



**JECRC Foundation**



**JAIPUR ENGINEERING COLLEGE  
AND RESEARCH CENTRE**

Class: - III Semester / II Year  
Subject: - Engineering Geology  
Code: - **3CE4-08**  
Unit:-2 General Geology (Mineralogy and  
Crystallography  
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## **VISION**

- To become a role model in the field of Civil Engineering for the sustainable development of the society.

## **MISSION**

- 1) To provide outcome base education.
- 2) To create a learning environment conducive for achieving academic excellence.
- 3) To prepare civil engineers for the society with high ethical values.

## **Course Outcomes**

CO1:-To understand about weathering, physical properties of minerals and geological action of river and wind.

CO2:-To understand the different types of rocks and their properties.

CO 3:-To understand the folds, faults, joints and unconformity.

CO4:-To understand the geophysical methods and application of remote sensing and GIS.

## Programme Outcomes (PO)

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations
6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

## Unit 2

**Mineralogy and Crystallography-** Fundamentals of mineralogy, study of common rock forming minerals, ores and minerals of economic importance to civil engineering. Elements of crystallography and introduction to crystal systems.

### Definition of a Mineral

A mineral is a naturally-occurring, homogeneous solid with a definite, but generally not fixed, chemical composition and an ordered atomic arrangement. It is usually formed by inorganic processes.

Or

Mineralogy is a subject of geology specializing in the scientific study of chemistry, crystal structure, and physical (including optical) properties of minerals and mineralized artifacts. Specific studies within mineralogy include the processes of mineral origin and formation, classification of minerals, their geographical distribution, as well as their utilization. Inorganic substances which has more or less definite atomic structure and chemical composition

- 1.) "Naturally occurring" means that synthetic compounds not known to occur in nature cannot have a mineral name. However, it may occur anywhere, other planets, deep in the earth, as long as there exists a natural sample to describe.
- 2.) "Homogeneous solid" means that it must be chemically and physically homogeneous down to the basic repeat unit of the atoms. It will then have absolutely predictable physical properties (density, compressibility, index of refraction, etc.). This means that rocks such as granite or basalt are not minerals because they contain more than one compound.
- 3.) "Definite, but generally not fixed, composition" means that atoms, or groups of atoms must occur in specific ratios. For ionic crystals (i.e. most minerals) ratios of cations to anions will be constrained by charge balance, however, atoms of similar charge and ionic radius may substitute freely for one another; hence definite, but not fixed.
- 4.) "Ordered atomic arrangement" means crystalline. Crystalline materials are three-dimensional periodic arrays of precise geometric arrangement of atoms. Glasses such as obsidian, which are disordered solids, liquids (e.g., water, mercury), and gases (e.g., air) are not minerals.
- 5.) "Inorganic processes" means that crystalline organic compounds formed by organisms are generally not considered minerals. However, carbonate shells are minerals because they are identical to compounds formed by purely inorganic processes.

An abbreviated definition of a mineral would be "a natural, crystalline phase". Chemists have a precise definition of a phase:

A phase is that part of a system which is physically and chemically homogeneous within itself and is surrounded by a boundary such that it is mechanically separable from the rest of the system. The third part of our definition of a mineral leads us to a brief discussion of stoichiometry, the ratios in which different elements (atoms) occur in minerals. Because minerals are crystals, dissimilar elements must occur in fixed ratios to one another. However, complete free substitution of very similar elements (e.g.,  $Mg^{+2}$  and  $Fe^{+2}$  which are very similar in charge (valence) and radius) is very common and usually results in a crystalline solution (solid solution). For example, the minerals forsterite ( $Mg_2SiO_4$ ) and fayalite ( $Fe_2SiO_4$ ) are members of the olivine group and have the same crystal structure, that is, the same geometric arrangement of atoms. Mg and Fe substitute freely for each other in this structure, and all compositions between the two extremes, forsterite and fayalite, may occur.

