sheets that sandwich an octahedral sheet. The three soil clay mineral groups with this structure are *illite*, *vermiculite*, and *smectite*. The layer charge decreases in the order *illite* > *vermiculite* > *smectite*. The vermiculite group is further distinguished from the smectite group by a greater extent of isomorphic substitution in the tetrahedral sheet. Among the smectites, two subgroups also are distinguished in this way, those for which the substitution of Al for Si exceeds that of Fe(II) or Mg for Al (called *beidellite*), and those for which the reverse is true (called *montmorillonite*).

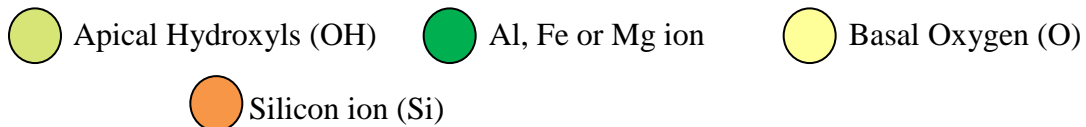
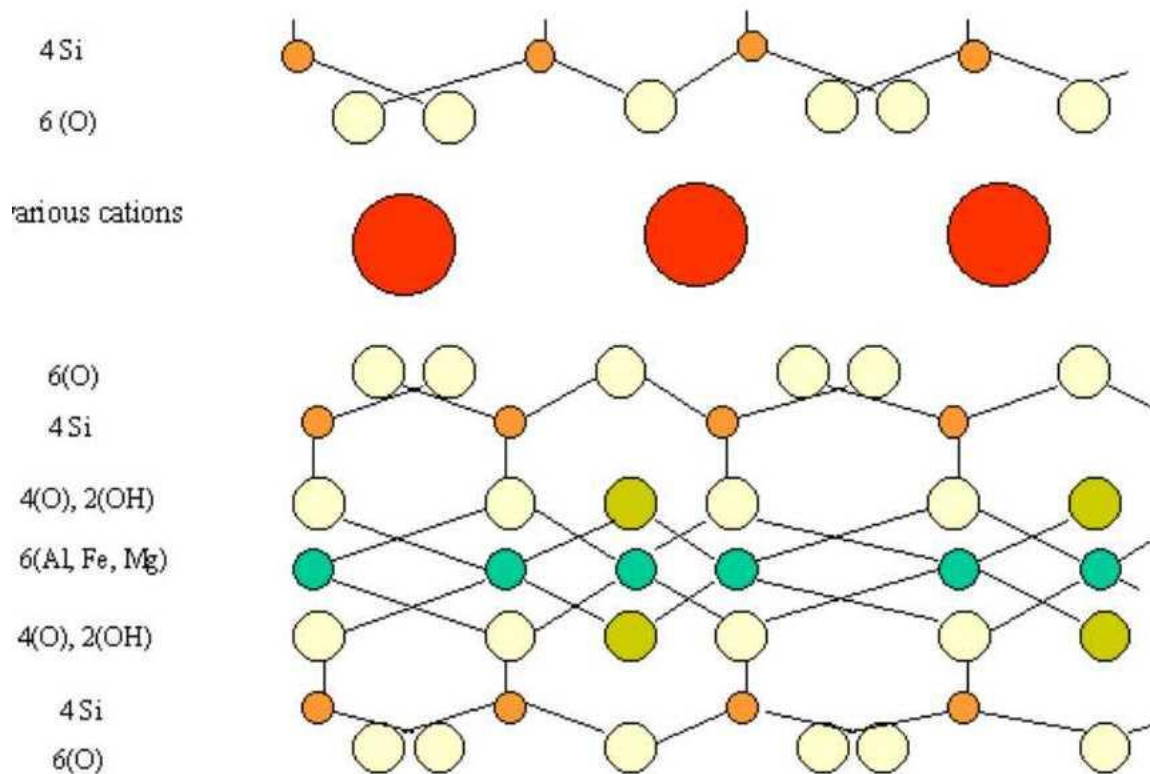
# Montmorillonite: 2 : 1 type



various cations



## Diagrammatic Representation of Montmorillonite



3. The 2:1:1 or 2:2 mineral type:

**Chlorites: 2 : 1 : 1 type**

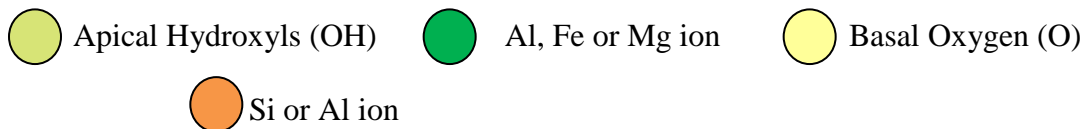
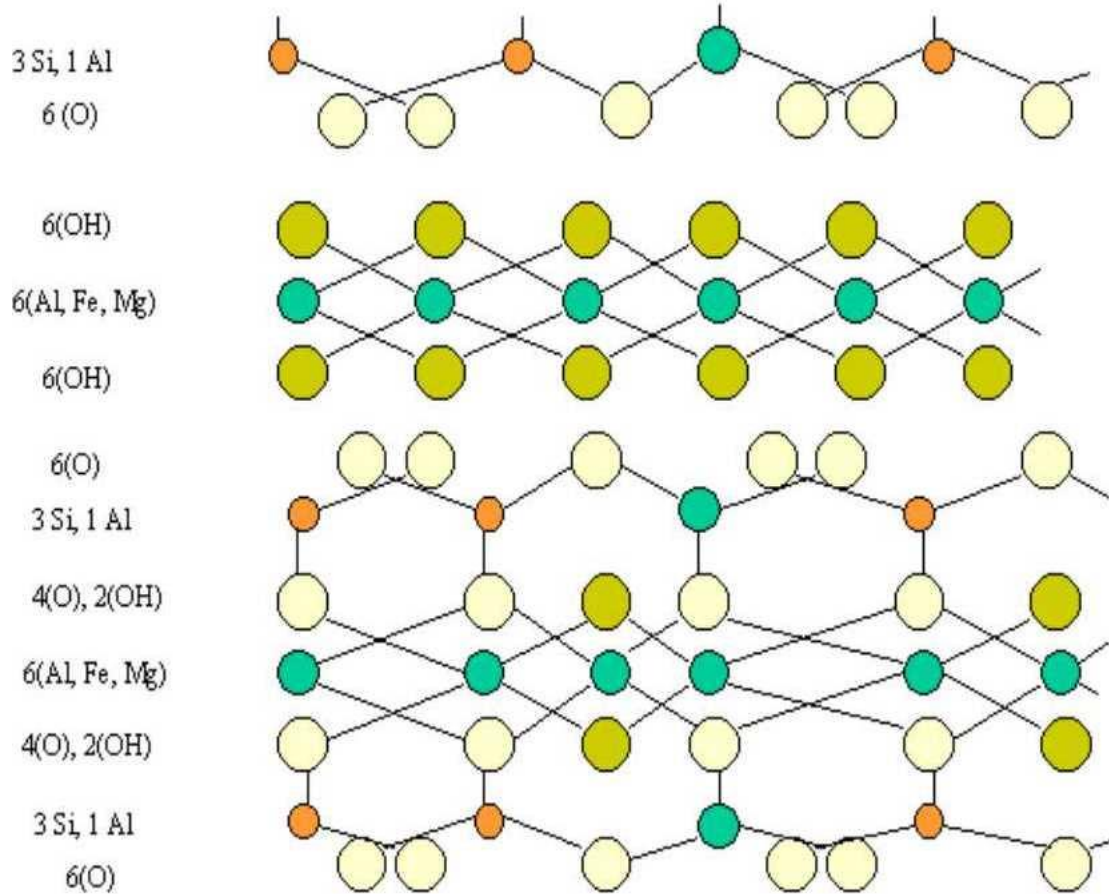
tetrahedral sheet (Si, Al, O, OH)

octahedral sheet (Al, Mg, OH)

tetrahedral sheet (Si, Al, O, OH)

octahedral sheet (Al, Mg, O, OH)

**Diagrammatic Representation of Chlorite**



## **4.0 CONCLUSION**

Soil clay minerals are categorized into primary and secondary minerals based on their origin.

## **5.0 SUMMARY**

Secondary minerals are categorized based on the number of silicon tetrahedral and aluminum octahedral units they possessed into 1:1, 2:1 and 2:1:1 or 2:2 clay minerals.

## **SELF-ASSESSMENT EXERCISE**

What is the composition of 1:1, 2:1 and 2:1:1 or 2:2 clay minerals?

## **6.0 TUTOR-MARKED ASSIGNMENT**

1. List five primary minerals with the group of each.
2. State two examples of 1:1 and 3 of 2:1 clay minerals.
3. List five non-silicate clay minerals in the soil.

## **7.0 REFERENCES/FURTHER READING**

Brady, N. C. & Weil, R. R. (1999). *The Nature and Properties of Soils*. (12th ed.). New Jersey: Prentice-Hall.