However, Mg or Fe do not substitute for Si or O, so that the three components, Mg/Fe, Si and O always maintain the same 2 to 1 to 4 ratio because the ratio is fixed by the crystalline structure. These two minerals are called end-members of the olivine series and represent extremes or "pure" compositions. Because these two minerals have the same structure, they are called isomorphs and the series, an isomorphous series. In contrast to the isomorphous series, it is also common for a single compound (composition) to occur with different crystal structures. Each of these structures is then a different mineral and, in general, will be stable under different conditions of temperature and pressure. Different structural modifications of the same compound are called polymorphs. An example of polymorphism is the different minerals of SiO<sub>2</sub> (silica); alpha- quartz, beta-quartz, tridymite, cristobalite, coesite, and stishovite. Although each of these has the same formula and composition, they are different minerals because they have different crystal structures. Each is stable under a different set of temperature and pressure conditions, and the presence of one of these in a rock may be used to infer the conditions of formation of a rock. Another familiar example of polymorphism is graphite and diamond, two different minerals with the same formula, C (carbon).

Glasses (obsidian), liquids, and gases however, are not crystalline, and the elements in them may occur in any ratios, so they are not minerals. So in order for a natural compound to be a mineral, it must have a unique composition and structure. We will

return in a few weeks to further discussion of stoichiometry and stability. The fourth part of our definition of a mineral, the part about the ordered atomic arrangement, leads us to a discussion of symmetry which will occupy our first few weeks.

#### Mineral Properties in Hand Specimen

Learning to recognize hand specimens of approximately 100 of the most common rock-forming minerals is an important part of this course. This recognition is based on seven easily examined properties plus a few unique properties such as magnetism or radioactivity that are strong clues to a mineral's identity. These seven properties are:

1. Crystal form and habit(shape).
2. Luster and transparency
3. Color and streak.
4. Cleavage, fracture, and parting.
5. Tenacity
6. Density
7. Hardness

#### Crystal form and habit.

Recognizing crystal forms (a crystal face plus its symmetry equivalents) in the various crystal systems is one of the reasons we spend some time in lab studying block models. The crystal faces developed on a specimen may arise either as a result of growth or of cleavage. In either case, they reflect the internal symmetry of the crystal structure that makes the mineral unique. The crystal faces commonly seen on quartz are growth faces and represent the slowest growing directions in the structure. Quartz grows rapidly along its c-axis (three-fold or trigonal symmetry axis) direction and so never shows faces perpendicular to this direction. On the other hand, calcite rhomb faces and mica plates are cleavages and represent the weakest chemical bonds in the structure. There is a complex terminology for crystal faces, but some obvious names for faces are prisms and pyramids. A prism is a face that is perpendicular to a major axis of the crystal, whereas a pyramid is one that is not perpendicular to any major axis.

Crystals that commonly develop prism faces are said to have a prismatic or columnar habit. Crystals that grow in fine needles are acicular; crystals growing flat plates are tabular. Crystals forming radiating sprays of needles or fibers are stellate. Crystals forming parallel fibers are fibrous, and crystals forming branching, tree-like growths are dendritic.

Luster and transparency.

The way a mineral transmits or reflects light is a diagnostic property. The transparency may be either opaque, translucent, or transparent. This reflectance property is called luster. Native metals and many sulfides are opaque and reflect most of the light

hitting their surfaces and have a metallic luster. Other opaque or nearly opaque oxides may appear dull, or resinous. Transparent minerals with a high index of refraction such as diamond appear brilliant and are said to have an adamantine luster, whereas those with a lower index of refraction such as quartz or calcite appear glassy and are said to have a vitreous luster.

Color and streak.

Color is a fairly self-explanatory property describing the reflectance. Metallic minerals are either white, gray, or yellow. The presence of transition metals with unfilled electron shells (e.g. V, Cr, Mn, Fe, Co, Ni, and Cu) in oxide and silicate minerals causes them to be opaque or strongly colored so that the streak, the mark that they leave when scratched on a white ceramic tile, will also be strongly colored.

Cleavage, fracture, and parting.

Because bonding is not of equal strength in all directions in most crystals, they will tend to break along crystallographic directions giving them a fracture property that reflects the underlying structure and is frequently diagnostic. A perfect cleavage results in regular flat faces resembling growth faces such as in mica, or calcite. A less well developed cleavage is said to be imperfect, or if very weak, a parting. If a fracture is irregular and results in a rough surface, it is hackly. If the irregular fracture propagates as a single surface resulting in a shiny surface as in glass, the fracture is said to be conchoidal.

## Tenacity

It is the ability of a mineral to deform plastically under stress. Minerals may be brittle, that is, they do not deform, but rather fracture, under stress as do most silicates and oxides. They may be sectile, or be able to deform so that they can be cut with a knife. Or, they may be ductile and deform readily under stress as does gold.

## Density

It is a well-defined physical property measured in  $\text{g/cm}^3$ . Most silicates of light element have densities in the range 2.6 to 3.5. Sulfides are typically 5 to 6. Iron metal about 8, lead about 13, gold about 19, and osmium, the densest substance, and a native element mineral, is 22. Density may be measured by measuring the volume, usually by displacing water in a graduated cylinder, and the mass. Specific gravity is very similar to density, but is a dimensionless quantity and is measured in a slightly different way. Specific gravity is measured by determining the weight in air ( $W_a$ ) and the weight in water ( $W_w$ ) and computing specific gravity from  $SG = W_a / (W_a - W_w)$ . In practice this is done using a Jolly balance as we will see in lab.

## Hardness

It is usually tested by seeing if some standard minerals are able to scratch others. A standard scale was developed by Friedrich Mohs in 1812. The standard minerals making up the Mohs scale of hardness are:

1. Orthoclase
2. Orthoclase
3. Quartz
4. Talc
5. Gypsum
6. Calcite
7. Topaz
8. Fluorite
9. Corundum
10. Apatite
11. Diamond

This scale is approximately linear up to corundum, but diamond is approximately 5 times harder than corundum.

## Unique Properties.

A few minerals may have easily tested unique properties that may greatly aid identification. For example, halite ( $\text{NaCl}$ ) (common table salt) and sylvite ( $\text{KCl}$ ) are very similar in most of their physical properties, but have a distinctly different taste on the tongue, with sylvite having a more bitter taste. Whereas it is not recommended that students routinely taste mineral specimens (some are toxic), taste can be used to distinguish between these two common minerals.

Another unique property that can be used to distinguish between otherwise similar back opaque minerals is magnetism. For example, magnetite ( $\text{Fe}_3\text{O}_4$ ), ilmenite ( $\text{FeTiO}_3$ ), and pyrolusite ( $\text{MnO}_2$ ) are all dense, black, opaque minerals which can easily be distinguished by testing the magnetism with a magnet. Magnetite is strongly magnetic and can be permanently magnetized to form a lodestone; ilmenite is weakly magnetic; and pyrolusite is not magnetic at all.

## Other Properties

There are numerous other properties that are diagnostic of minerals, but which generally require more sophisticated devices to measure or detect. For example, minerals containing the elements U or Th are radioactive (although generally not dangerously so), and this radioactivity can be easily detected with a Geiger counter. Examples of radioactive minerals are uraninite ( $\text{UO}_2$ ), thorite ( $\text{ThSiO}_4$ ), and carnotite ( $\text{K}_2(\text{UO}_2)(\text{VO}_4)_2 \cdot \text{rH}_2\text{O}$ ). Some minerals may also be fluorescent under ultraviolet light, that is they absorb UV light and emit in the visible. (There is a display of fluorescent mineral on the first floor of the (old) Geology Building.) Other optical properties such as index of refraction and pleochroism (differential light absorption) require an optical microscope to measure and are the subject of a major section of this course. Electrical conductivity is an important physical property but requires an impedance bridge to measure. In general native metals are good conductors, sulfides of transition metals are semi-conductors, whereas most oxygen-bearing minerals (i.e., silicates, carbonates, oxides, etc.) are insulators. Additionally, quartz ( $\text{SiO}_2$ ) is piezoelectric (develops an electrical charge at opposite end under an applied mechanical stress); and tourmaline is pyroelectric (develops an electrical charge at opposite end under an applied thermal gradient).

## Mineral Occurrences and Environments

In addition to physical properties, one of the most diagnostic features of a mineral is the geological environment in which it occurs. Learning to recognize different types of geological environments can be thus be very helpful in recognizing the common minerals.