Biswas, T.D. and S.K. Mukherjee, S.K. 2001. *Textbook of Soil Sciences*. Tata McGraw-Hill Education

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## Module 2

### UNIT 1

## SILICATE AND NON-SILICATE MINERAL STRUCTURE

1.0 Introduction

2.0 Objectives

3.0 Main Content

3.1. Framework silicates

3.2. Chain Silicates

4.0. Conclusion

5.0. Summary

6.0. Tutor-Marked Assignment

7.0. References/Further Reading

### 1.0 Introduction

Most of the primary minerals (primary silicates) have a crystalline structure, i.e., a structure in which ions are arranged in an orderly and repeated spatial pattern. The fundamental unit in silicates is the silicon-oxygen tetrahedron, which is composed of a central silicon ion surrounded by four closely-packed and equally-spaced oxygen ions. The four positive charges of  $\text{Si}^{4+}$  are balanced by four negative charges from the four oxygen ions ( $\text{O}_2^-$ ), one from each ion, thus each discrete tetrahedron has four negative charges.

### 2.0 Objectives

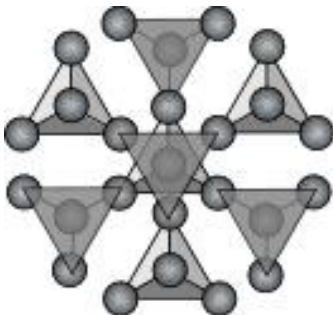
The students should be able to do the following at the end of this unit:

- Recognize the structural arrangement of silicate clay minerals`
- Differentiate framework silicate from chain silicate structures

### 3.0 Main Content

#### 3.1 Framework Silicates

They are composed of tetrahedra linked through their corners into a continuous 3D-structure. Quartz is a framework silicate composed entirely of silicon-oxygen tetrahedra. The bulk density of quartz is  $2.65 \text{ g/cm}^3$  and quartz is highly resistant to mechanical abrasion and chemical weathering. Quartz is very common in most igneous, metamorphic and sedimentary rocks. In feldspars the  $\text{Si}^{4+}$  is partly replaced by  $\text{Al}^{3+}$ , which results in a positive charge balanced by  $\text{Na}^+$ ,  $\text{K}^+$  or  $\text{Ca}^{2+}$  ions. In the alkali feldspars  $\text{Na}^+$  and  $\text{K}^+$ , and in the plagioclase,  $\text{Na}^+$  and  $\text{Ca}^{2+}$  are the dominant accessory cations. Feldspars are the most abundant minerals in the earth's crust; they make up 50 - 60 % of the crustal rocks.

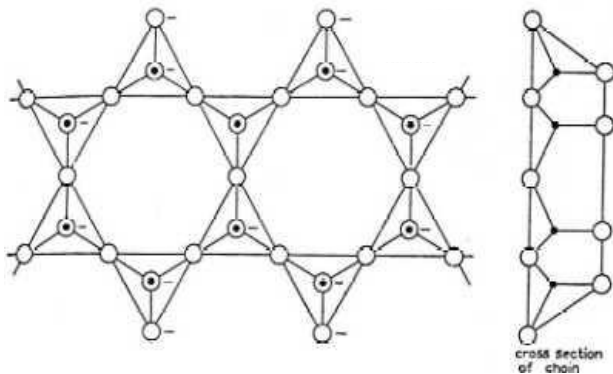


**A common example of a Silicate Framework Structure**

The oxygen ions in the basal plane of the tetrahedral sheet in kaolinite are bonded to a pair of  $\text{Si}^{4+}$ , whereas the apical oxygen ions are bonded to one  $\text{Si}^{4+}$  and two  $\text{Al}^{3+}$ . Similarly, the OH ions in the basal plane of the octahedral sheet are bonded to two  $\text{Al}^{3+}$ , as are the OH in the interior of the layer. An exposed oxygen ion bound to a single  $\text{Si}^{4+}$  at an edge, for example, bears an excess charge of  $-1.0$  vu and, therefore, requires a cation partner with a bond valence of  $1.0$  vu to be stable. This requirement can be met easily if a proton from aqueous solution becomes bound to the oxygen ion.

### 3.2 Chain Silicates

The amphibole and pyroxene are chain silicates, whereas the  $\text{Si}^{4+}$  is also partly replaced by  $\text{Al}^{3+}$ , but the chains are held together by  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{Al}^{3+}$  and /or  $\text{Ti}^{3+}$  ions. The tetrahedras are linked to each other by sharing two of the three basal corners to form continuous chains. The pyroxenes are composed of silica tetrahedra which form single chains, whereas the amphiboles are composed of silica tetrahedra double chains. Because the bonding between chains is not strong the amphibole and pyroxene are easily weatherable.



**A Typical Chain Silicate**

### 4.0. CONCLUSION

Framework silicates are composed of tetrahedra linked through their corners into a continuous 3D-structure while tetrahedral units of chain silicates are linked by sharing 2 of the 3 basal oxygen.

### 5.0 SUMMARY

Framework silicates are 3D-structure composed of mainly oxygen-silicon tetrahedral units which are very resistant to weathering, a common example is quartz. Chain silicates are made up of single chain of silica tetrahedral and are easily weatherable, examples are the pyroxenes and amphiboles.

### 6.0. TUTOR-MARKED ASSIGNMENT

- What is the major difference between framework silicate and chain silicates?

## 7.0. REFERENCES/FURTHER READING

Biswas, T.D. and S.K. Mukherjee, S.K. 2001. Textbook of Soil Sciences. Tata McGraw-Hill Education

Dixon, J.B. Weed, S.B., and Dinaure, R.C. 1989. Minerals in Soil Environments. Soil Science Society of America, W.I. Madison, Wisconsin

Sposito, G. 2018. The Chemistry of Soils. Oxford University Press

## UNIT 2 SILICATE AND NON-SILICATE MINERAL STRUCTURE (CONTINUED)

1.0 Introduction

2.0 Objectives

3.0 Main Content

3.1. Sheet silicates

3.2. Ortho- and Ring Silicates

4.0. Conclusion

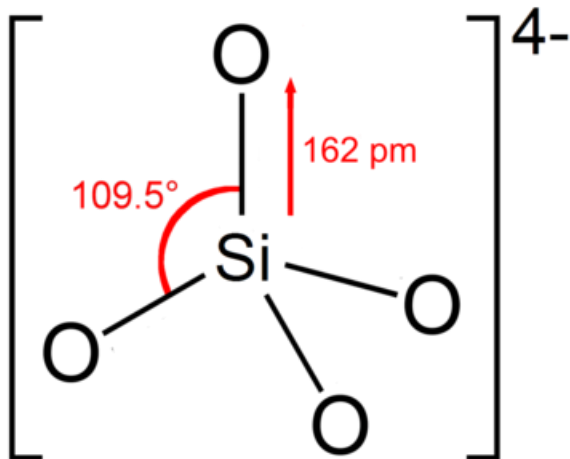
5.0. Summary

6.0. Tutor-Marked Assignment

7.0. References/Further Reading

### 1.0 Introduction

In the previous unit we learnt that the fundamental unit in silicates is the silicon-oxygen tetrahedron. Where we have the central ion may be either  $\text{Al}^{3+}$ ,  $\text{Fe}^{2+}$ , or  $\text{Mg}^{2+}$  with six-folded coordination, oxygen form an eight-sided octahedron. If larger  $\text{Ca}^{2+}$ ,  $\text{Na}^+$ , or  $\text{K}^+$  ions are present, they occur at the center of clusters of tetrahedra, with each tetrahedron supplying a part of all the oxygen needed for eight-fold or twelve fold coordination. In this arrangement, the larger cations provide a center of positive charge that attracts and holds the clusters of tetrahedra together. The cations occurring in this position, i.e., outside or between neighboring tetrahedra are called accessory cations.  $\text{Si}^{4+}$  and  $\text{Al}^{3+}$  ions are small and have a high charge (valence). In general, the smaller the cation and the higher its valence the stronger the bond between it and the oxygen.



**Silicon-oxygen tetrahedron Unit**

## 2.0 Objectives

The students should be able to do the following at the end of this unit:

- Recognize the structural arrangement of silicate clay minerals`
- Differentiate sheet silicate from ortho-and ring silicate structures

## 3.0 MAIN CONTENT

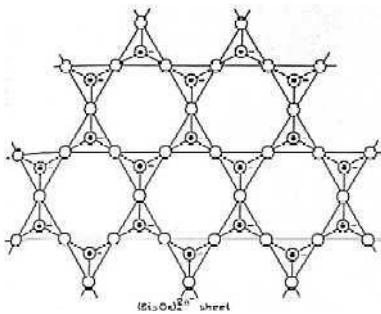
### 3.1 Sheet Silicates

Sheet silicates are composed of three basic sheets:

Silicon tetrahedral sheet: Composed of silicon-tetrahedra linked together in a hexagonal arrangement with the three basal oxygen ions of each tetrahedron in the same plane and all the apical oxygen ions in a second plane. Thus the silicon tetrahedral sheet is a hexagonal planar pattern of silicon-oxygen tetrahedra.

Aluminum hydroxide sheet: The basic unit of this sheet is the aluminum-hydroxyl octahedron in which each ion is surrounded by six closely packed hydroxyl groups, in such a way that there are two planes of hydroxyl ions, with a third plane containing aluminum ions sandwiched between the two hydroxyl planes. In order that all the valencies of the structure be satisfied only two out of every three positions in the aluminum hydroxide sheet are occupied by aluminum ions forming what is known as a dioctahedral structure.