For the purposes of aiding mineral identification, we have developed a very rough classification of geological environments, most of which can be visited locally.

**Igneous Minerals:** Minerals in igneous rocks must have high melting points and be able to co-exist with, or crystallize from, silicate melts at temperatures above  $800^\circ\text{C}$ . Igneous rocks can be generally classed according to their silica content with low-silica ( $\ll 50\% \text{SiO}_2$ ) igneous rocks being termed basic or mafic, and high-silica igneous rocks being termed silicic or acidic. Basic igneous rocks (BIR) include basalts, dolerites, gabbros, kimberlites, and peridotites, and abundant minerals in such rocks include olivine, pyroxenes, Ca-feldspar (plagioclase), amphiboles, and biotite. The abundance of Fe in these rocks causes them to be dark-colored. Silicic igneous rocks (SIR) include granites, granodiorites, and rhyolites, and abundant minerals include quartz, muscovite, and alkali feldspars. These are commonly light-colored although color is not always diagnostic. In addition to basic and silicic igneous rocks, a third igneous mineral environment representing the final stages of igneous fractionation is called a pegmatite (PEG) which is typically very coarse-grained and similar in composition to silicic igneous rocks (i.e. high in silica). Elements that do not readily substitute into the abundant minerals are called incompatible elements, and these typically accumulate to form their own minerals in pegmatites. Minerals containing the incompatible elements, Li, Be, B, P, Rb, Sr, Y, Nb, rare earths, Cs, and Ta are typical and characteristic of pegmatites.



**Metamorphic minerals:** Minerals in metamorphic rocks have crystallized from other minerals rather than from melts and need not be stable to such high temperatures as igneous minerals. In a very general way, metamorphic environments may be classified as low-grade metamorphic (LGM) (temperatures of 60 ° to 400 ° C and pressures  $\ll$  .5 GPa (=15km depth) and high-grade metamorphic (HGM) (temperatures  $>$  400 ° and/or pressures  $>$  .5GPa). Minerals characteristic of low-grade metamorphic environments include the zeolites, chlorites, and andalusite. Minerals characteristic of high grade metamorphic environments include sillimanite, kyanite, staurolite, epidote, and amphiboles.

**Sedimentary minerals:** Minerals in sedimentary rocks are either stable in low-temperature hydrous environments (e.g. clays) or are high temperature minerals that are extremely resistant to chemical weathering (e.g. quartz). One can think of sedimentary minerals as exhibiting a range of solubilities so that the most insoluble minerals such as quartz, gold, and diamond accumulate in the coarsest detrital sedimentary rocks, less resistant minerals such as feldspars, which weather to clays, accumulate in finer grained siltstones and mudstones, and the most soluble minerals such as calcite and halite (rock-salt) are chemically precipitated in evaporite deposits. Accordingly, I would classify sedimentary minerals into detrital sediments (DSD) and evaporites (EVP). Detrital sedimentary minerals include quartz, gold, diamond, apatite and other phosphates, calcite, and clays. Evaporite sedimentary minerals include calcite, gypsum, anhydrite, halite and sylvite, plus some of the borate minerals.

**Hydrothermal minerals:** The fourth major mineral environment is hydrothermal, minerals precipitated from hot aqueous solutions associated with emplacement of intrusive igneous rocks. This environment is commonly grouped with metamorphic environments, but the minerals that form by this process and the elements that they contain are so distinct from contact or regional metamorphic rocks that it is useful to consider them as a separate group. These may be sub-classified as high temperature hydrothermal (HTH), low temperature hydrothermal (LTH), and oxidized hydrothermal (OXH). Metals of the center and right-hand side of the periodic table (e.g. Cu, Zn, Sb, As, Pb, Sn, Cd, Hg, Ag) most commonly occur in sulfide minerals and are termed the chalcophile elements. Sulfides may occur in igneous and metamorphic rocks, but are most typically hydrothermal. High temperature hydrothermal minerals include gold, silver, tungstate minerals, chalcopyrite, bornite, the tellurides, and molybdenite. Low temperature hydrothermal minerals include barite, gold, cinnabar, pyrite, and cassiterite. Sulfide minerals are not stable in atmospheric oxygen and will weather by oxidation to form oxides, sulfates and carbonates of the chalcophile metals, and these minerals are characteristic of oxidized hydrothermal deposits. Such deposits are called gossans and are marked by yellow-red iron oxide stains on rock surfaces. These usually mark mineralized zones at depth and are very common in Colorado.