Magnesium hydroxide sheet: This has a similar structure to the aluminum hydroxide sheet but the aluminum is replaced by magnesium, and because magnesium is divalent all the sites in the middle plane are occupied, forming a trioctahedral structure.



### A Typical Sheet Silicate

In pyrophyllite one aluminum hydroxide sheet is lying between two silicon tetrahedral sheets and is known as a 2 : 1 type mineral. Micas are the most common primary sheet silicates, such as muscovite (white mica) and biotite (black mica). The micas contain oxygen in octahedra as well as in tetrahedra, with both occurring in a sheet like arrangement. Because of the ratio of two tetrahedral sheets to each octahedral sheet, the micas are called 2 : 1 layer minerals. Micas are generally found in granitic pegmatites, which are coarsely crystalline, igneous rocks. In muscovite one-quarter of the silicon ions is substituted by aluminum ions in the silicon tetrahedral layers. This imbalance in charges is satisfied by potassium, which bonds the composite sheets together. In biotite within the Mg-hydroxide sheet about one-third of Fe<sup>2+</sup> is substituted for Mg<sup>2+</sup>. The negative charges occurring in this sheet are neutralized by potassium,



which bonds the composite sheets together. The potassium is positioned in the interlayer space between neighboring layers. The potassium bonding is weak, where splitting may occur.

### **3.2 Ortho- and Ring Silicates**

They include the olivines, zircon, and titanite. In olivines the silicon-tetrahedra is arranged in sheets and linked by  $Mg^{2+}$  and / or  $Fe^{2+}$  ions. Olivine is found in basalt and volcanic rocks.

### **4.0. CONCLUSION**

Sheet silicates are composed of silicon tetrahedral, aluminum octahedral and magnesium hydroxyl or brucite sheet.

### **5.0 SUMMARY**

Framework silicates are 3D-structure composed of mainly oxygen-silicon tetrahedral units which are very resistant to weathering, a common example is quartz. Chain silicates are made up of single chain of silica tetrahedral and are easily weatherable, examples are the pyroxenes and amphiboles.

### **6.0. TUTOR-MARKED ASSIGNMENT**

What is the major difference between framework silicate and chain silicates?

### **7.0. REFERENCES/FURTHER READING**

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## **MODULE 3                    PROPERTIES OF MINERALS**

### **Unit 1                                    Chemical Properties of minerals in the soil**

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1. Representation of mineral formula
  - 3.2. Calculation of chemical formula of minerals
  - 3.3. Solid solution or isomorphism
  - 3.4. Exsolution or unmixing
  - 3.5. Pseudomorphism
- 4.0. Conclusion
- 5.0. Summary
- 6.0. Tutor-marked assignment
- 7.0. References/further reading

## 1.0 INTRODUCTION

The chemical composition of a mineral is of fundamental importance. Many of mineral properties depend on its chemistry and its crystalline structure.

**Atom:** smallest subdivision of an **element**. From  ${}_1\text{H}$  to  ${}_{103}\text{Lr}$ .

**Atomic Number:** number of **p**.

**Atomic Mass:** (**p** + **n**).

**Atomic Weight:** (**p** + **n**) of an element which is a whole number and its elemental abundance compared to that of **O=16**.

**Isotope:** Same atomic number but different atomic mass and therefore different **n**. Eg.,  ${}_{92}\text{U}^{238}$ ,  ${}_{92}\text{U}^{235}$

**Ion:** charged atoms.  $\text{Cl}^-$  **anion**;  $\text{Na}^+$  **cation**.

**Valence:** number of electron lost or gained.  $\text{O}^{2-}$   $\text{Fe}^{3+}$

**Molecule:** combined atoms with different bonds.

**Molecular Weight:** total atomic weights of its components.

**Radical:** strong bonding between two or more atoms.  $(\text{NH}_4)^+$ ,  $(\text{OH})^-$ ,  $(\text{SiO}_4)^{4-}$ ,  $(\text{CO}_3)^{2-}$ .

**Acid:** compound of  $\text{H}^+$  with an anion like  $\text{Cl}^-$  ( $\text{HCl}$ ) or a negative radical  $(\text{CO}_3)^{2-}$  ( $\text{H}_2\text{CO}_3$ )

**Base:** compound of cation like  $\text{Na}^+$  with a negative radical  $(\text{OH})^-$  ( $\text{NaOH}$ )

**Salt:** formed by a reaction of an acid and a base.  $\text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O}$

**Water of Crystallization:** some minerals contain free  $\text{H}_2\text{O}$  molecule or  $(\text{OH})^-$  radical or both within its crystal structure. **Gyp**  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ , **Col**  $\text{CaB}_3\text{O}_4(\text{OH})_3 \cdot \text{H}_2\text{O}$ . This water is shown as  $+\text{H}_2\text{O}$  in chemical analyses. Water absorbed as moisture on minerals shown as  $-\text{H}_2\text{O}$ .

## 2.0 OBJECTIVES

At the end of this unit student will able to identify:

- Chemical properties that affects the composition of soil minerals
- How to determine the proportion of individual elemental contents of a mineral

## 3.0 MAIN CONTENT

### 3.1 REPRESENTATION OF MINERAL FORMULA

Mineral formulas are expressed as elemental cation-anion pairs or sometimes are broken down to simple compounds such as oxides.

<b>Cal</b>	$\text{CaCO}_3$	$\text{CaO} \cdot \text{CO}_2$
<b>Dol</b>	$\text{CaMg}(\text{CO}_3)_2$	$\text{CaO} \cdot \text{MgO} \cdot 2\text{CO}_2$
<b>Kya</b>	$\text{Al}_2\text{SiO}_5$	$\text{Al}_2\text{O}_3, \text{SiO}_2$
<b>Ort</b>	$\text{KAlSi}_3\text{O}_8$	$\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$
<b>Oli</b>	$(\text{MgFe})_2\text{SiO}_4$	$\text{MgO} \cdot \text{FeO} \cdot \text{SiO}_2$
<b>Apa</b>	$\text{Ca}_5(\text{PO}_4)_3(\text{F}, \text{Cl}, \text{OH})$	$9\text{CaO} \cdot \text{Ca}(\text{F}, \text{Cl}, \text{OH})_2 \cdot 3\text{P}_2\text{O}_5$
<b>Mat</b>	$\text{Fe}_3\text{O}_4$	$\text{FeO} \cdot \text{Fe}_2\text{O}_3$ or $\text{Fe}^{2+}\text{O} \cdot \text{Fe}^{3+}_2\text{O}_3$

### 3.2 CALCULATION OF CHEMICAL FORMULA OF MINERALS

A quantitative chemical analysis of a mineral provides the basic information for the atomic or molecular formula of the mineral. It is given as **wt%** in terms of elements or oxides and outlines a listing of what elements or oxides are present.

A quantitative chemical analysis should add up close  $100 \pm 1\%$ .

#### Steps in the calculation;

#### A. From Elemental Analysis

1. Compare the maximum wt% for possible anion (!) and name the major mineral group as Sulphide Sulphate Silicate Carbonate Phosphate etc.
2. Consider and group the cations according to their valency as  
 $\text{Na}^+, \text{K}^+$   
 $\text{Mg}^{2+}, \text{Fe}^{2+}, \text{Zn}^{2+}$   
 $\text{Al}^{3+}, \text{Fe}^{3+}$   
 $\text{Si}^{4+}, \text{Ti}^{4+}$  etc. Because they may replace each other in the formula.
3. Divide wt% values by atomic weight given and multiply by 1000 to avoid fractions.
4. Omit trace and minor elements or oxides.
5. Add atomic proportions of possible substitutions, i.e.  $\text{Zn} \leftrightarrow \text{Fe}$ .
6. Determine atomic proportions as approximate whole numbers.
7. Write chemical formula cations first anions last,  $(\text{Zn,Fe})\text{S}$ .
8. If required recalculate atomic percentage of cations in the formula.
9. Write chemical formula cations percentages first anion last,  $(\text{Zn}_{87}, \text{Fe}_{13}) \text{S}$ .

Example 1.

	Wt%	Atomic Weights	Atomic Proportions x 1000		Atomic Ratios
Fe	18.25	55.85	327	1060	≈1
Mn	2.66	54.94	48		
Zn	44.67	65.38	683		
Cd	0.28	112.40	2		
In	0.01	114.82	0.1 (omitted)	1047	≈1
S	<u>33.57</u>	32.07	1047		
Σ	99.44				

**It is a sulphide. General formula (Zn,Fe,Mn,Cd)S. Name SPHALERITE.**

If atomic percentages of cations are required:

Fe	327	Mn	48	Zn	683	Cd	2	Total 1060	Factor 100/1060XAP
Fe	30.8	Mn	4.5	Zn	64.4	Cd	0.2		

Now the formula is  $(\text{Zn}_{64.4}\text{Fe}_{30.8}\text{Mn}_{4.5}\text{Cd}_{0.2})\text{S}$

**B. From Oxide Analysis**

Steps 1 & 2 are same

3. Divide wt% values by molecular weights given and multiply by 1000 to avoid fractions to obtain Molecular Proportions.

Steps 4 to 9 are same again but remember we are dealing with molecular proportions of oxides.

Example 2.

	<b>Wt%</b>	<b>Molecular Weights</b>	<b>Molecular Proportions x 1000</b>	<b>Molecular Ratios</b>
SiO <sub>2</sub>	34.96	60.09	582	≈1
TiO <sub>2</sub>	0.02	79.90	0.3 (omitted)	
Al <sub>2</sub> O <sub>3</sub>	0.12	101.96	1 (omitted)	≈2
Fe <sub>2</sub> O <sub>3</sub>	0.03	159.70	0.2 (omitted)	
FeO	36.77	71.85	512	
MnO	0.52	70.94	7	≈2
MgO	27.04	40.31	671	
Σ	99.46			

**It is a silicate. General formula 2(Mg,Fe,Mn)O.SiO<sub>2</sub> or (Mg,Fe,Mn)<sub>2</sub>SiO<sub>4</sub>. Name OLIVINE**

If atomic percentages of cations are required:

FeO 512	MnO 7	MgO 671	Total 1190	Factor 100/1190
FeO 43.0	MnO 0.6	MgO 56.4		

Now the formula is (Mg<sub>56.4</sub>Fe<sub>43.0</sub>Mn<sub>0.6</sub>)<sub>2</sub>SiO<sub>4</sub> or **Fos<sub>57</sub>Fay<sub>43</sub>**

**C. For Analysis of Mineral Mixtures**

Steps 1 to 9 are the same again. But we have to make some assumptions about the number of minerals and about whether their being pure end members. If there are same elements present in different mineral phases than the calculations is very difficult, if not impossible.

Example 3

	<b>Wt%</b>	<b>Atomic Weights</b>	<b>Atomic Proportions x 1000</b>	<b>Atomic Ratios</b>
Pb	4.43	207.20	21	≈1
Zn	11.56	65.38	177	
Cu	26.54	63.55	418	≈1
Fe	23.84	55.85	427	
In	0.01	114.82	0.1 (omitted)	≈2
S	33.57	32.07	1065	
Σ	100.54		-25=1044	

Formulas of the minerals are PbS (**Gal**), ZnS (**Sph**) and CuFeS<sub>2</sub>.

If percentages of minerals are required

PbS	21X2	42	2.0%
ZnS	177X2	354	16.8%
CuFeS <sub>2</sub>	rest	<u>1712</u>	<u>81.2%</u>
		2108	100,0

### 3.3 SOLID SOLUTION or ISOMORPHISM

Generally minerals are not pure substances. There is extensive variation in chemical composition. This variation is result of **substitution**. In a **solid solution**, specific atomic sites of the mineral structure are occupied in variable proportions by different atoms. This is controlled by the (1) size of the atoms or ions (<15% in size difference), (2) valency of the substituting ions (electric charge must be balanced, hence **coupled substitution**  $\text{Si}^{4+} \Leftrightarrow \text{Al}^{3+} + \text{Na}^+$ ), (3) at high temperatures due to thermal vibrations atomic sites are larger and therefore greater possibility for substitution. There are three types of solid solutions:

- **Substitutional Solid Solution**
- **Interstitial Solid Solution**
- **Omission Solid Solution**

Common solid solution series:

1. Isometric (Cubic) system: **Spinel** group, **Garnet** group,
2. Tetragonal system: **Rutile** group, **Scheelite** group,
3. Hexagonal system: **Apatite** group, **Corundum** group,
4. Orthorhombic system: **Aragonite** group, **Barite** group,
5. Monoclinic system: **Pyx** group, **Amp** group,
6. Triclinic system; **Feld** group.

In solid solution series some physical properties of the mineral groups show more or less linear variation from one end member to another.

1. Melting point, boiling point, crystallization **T**,
2. Specific gravity,
3. Hardness,
4. Cell dimensions,
5. Optical properties **RI**, birefringence, extinction angle etc.

### 3.4 EXSOLUTION or UNMIXING

This process is the opposite of solid solution. Exsolution is due to the substitution of atoms or ions having different size. Generally, at lower **T** enlarged atomic sites at high **T** in the mineral structure, becomes smaller. Hence, larger ions present in the structure leads to chemical disorder. Therefore at high **T** initially homogeneous solid solution separates into two distinct minerals having different chemical composition. The bulk composition remains same. **Exsolution lamellae** that separates from the host crystal are generally crystallographically oriented.

### 3.5 PSEUDOMORPHISM

If a crystal of a mineral is altered so that the internal structure or chemical composition is changed but the external form is preserved it is called a pseudomorph.

Eg. **Lim** FeO.OH  $n\text{H}_2\text{O}$  after **Pyt** FeS<sub>2</sub>. Crystal form is that of **Pyt** but composition is altered to amorphous **Lim**.

1. Loss of a constituent **Cuprite** Cu<sub>2</sub>O→Native **Cu**
2. Gain of a constituent **Anhydrite** CaSO<sub>4</sub>→**Gyp** CaSO<sub>4</sub> 2H<sub>2</sub>O
3. Partial exchange of constituents Limonite FeO.OH  $n\text{H}_2\text{O}$ →**Goethite**  $\alpha\text{FeO.OH}$
4. Complete exchange of constituents **Flu** CaF<sub>2</sub>→**Qua** SiO<sub>2</sub>; Silicified wood where organic compounds are replaced by silica.

Their typical particle size is less than 10 $\mu\text{m}$  in diameter (fine silt and clay fractions), and their specific surface area ranges from 0.5 to 4.0 $\times 10^4$  m<sup>2</sup> kg<sup>-1</sup>, with the larger values being measured for poorly crystalline varieties.

Therefore, if the layer were infinite in lateral extent, it would be completely stable according to the Pauling rules. However, the oxygen and OH ions at the edge surfaces of a finite layer structure will always be missing some of their cation bonding partners, leading to the ability to bind additional cationic charge.

Particle sizes of the 2:1 clay minerals place them in the clay fraction, with illite and vermiculite typically occurring in larger aggregates of stacked layers than smectite, for which lateral particle dimensions around 100 to 200 nm are characteristic. Specific surface areas of illite average about 105 m<sup>2</sup> kg<sup>-1</sup>, whereas those of vermiculite and smectite can approach 8 $\times 10^5$  m<sup>2</sup> kg<sup>-1</sup>, depending on the number of stacked layers in an aggregate. The origin of this latter value, which is very large (equivalent to 80 ha kg<sup>-1</sup> clay mineral), can be seen by calculating the specific surface area (as) of an Avogadro number of unit cells (unit cells are the basic repeating entities in a crystalline solid) forming a layer of the smectite.

#### 4.0. CONCLUSION

The chemical composition of a mineral is of fundamental importance in determining its properties and crystalline structure.

#### 5.0. SUMMARY

Generally minerals are not pure substances. There is extensive variation in chemical composition and this is as a result of the different chemical properties of the minerals.

#### 6.0. TUTOR-MARKED ASSIGNMENT

- **What are the basic steps involved in** quantitative chemical analysis
- Define the following terms: Isomorphism, exsolution and pseudomorphism

#### 7.0. REFERENCES/FURTHER READING

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## Unit 2 Physical properties minerals

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1. Other wave properties of light waves
  - 3.2. Reflection-total reflection-refraction-index of refraction
  - 3.3. Relief-twinkling-becke line
  - 3.4. Colour and pleochroism
- 4.0. Conclusion
- 5.0. Summary
- 6.0. Tutor-Marked Assignment
- 7.0. References/Further Reading

### 1.0 INTRODUCTION

Physical properties of minerals are important and useful diagnostic parameters. They are used to identify minerals macroscopically. These properties are also important for the use of minerals in industry eg. **Tal** is the softest mineral and used as talcum powder for skin care; **Cor** is a very hard mineral and used as abrasive, **Mus** has a very low electrical conductivity and hence is used as insulator, etc.

### 2.0. OBJECTIVES

- Students will understand fully how optical properties affects the quality of soil minerals

### 3.0 MAIN CONTENT

#### 3.1 ISOTROPISM

Minerals are grouped according to their physical properties, which may be direction dependent.

**Isotropic:** physical properties are same in all directions. Gases, liquids, amorphous and cubic minerals crystallizing in isometric system are isotropic.

**Anisotropic:** physical properties vary with crystallographic directions. Minerals crystallized in tetragonal, orthorhombic, hexagonal, monoclinic and triclinic systems are anisotropic. Anisotropy is best displayed in optical properties, which will be dealt with later in optical mineralogy. Macroscopic anisotropy may not be obvious in hand specimens.

#### 3.2 POLYMORPHISM

Physical properties of minerals are directly related to their atomic structure, bonding forces and chemical composition. Bonding forces as electrical forces exist between the atoms and ions are related to the type of elements, and the distance between them in the crystalline structure. Thus,

minerals having same chemical composition may show different crystal structure (as a function of changes in **P & T** or both). So, being crystallized in different Symmetry Systems they exhibit different physical properties, this is called polymorphism. These minerals are said to be polymorphous. They may be **Dimorphic**, **Trimorphic** or **Polymorphic** according to the number of mineral species present in their group.