**Classification of Minerals**

It has constant physical property which are used in the identification of mineral in the field, It can be divided into 2 groups

Rock forming mineral: Which are found in abundance of earth crust.

Ore forming minerals: which are economic valuable mineral.

Minerals are classified on their chemistry, particularly on the anionic element or polyanionic group of elements that occur in the mineral. An anion is a negatively charge atom, and a polyanion is a strongly bound group of atoms consisting of a cation plus several anions (typically oxygen) that has a net negative charge. For example carbonate,  $(\text{CO}_3)^{2-}$ , silicate,  $(\text{SiO}_4)^{4-}$  are common poly anions. This classification has been successful because minerals rarely contain more than one anion or polyanion, whereas they typically contain several different cations.

Native elements: The first group of minerals is the native elements, and as pure elements, these minerals contain no anion or polyanion. Native elements such as gold (Au), silver (Ag), copper (Cu), and platinum (Pt) are metals, graphite is a semi-metal, and diamond (C) is an insulator.

Sulfides: The sulfides contain sulfur (S) as the major "anion". Although sulfides should not be considered ionic, the sulfide minerals rarely contain oxygen, so these minerals form a chemically distinct group. Examples are pyrite ( $\text{FeS}_2$ ), sphalerite (ZnS), and galena (PbS). Minerals containing the elements As, Se, and Te as "anions" are also included in this group.

Halides: The halides contain the halogen elements (F, Cl, Br, and I) as the dominant anion. These minerals are ionically bonded and typically contain cations of alkali and alkaline earth elements (Na, K, and Ca). Familiar examples are halite (NaCl) (rock salt) and fluorite ( $\text{CaF}_2$ ).

Oxides: The oxide minerals contain various cations (not associated with a polyanion) and oxygen. Examples are hematite ( $\text{Fe}_2\text{O}_3$ ) and magnetite ( $\text{Fe}_3\text{O}_4$ ).

Hydroxides: These minerals contain the polyanion  $\text{OH}^-$  as the dominant anionic species. Examples include brucite ( $\text{Mg}(\text{OH})_2$ ) and gibbsite ( $\text{Al}(\text{OH})_3$ ).

Carbonates: The carbonates contain  $\text{CO}_3^{2-}$  as the dominant polyanion in which  $\text{C}^{4+}$  is surrounded by three  $\text{O}^{2-}$  anions in a planar triangular arrangement. A familiar example is calcite ( $\text{CaCO}_3$ ). Because  $\text{NO}_3^-$  shares this geometry, the nitrate minerals such as soda niter (nitratite) ( $\text{NaNO}_3$ ) are included in this group.

Sulfates: These minerals contain  $\text{SO}_4^{2-}$  as the major polyanion in which  $\text{S}^{6+}$  is surrounded by four oxygen atoms in a tetrahedron. Note that this group is distinct from sulfides which contain no O. A familiar example is gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ).

Phosphates: The phosphates contain tetrahedral  $\text{PO}_4^{3-}$  groups as the dominant polyanion. A common example is apatite ( $\text{Ca}_5(\text{PO}_4)_3(\text{OH})$ ) a principal component of bones and teeth. The other trivalent tetrahedral polyanions, arsenate  $\text{AsO}_4^{3-}$ , and vanadate  $\text{VO}_4^{3-}$  are structurally and chemically similar and are included in this group.

Borates: The borates contain triangular  $\text{BO}_3^{3-}$  or tetrahedral  $\text{BO}_4^{5-}$ , and commonly both coordinations may occur in the same mineral. A common example is borax,  $(\text{Na}_2\text{B}^{\text{III}}_2\text{B}^{\text{IV}}_2\text{O}_5(\text{OH})_4 \cdot 8\text{H}_2\text{O})$ .