<b>Dimorphic</b>	Composition	Specific Gravity	System	Hardness
<b>Diamond</b>	C	3.51	Cubic	10
<b>Graphite</b>	C	2.23	Hexagonal	1-2
<b>Calcite</b>	CaCO <sub>3</sub>	2.71	Rhombic	3
<b>Aragonite</b>	CaCO <sub>3</sub>	2.95	Orthogonal	3.5-4
<b>Trimorphic</b>				
<b>Rutile</b>	TiO <sub>2</sub>	~4.2	Tetrahedral	6.6.5
<b>Anatase</b>	TiO <sub>2</sub>	~3.9	Tetrahedral	5.5-7.0
<b>Brookite</b>	TiO <sub>2</sub>	~4.0	Orthogonal	5.5-6
<b>Andalusite</b>	Al <sub>2</sub> SiO <sub>5</sub>	3.13-3.16	Orthogonal	6.5-7.5
<b>Kyanite</b>	Al <sub>2</sub> SiO <sub>5</sub>	3.53-3.65	Trigonal	5.5-7.0
<b>Sillimanite</b>	Al <sub>2</sub> SiO <sub>5</sub>	3.23-3.27	Orthogonal	6.5-7.5
<b>Polymorphic</b>				
Low <b>Quartz</b>	SiO <sub>2</sub>	2.65	Hexagonal	7
High <b>Quartz</b>	SiO <sub>2</sub>	2.53	Hexagonal	7
High <b>Tridymite</b>	SiO <sub>2</sub>	2.26	Mono; Ortho	6.5
<b>Coesite</b>	SiO <sub>2</sub>	3.01	Monogonal	7.5
<b>Stishovite</b>	SiO <sub>2</sub>	4.35	Tetragonal	7

## I. Characters Depending upon Cohesion and Elasticity

**Cohesion:** The force of attraction existing between molecules. It shows resistance to any external influence that tends to separate them, eg., breaking or scratching the surface of a solid mineral. Cohesion force is related to bonding force.

**Elasticity:** The force that tends to restore the molecules of a body into their original position from which they have been disturbed. The result of cohesion and elasticity in a mineral appears as **cleavage, parting, fracture, hardness** and **tenacity**.

### CLEAVAGE

Cleavage is tendency of a crystalline mineral to break in certain directions yielding more or less smooth planar surfaces. These planes of lowest bond energy have minimum value of cohesion. An amorphous body of course has no cleavage.

- Cleavage planes are usually // to the crystallographic planes. Exceptions: **Cal, Flu**.
- Cleavage is always consistent with the symmetry. Eg., in cubic cleavage {001}, if one cubic face develops cleavage, it follows that other faces // to other two directions also show it.
- Compared with other atomic planes, distance between cleavage planes must be large → electrical forces small → cohesion less.
- Cleavage planes often show pearly luster due to partial separation of crystal into



parallel plates and reflection of light from these plates. If plates are wedge shaped then interference colours may be seen.

Being related to the atomic structure of the mineral, cleavage may be in several directions and depending on the force of cohesion some of them may be more developed than the others. So they are classified according to their distinction and smoothness:

1. **Good, distinct, perfect,**
2. **Fair, indistinct, imperfect,**
3. **Poor, in traces, difficult.**

## **PARTING**

Parting is obtained when the mineral is subjected to external force. The mineral breaks along planes of structural weakness. The weakness may result from pressure, twinning or exsolution. Composition planes of twinning and glide planes are usually the direction of easy parting. Parting resembles cleavage. However, unlike cleavage, parting may not be shown by all individuals of the mineral species. Parting is not continuous on crystals.

## **FRACTURE**

In some crystals structures and amorphous solids the strength of the bonds are approximately the same in all directions. Breaking of such crystals or massive minerals in a direction other than the cleavage or parting planes yield generally irregular surfaces. Different kinds of fractures are:

1. **Conchoidal:** smooth fracture (**Qua**, glass )
2. **Fibrous** and **splintery:** sharp pointed fibers (**Asbestos**, **Serpentine**),
3. **Uneven** or **irregular:** rough and irregular surfaces,
4. **Even:** more or less smooth surfaces, may resemble cleavage,
5. **Hackly:** jagged fractures with very sharp edges (**Mat**).

## **HARDNESS**

The resistance that a smooth surface of a mineral offers to scratching is its **hardness** (H). It is mineral's "scratchability". It is related to the attraction force between atoms. The degree of H is determined by observing comparatively the relative ease or difficulty with which one mineral is scratched by another, or by a finger nail, file or knife.

Variation in the Mohs scale is not linear when compared with absolute hardness measurements Eg., **Cor** is 4 times harder than **Qua**.

Relation between H and chemical composition is very characteristic and useful in identification of minerals in hand specimens. These are:

1. Native Minerals (**Au**, **Ag**, **Cu**) are soft → max. 3.
2. Sulphides are mostly soft → max. 4 (Exceptions are minerals with Fe, Co, Ni).
3. Carbonates, sulphates and phosphates are soft → max. 5
4. Most hydrated minerals are soft → max. 5.
5. Oxides and silicates are hard → more than 6 (Few exceptions like **Tal**).

## **TENACITY**

The resistance that a mineral offers to breaking, crushing, bending, cutting, drawing or tearing is its tenacity. It is mineral's cohesiveness.

1. **Brittle:** A mineral that breaks and powders easily (Sulfides, Carbonates, Silicates and

Oxides),

**2. Malleable:** A mineral that can be hammered out without breaking, into thin sheets. They are plastic (Native metals),

**3. Sectile:** A mineral that can be cut with a knife into thin shavings (Native metals),

**4. Ductile:** A mineral that can be drawn into wire (Native metals),

**5. Flexible:** A mineral that bends but retains its bent form. Does not resume its original shape → permanent deformation (**Asb**, clay minerals, **Chl**, **Tal**)

**6. Elastic:** A mineral that after bending springs back and resumes its original position. (**Mus**).

## II. Characters Depending upon Specific Gravity

**Specific gravity (SG)** or relative density is a unitless number that expresses the ratio between the weight of a substance and the weight of an equal volume of water at 4° (Max.  $\rho$ ).

**Density ( $\rho$ ) is the weight** of a substance per volume =  $\text{g/cm}^3$ . It is different than **SG**, and varies from one locality to another (max. at poles, min. at equator).

**SG** is measured with a simple balance by weighing the specimen in air ( $W_a$ ) then in water ( $w_w$ ) Then  $\text{SG} = W_a / (W_a - w_w)$ . Here ( $w_a - w_w$ ) gives the volume of the substance. Specimen must be clean and free of any air bubbles and cavities or erroneous value might be obtained.

Relation between **SG** and other physical and chemical properties:

1. Minerals with non-metallic luster have average SG between 2.6-3.0, (**Qua**=2.65, **Cal**=2.72, **Feld's**=2.60-2.75).

2. Hydrated and soft minerals have **SG**<2.6.

3. Hard minerals with heavy elements (Sr, Ba, Fe, W, Cu, Ag, Pb, Hg) have **SG**>3.5.

4. Minerals with metallic luster have **SG**>=5 (**Pyt**=5, **Gal**=7.5, **Mat**=5.18)

5. In isostructural compounds, those with heavy element have higher **SG**.

Mineral	Composition	Atomic Wt.	SG
<b>Aragonite</b>	$\text{CaCO}_3$	40.08	2.94
<b>Strontianite</b>	$\text{SrCO}_3$	87.62	3.78
<b>Witherite</b>	$\text{BaCO}_3$	137.34	4.31
<b>Cerussite</b>	$\text{PbCO}_3$	207.19	6.58

6. In solid solution series, there is a continuous change in **SG** with change in chemical composition.

(Eg., **Fos**=3.3 → **Fay**=4.4)

7. In polymorphous compounds those with closest atomic packing have higher **SG**. (eg. **Gra**=2.23 → **Dia**=3.5)

## III. Characters Depending upon Light

### REFRACTIVE INDEX

Refractive index (**RI**) of a mineral is the ratio of velocity of light in the vacuum (or air) to the velocity of light in the mineral. ( $n=c/v$ )

In isotropic media there is only one **RI**, whereas in anisotropic media **RI** changes with crystallographic directions from a min. value to a max. Due to the inequality of **RI**'s, the light ray entering into an anisotropic mineral is split into two rays with different velocities and directions. This is known as **double refraction**, numerically it is equal to the difference between

the **RI**'s (eg., **Cal**=0.143; double-dot exp., **Qua**=0.009).

### DIAPHENEITY

**Diapheneity** is the amount of light transmitted or absorbed by a solid. It is used strictly for hand specimens because most minerals that are opaque as hand specimen becomes transparent when very thin.

1. **Transparent**: object behind it can be seen clearly, Eg., **Qua**, **Cal**, **Flu**. Size affects diapheneity thicker specimens may become translucent.
2. **Translucent**: light transmitted but the object cannot be seen, Onyx marble, and impure and thicker transparent minerals.
3. **Opaque**: light is wholly absorbed, Eg., **Mat**, **Hem**.

### COLOUR

Colour: is the  $\lambda$  of the visible light region which is reflected or transmitted from the mineral. Human eye is sensitive in the region between 4200-7500 Å. The mineral must be observed in the white light. If monochromatic light is used the colour of the mineral may change completely.

When light waves interacts with a mineral, those  $\lambda$ 's whose energies correspond exactly to the energy difference between the electronic levels of the atom, will be absorbed. This results in electrons being excited from one level to another. Thus,  $\lambda$  which is not absorbed, interfere on each other and forms the colour of the mineral. The most common chromophoric (colour causing) transition metals with unfilled electron shells are. Ti, V, Cr, Mn, Fe, Co, Ni, Cu. In ionically bonded crystals whose ions have noble gas configuration next energy level of unoccupied orbital is much greater than the energy of visible light, thus no absorption and they appear white or colourless.

Other causes of colour are the impurities. **Chl** → green **Qua**; Mn oxide or C → black **Cal**; **Hem** → red **Feld**, **Cal**, **Qua** (Jasper).

### STREAK

Streak is the colour of the mineral powder. Colour of a mineral may vary but streak is usually constant. It is obtained by rubbing a mineral on a hard (H~7), white, unglazed porcelain. Eg: **Mat**; colour: black, streak: black; while **Hem** colour: black or red, but streak: red.

### LUSTER

Luster is the general appearance of a mineral surface in reflected light. It is the degree of reflected light and directly related to optical properties (mainly **RI**) and surface conditions.

**Metallic luster**: strictly belongs to opaque minerals, where light is completely reflected from the surface. Most of the ore minerals having high content of metals shows metallic luster. Eg., **Gal**, **Mat**, **Pyt**, **Cpy**. Imperfect metallic luster → sub metallic.

**Non-metallic luster**: other luster types are collectively known as non-metallic luster. It may be brilliant or faint where reflection is poor which is due to scattering of light from the mineral surface.

**Adamantine**: an exceptionally brilliant luster shown by minerals having very high **RI**. Eg., **Dia**, **Zir**, **Cor** (**Rub**, **Sapp**). These minerals are used as valuable gem stones.

**Vitreous:** shown by broken glass. Eg., Silicates (**Q, Feld**), Carbonate (**Cal**) with relatively low **RI**.

**Resinous:** shown by resins. Eg., **Sph, S**.

**Greasy:** shown by oily glass. It results from light scattered by a microscopically rough surface. Eg. **Nep** (due to surface hydration having different **RI**), massive **Qua**.

**Pearly:** pearl-like. It is due to reflection from successive layers, such as cleavage surfaces. Eg., **Tal, Mus**.

**Iridescent:** reflection of brilliant spectral colours due to diffraction from regularly spaced planes. Eg., precious **Opa**.

**Silky:** silk-like. It is due to the reflection from fibrous structure of minerals. Eg. **Gyp, Asb, Mal**.

**Earthy:** luster of a surface from which there is little or no reflection. It is due to the porous and fine-grained nature of mineral. Eg., **Lim, Kaol**.

#### IV. Characters Depending upon Magnetism

**Magnetism:** The basic cause of magnetism is the orbital and spin motions of electrons. Charged particle in motion creates magnetic moment. Thus spin and orbital motion of electrons produce magnetism. The resultant of these two moments is the magnetic moment of the atom, Eg., unpaired electrons in transition metals.

**Ferromagnetism:** Generally the magnetic moments of atoms are randomly oriented. But in ferromagnetic substances they become aligned in domains due to exchange interactions between neighbouring atoms. They become permanent magnets in a magnetic field. Magnetic moment of some of the neighbouring atoms may align themselves in opposite direction, and cancel each other (**FIG. 2.13**). They also become permanent magnets. (Eg., **Mat**  $\text{Fe}_3\text{O}_4$ -**Ulv** spinel  $\text{Fe}_2\text{TiO}_4$ ; **Hem**  $\text{Fe}_2\text{O}_3$ -**Ilm**  $\text{FeTiO}_3$ , **Franklinite**  $(\text{Zn,Fe,Mn})(\text{FeMn})_2\text{O}_4$ , **Maghemite**  $\gamma\text{-Fe}_2\text{O}_3$ , native **Pt**, and **Pyrrhotite**  $\text{Fe}_{1-x}\text{S}$ ).

The permanent magnetism of ferrimagnetic minerals in various rock types allows for the study of the ancient geomagnetic fields of the earth → **paleomagnetism**.

#### V. Characters Depending upon Senses

**TASTE:** Most minerals have no taste.

1. **Asterigent:** Taste of vitriol HCl.
2. **Saline:** Taste of salt, **Hal** NaCl.
3. **Alkaline:** Taste of soda  $\text{NaCO}_3$ .
4. **Cooling:** Taste of Saltpeter or **Niter**  $\text{KNO}_3$ .
5. **Bitter:** Taste of Epsomsalt  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ .
6. **Sticky:** Taste of clay minerals. Due to hygroscopic character adhere to the tongue.

**ODOUR:** Most minerals have no odour.

1. **Garlic:** Minerals with As.
2. **Horseradish** (kara turp) :when heated, minerals with Se,
3. **Bituminous:** asfaltite, petroleum products.

4. **Sulphurous:** when heated, minerals with S.
5. **Fetid:** minerals with S. When heated H<sub>2</sub>S (rotten eggs) evolves.
6. **Argillaceous:** Moistened clay minerals.

**FEEL:**

1. **Smooth:** Sepiolite.
2. **Greasy:** Tal.
3. **Harsh:** Most minerals have rough surface and harsh feel.
4. **Cold:** Cor Al<sub>2</sub>O<sub>3</sub>.
5. **Sticky feel to the tongue:** Clay minerals due to hygroscopic character adhere to the tongue.

**VI. Characters Depending upon CRYSTAL and AGGREGATES HABITS**

Special terms are used for habit or general form or the appearance of single crystals as well as the manner in which crystals grow together in aggregates:

1. Isolated or distinct crystals:

- Acicular:** slender, needle-like. **Rut.**  
**Capillary and filiform:** hair-like or thread-like. **Sid.**  
**Bladed:** elongated, flattened knife-like. **Kya.**

2. Groups of distinct crystals:

- Dendritic and arborescent:** slender divergent branches, plant-like. Native **Cu, Ag, Au,** and **Pyrl.**  
**Reticulated:** lattice-like slender crystals.  
**Divergent or radiated:** **Strontianite.**  
**Drusy:** A surface covered with a layer of small crystals.

3. Parallel or radiating groups of individual crystals:

- Columnar:** stout, column-like, **Qua.**  
**Bladed:** aggregate of flattened blades, **Stibnite.**  
**Fibrous:** aggregate of slender fibers, radiating or parallel, **Rut, Asb.**  
**Stellated:** radiating individuals forming star-like, circular groups.  
**Globular:** radiating individuals forming small spherical→hemispherical groups, **Hem.**  
**Botryoidal:** same as globular, resembling bunch of grapes, **Hem.**  
**Reniform:** same as globular, but in kidney shaped masses.  
**Mammillary:** same as globular, but in mammae shaped masses.  
**Colloform:** same as globular~mammillary, **Agate.**

4. Aggregate composed of scales or lamellae:

- Foliated:** as thin plates and leaves.  
**Micaceous:** same as foliated but splits into exceedingly thin sheets, **Micas.**  
**Lamellar or tabular:** flat, plate-like.  
**Plumose:** fine scales, with divergent or feather-like structure.

5. Aggregate composed of equant grains:

**Granular:** equal sized anhedral grains (fine, medium or coarse), **Cal** in marble.

#### 6. Miscellaneous:

**Stalagmitic:** successive layer in cylinder or cone shapes, **Cal**.

**Concentric:** spherical layers around a common centre.

**Pisolitic:** rounded masses about pea-sized, Bauxite.

**Oölitic:** same as pisolitic about fish roe sized, **Cal**.

**Banded:** narrow band of different texture and colour, **Chromite**.

**Massive:** compact minerals without form or distinguishing features. Most minerals.

**Amygdaloidal:** almond shaped, **Zeolites**, **Cal** in basalt.

**Geode:** a rock cavity wholly or partly filled with same or different minerals. Banded or with crystals projecting from walls, Agate.

**Concretion:** deposition around a nucleus. Spherical or irregular shapes.

#### **4.0. CONCLUSION**

Physical properties of minerals are very essential in microscopic identification of mineral and in determination of their industrial applications.

#### **5.0. SUMMARY**

Physical properties of minerals are the most abundant mineral properties that describe mineral morphology, microscopic content and economic importance.

#### **6.0. TUTOR-MARKED ASSIGNMENT**

- List two mineral characteristics that depends each on senses and light
- Define the following terms; isomorphism, cleavage and tenacity

#### **7.0. REFERENCES/FURTHER READING**

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## UNIT 3      OPTICAL PROPERTIES OF MINERALS

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1. Other wave properties of light waves
  - 3.2. Reflection-total reflection-refraction-index of refraction
- 4.0. Conclusion
- 5.0. Summary
- 6.0. Tutor-Marked Assignment
- 7.0. References/Further Reading

### 1.0 INTRODUCTION

The light has a dual nature. Firstly, light behaves like a particle. In this behavior light particle known as photon act as a compact entity and can knock out loosely metallic bonded electrons from large atoms like Cs and Rb. This effect is known as photoelectric effect.

### 2.0 OBJECTIVES

In this unit students will be introduced into the optical properties of mineral that affects its morphology and economic value

### 3.0 MAIN CONTENT

#### 3.1 OTHER WAVE PROPERTIES OF LIGHT WAVES

The properties of light with marked influence on plant growth and development are **light quality, light intensity and light duration or photoperiod**. A substantial understanding of light in relation to plant growth and development is essential in crop production.

When light rays move away from a source in a medium, at a given moment these rays will have traveled and define a 3-D surface known as **Ray Velocity Surface (RVS)**. This property is very essential in soil mineral identification. In isotropic minerals these rays will have travelled same distance, independent of the direction they travel hence spherical **RVS** forms. However, in anisotropic minerals, because the minerals have different atoms along different directions, light will travel at different velocities along different crystallographic direction, hence **RVS** surface is not spherical, but will form complex double surfaces.

Tangent to the **RVS** along any light ray is known as the **wave front**. Followed from above discussion in isotropic minerals wave front is perpendicular to the ray (or propagation direction) and its **wave normal** will be along the propagation direction. However, in anisotropic minerals wave front is perpendicular to the propagation direction only at special directions, but will be at an angle in other directions. Similarly, wave normal will be along the propagation direction only at special crystallographic direction, but will be at an angle in other directions.

#### 3.2 REFLECTION-TOTAL REFLECTION-REFRACTION-INDEX OF REFRACTION

In optics, the refractive index or index of refraction of a material is a dimensionless number that describes how fast light travels through the material.

Since refractive index is a fundamental physical property of a substance, it is often used to identify a particular substance, confirm its purity, or measure its concentration. Refractive index

is used to measure solids, liquids, and gases. Most commonly it is used to measure the concentration of a solute in an aqueous solution. It can also be used as a useful tool to differentiate between different types of gemstone, due to the unique chatoyance each individual stone displays. A refractometer is the instrument used to measure refractive index. For a solution of sugar, the refractive index can be used to determine the sugar content in such solution. It is widely used in agriculture and food industries. It is used in determining the quality of oil. It is also used in diagnosing plant pathological disorders through color identification of diseases. Refractive index also gives an insight of soil chemical compositions most especially Fe and Al oxides contents.

Currently, it is used in precision agriculture which relies on spatially heterogeneous application of inputs such as fertilizers, pesticides etc. This requires a quick remote analysis of the state of plants in the fields and greenhouse. This requires various spectral indices based on measurement of reflected light in narrow spectral bands.

#### **4.0. CONCLUSION**

Light plays a significant role in determining the optical properties of minerals and this is important with respect to their economic value and uses

#### **5.0. SUMMARY**

There is a direct relationship between the optic properties of minerals and their symmetry, where light is affected similarly in the same crystal system.

#### **6.0. TUTOR-MARKED ASSIGNMENT**

- Define the term twinkling
- The six crystal systems can be divided into three groups based on the number of the unique optical axes they have. Name the three groups
- State Snell's law

#### **7.0. REFERENCES/FURTHER READING**

Deer WA, Howie RA, Zussman J (1962-1986) Rock-forming minerals, 8 vols, J Wiley & Sons, New York

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## **UNIT 4 AND 5          METHODS OF SOIL MINERAL IDENTIFICATION**

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1. X-Ray Diffraction
    - 3.1.2 X-Ray spectrometer
    - 3.1.2. Laue camera:
    - 3.1.3. Rotating crystal method:
    - 3.1.4. Powder method
    - 3.1.5. Diffractometer Method:
    - 3.1.6. Advantages of X-ray diffraction
  - 3.2. Thermal analysis
    - 3.2.1 Differential thermal analysis
    - 3.2.2 Thermogravimetric Analysis
  - 3.3. Electron microscopy
- 4.0. Conclusion
- 5.0. Summary
- 6.0. Tutor-Marked Assignment
- 7.0. References/Further Reading

### **1.0 INTRODUCTION**

The mineralogical composition of the soil is determined frequently because of its strong influence on soil behavior, in classification of soil and its relevance to soil formation processes. Identifying minerals is the first step in mineral analysis. Sometimes, one single analytical method is sufficient to accomplish the job, and sometimes, several analytical techniques have to be employed. Some of these methods would be discussed in this unit.

### **2.0 OBJECTIVES**

At the end of this unit students should know and understand the different methods used in mineral identification

### **3.0 MAIN CONTENT**

#### **3.1 X-Ray Diffraction**

The principle involved with estimating the spacing of crystal planes will not be covered in these notes. It is assumed that the reader is familiar with the concept that, for a given set of parallel planes, spaced  $d$  apart, the X-rays emitted from each plane will be in phase when

$$n\lambda = 2d \sin \theta$$

where  $\lambda$  = wavelength of radiation

$\theta$  = angle of incidence of radiation to the planes

$n$  = integer

X-Ray diffraction can be utilised to identify the  $(h, k, l)$  spacings of clay mineral crystals.\*  $hk$  spacings correspond to the  $a$  and  $b$  directions of the unit cell (except triclinic), whilst  $l$  gives spacings normal to the plane along  $c$  (basal) spacings.

Since clay minerals have mostly layer-lattice structures, the basal spacing can be used as a useful categorisation technique. The  $l$  spacing is also most susceptible to changes in environment - a property which can be utilised as an aid to identification. The most common identification technique involves the preparation of an oriented sample, with detection of intensity of radiation made using a diffractometer - as shown in Fig. 1 below. Orientation of a specimen ensures that the basal plane lies parallel to the bed of the mount - in this way, reflections from planes other than basal planes is suppressed. Fig. 4.5 shows traces for both an un-oriented and oriented sample. For the un-oriented sample reflections from planes other than (0 0 1) are apparent.

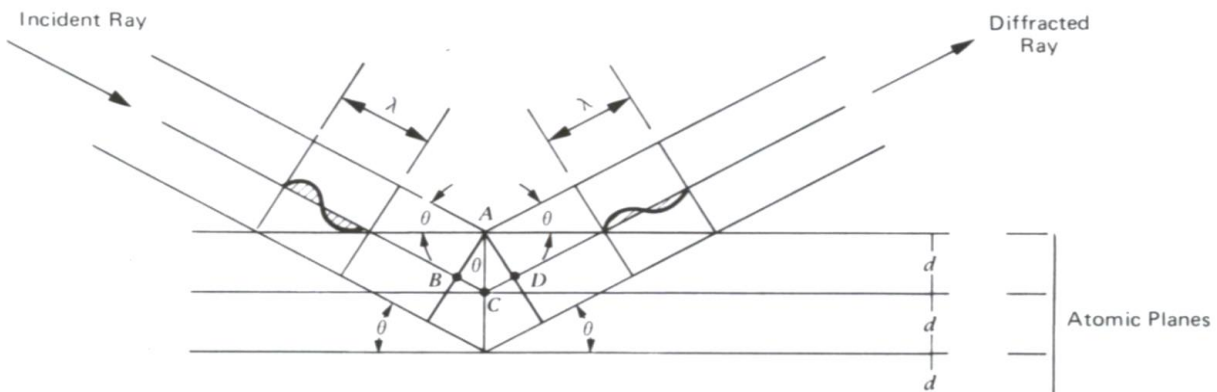
To identify positively certain mineral groups, some pre-treatment is necessary. This pre-treatment commonly includes heating to an elevated temperature and exposure to an ethylene glycol atmosphere. Carroll (1970) recommends the preparation of three oriented slides from the one soil suspension. Three traces can be obtained:

- (a) normal,
- (b) after glycolation (to detect any swelling tendency), and
- (c) after heating (to determine changes in crystal structure).

If equation (1) is simplified to

$$l = 2d \sin \theta$$

it can be seen that X-rays emitted from planes spaced  $d$  apart will be in phase. These reflections are known as first-order basal reflections from the (001) plane. Note that for  $n = 2$ , an apparent reflection from a plane  $d/2$  is obtained. (The (002) plane). The intensity of reflection from these planes, and their spacings can be used to characterise the clay mineral.



**A Figure showing X-Ray Diffraction Technique**

**A simple procedure used in X-ray diffraction analysis can be described follows:**

1. Obtain XRD pattern.
  2. Determine the  $d$ -spacings using Bragg's law.
  3. Obtain integrated intensities.
  4. Compare data with known standards in the JCPDS file, which are for random orientations.
- There are more than 50000 JCPDS (Joint Committee on Powder Diffraction Standards that is replaced by International Centre for Diffraction Data, ICDF) cards of inorganic materials and JCPDS stands for which has the diffraction patterns of 50000 inorganic and 25000 organic single component, crystalline phases.

5. A typical XRD pattern is analyzed for (a) Peak position, (b) Peak intensity, and (c) Peak width. Peak width is the width of the peak at half of maximum intensity. The areas under the peak are related to the amount of each phase present in the sample.

**Methods that uses the principle of X-ray diffraction**

**3.1.1. X-Ray Spectrometer:**

Rotation of a perfect crystal in an X-ray beam is one method to determine the X-ray spectrum using Bragg’s law. By rotation of a single crystal with a fixed detector or using a position sensitive detector with a fixed crystal, we can perform X-ray spectroscopy experiments similar to how a diffraction grating can be used in an IR or UV spectrometer.

**3.1.2. Laue Camera:**

With a polychromatic incident beam, many planes will meet the Bragg condition and tracing the 2D pattern on a photographic film will reveal the planes of a zone.

**3.1.3. Rotating Crystal Method:**

For a monochromatic beam and a single crystal, rotate the crystal during diffraction experiment to bring Bragg planes into alignment.

**3.1.4. Powder Method:**

Monochromatic beam, polycrystalline sample. Usually done with a flat film in pinhole arrangement.

**3.1.5. Diffractometer Method:**

Similar to the powder method but uses a step-scanner and a line beam.

**3.1.6 Advantages of X-Ray Diffraction:**

X-ray diffraction is a non-destructive and rapid method of identification of minerals. Sample preparation is simple. Calculation of d-spacing is accurate. The method can also be applied in situ for single crystal, poly-crystalline, and amorphous materials. Standards are available for thousands of material systems.

**Table 1 Summarizes X-ray characteristics for certain clay minerals.**

Mineral	Basal spacing (001)	Glycolation Effect (1 hr, 60_C)	Heating Effect - 1 hr
Kaolinite	7.15°A (001) : 3.57°A (002)	No change	Becomes amorphous 550-600°C
Kaolinite disordered	7.15°A (001) Broad: 3.75°A (002) Broad	No change	As above - at lower temperature
Halloysite 4H <sub>2</sub> O 2H <sub>2</sub> O	10°A (001) Broad 7.2°A (001) Broad	No change No change	Dehydrates to 2H <sub>2</sub> O form at 110°C Dehydrates at 125-150°C
Illite	10°A (002) Broad	No change	Amorphous 560-590°C (001) Enhanced on Heating
Smectite	15°A	(001) and	At 300°C (001)

(Montmorillonite)		integral series of basal spacings (001) expands to 17°A	Becomes 9A
Mg Chlorite	14°A (001) and integral series of basal spacings	No change	(001) increases in intensity : < 800°C Mass Loss - No Structural change

X-ray diffraction is an extremely powerful, and most definitive method for identifying clay minerals. However, a complete identification will usually require additional testing.

### 3.2 Thermal Analysis

#### 3.2.1 Differential Thermal Analysis

The application of Differential Thermal Analysis (DTA) to the identification of soils used in engineering applications was reported extensively by Lambe (1952). The technique has as its greatest advantage simplicity and rapidity. It is claimed that the order of accuracy for the determination of constituent minerals is of the same order as X-ray diffraction i.e. 5-10%. A schematic arrangement of the equipment involved is as shown in Fig. 4.6.

As a sample is heated, reactions will occur. If the heat absorbed or emitted during these reactions is compared to characteristics displayed by an inert material (usually calcined alumina) undergoing the same temperature change, a trace is obtained of differential thermal response versus temperature.

If the sample absorbs heat with respect to the standard, a trough occurs in the trace (an endothermic reaction). Where the sample evolves heat compared to the standard, a peak occurs (an exothermic reaction). A heating rate of 10°C/min is usually adopted through a range up to 1000°C.

Important reactions include:

- Dehydration (Endothermic)

(i) adsorbed water (driven off between 100-300°C)

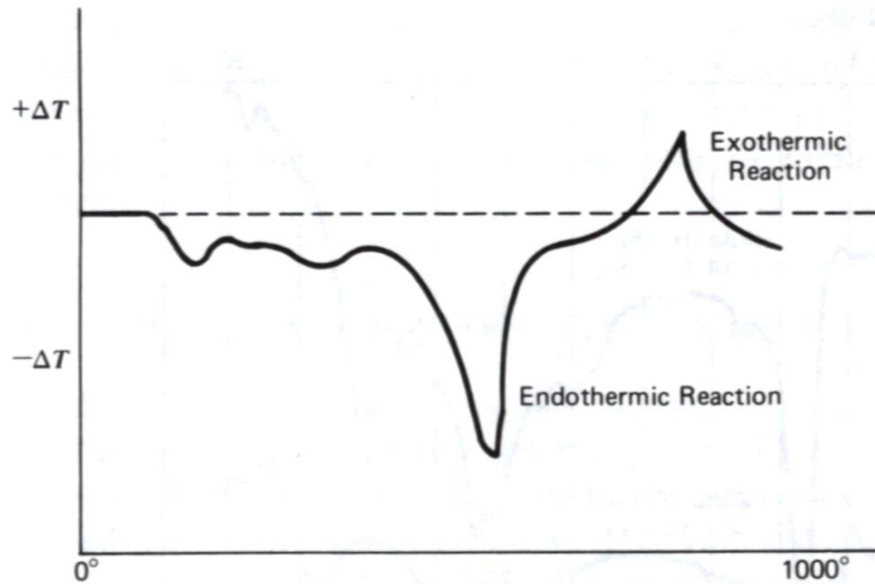
(ii) crystal lattice water (the (OH) ions) - termed dehydroxylation.

Dehydroxylation causes a complete destruction of the mineral structure.

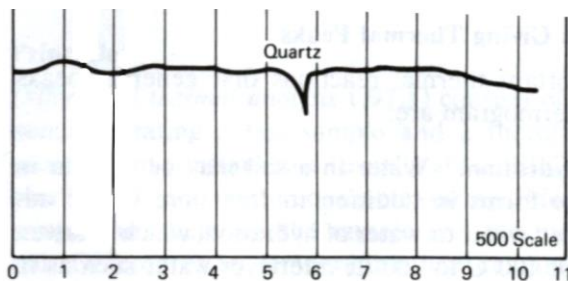
- Exothermic Reactions

(i) Crystallisation: new crystals may form from amorphous materials, or from old crystals destroyed at lower temperatures,

(ii) Oxidation: e.g. of organic matter between 250-450°C.



**Differential Thermal Analysis**



## **Mineral Identification using Thermal Analysis**

### **3.2.2. Thermogravimetric Analysis**

Thermogravimetric Analysis (TGA) involves a measurement of the change in mass of a sample as it is heated. Changes in mass of a sample can result from:

- (i) Loss of adsorbed water ( $t < 200^{\circ}\text{C}$ )
- (ii) Removal of lattice water ( $t < 800^{\circ}\text{C}$ )
- (iii) Loss of  $\text{CO}_2$  from carbonates
- (iv) Removal of volatile components from non-clay mineral constituents in the sample
- (v) Oxidation, eg. Ferrous to Ferric Iron can produce an increase in mass of the sample.

Where it is important to minimise the mass change caused by non-clay components, pre-treatment of the sample is often performed, eg. removal of carbonates can be affected by repeated treatment with hydrochloric acid.

### **3.3. Electron Microscopy**

An electron beam performs a similar function to a light beam, but because the wavelength of the electron beam  $\lll$  the wavelength of visible light the potential resolving power of an electron

microscope is much greater than that for a light microscope. Magnifications of 100 000+ can be achieved readily.

The transmission electron microscope (TEM), as its name implies relies on transmitting an electron beam through the sample. Since the penetrating power of an electron beam is low at the potential differences commonly employed, very thin specimens must be used.

For TEM work a replica is often made of the specimen surface. A replica is a thin film which is transparent to electrons. The replica, which can be used to great effect in textural studies will produce a negative impression of the soil surface - to overcome this a second replica is often taken, using the original as a base.

A scanning electron microscope (SEM) utilises a reflection geometry. An electron beam is scanned over the soil surface and the secondary electrons emitted are collected and displayed on a cathode ray tube. Whilst the resolution of the SEM is not as good as the TEM a greater depth of field is obtained - particularly useful for morphological studies.

Sample preparation for the SEM is relatively simple (although special techniques have to be used to dry the specimen and prepare a "clean" surface). Since a clay surface is non-conducting a thin layer of gold or gold alloy is plated onto the surface prior to examination.

### **3.4. Field Identification**

In some cases the presence of a soil type that may cause problems can be detected during a field inspection. Depending on the magnitude of the project, field identification may provide an adequate categorisation of clay mineral type. Ingles and Metcalf (1972) have produced a simple identification table which utilized features such as colour of retained water, surface relief, rock type, erosion and soil profile as an aid to mineral identification. Emerson (1967) has devised a simple field (or laboratory test) which can be used to aid further the identification of predominant clay minerals.

#### **Other methods used in mineral identification include:**

- ✓ Electron Microscopy
- ✓ Specific Surface
- ✓ Plasticity chart
- ✓ Imaginary technique

### **4.0. CONCLUSION**

Both the crystalline and amorphous soil minerals can be effectively identified in the soil using a host of analytical methods

### **5.0. SUMMARY**

Despite the many methods for identification of soil minerals, X-ray diffraction is the most widely used because of its reliability and ease of adoption

### **6.0. TUTOR-MARKED ASSIGNMENT**

- What are the most important reactions in differential thermal analysis of minerals?
- List any four methods of mineral identification that uses the principle of X-ray diffraction

### **7.0. REFERENCES/FURTHER READING**

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