Silicates: This group of minerals contains  $\text{SiO}_4^{4-}$  as the dominant polyanion. In these minerals the  $\text{Si}^{4+}$  cation is always surrounded by 4 oxygens in the form of a tetrahedron. Because Si and O are the most abundant elements in the Earth, this is the largest group of minerals and is divided into subgroups based on the degree of polymerization of the  $\text{SiO}_4$  tetrahedral.

Orthosilicates: These minerals contain isolated  $\text{SiO}_4^{4-}$  polyanionic groups in which the oxygens of the polyanion are bound to one Si atom only, i.e., they are not polymerized.

Examples are forsterite (Mg-olivine,  $Mg_2SiO_4$ ), and pyrope (Mg-garnet,  $Mg_3Al_2Si_3O_{12}$ ).

Sorosilicates.: These minerals contain double silicate tetrahedra in which one of the oxygens is shared with an adjacent tetrahedron, so that the polyanion has formula  $(Si_2O_7)^{6-}$ . An example is epidote ( $Ca_2Al_2FeO(OH)SiO_4Si_2O_7$ ), a mineral common in metamorphic rocks.

Cyclosilicates: These minerals contain typically six-membered rings of silicate tetrahedra with formula.  $(Si_6O_{17})^{10-}$ . An example is tourmaline.

Chain silicates: These minerals contain  $SiO_4$  polyhedra that are polymerized in one direction to form chains. They may be single chains, so that of the four oxygen coordinating the Si atom, two are shared with adjacent tetrahedra to form an infinite chain with formula  $(SiO_3)^{2-}$ .

The single chain silicates include the pyroxene and pyroxenoid minerals which are common constituents of igneous rocks. Or they may form double chains with formula  $(Si_4O_{11})^{8-}$ , as in the amphibole minerals, which are common in metamorphic rocks.

Sheet silicates: These minerals contain  $SiO_4$  polyhedra that are polymerized in two dimensions to form sheets with formula  $(Si_4O_{10})^{4-}$ . Common examples are the micas in which the cleavage reflects the sheet structure of the mineral.

Framework silicates: These minerals contain  $SiO_4$  polyhedra that are polymerized in three dimensions to form a framework with formula  $(SiO_2)_0$ . Common examples are quartz ( $SiO_2$ ) and the feldspars ( $NaAlSi_3O_8$ ) which are the most abundant minerals in the Earth's crust. In the feldspars  $Al^{3+}$  may substitute for  $Si^{4+}$  in the tetrahedral, and the resulting charge imbalance is compensated by an alkali cation (Na or K) in interstices in the framework.

#### MINERAL GROUPS:

MINERAL GROUP	EXAMPLES
Oxides	Quartz, magnetite, hematite, etc
Silicates	Feldspar, mica, hornblende, augite, olivine, etc
Carbonates	Calcite, dolomite, etc
Sulphides	Pyrites, galena, Sphalerite, etc
Sulphates	Gypsum
Chlorite	Rock salt, etc

Over 4000 minerals exist in earth's crust; all are composed of oxygen, silicon, aluminum, iron, calcium, potassium, sodium and magnesium.

#### PHYSICAL PROPERTIES:

Physical properties can be determined by inspection or by simple tests. It can be determined by hand specimen. The chief physical properties are colour, streak, lustre, hardness, habit, cleavage, fracture, odour, tenacity, specific gravity and crystal forms. Correct identification is made with a polarizing microscope.

**COLOUR:** Occurs due to certain wavelengths of light by atoms making of crystals. On the basis of colour of a mineral; may belong to any one of three types,

**IDIOCHROMATIC:** show a constant colour appear metallic crystal ex. Copper

**ALLOCHROMATIC:** Show variable colors, appear non-metallic ex. Quartz

**PSEUDOCHROMATIC;** Shows false colour

Some minerals viewed in different directions show irregular changes in colour

1. **PLAY OF COLOR:** Change in rapid succession on rotation ex. Diamond
2. **CHANGE OF COLOR:** Rate of change of colours on rotation and intensity is low ex. Labradorite
3. **IRIDESCENCE:** Shows rainbow colours in interior or exterior surface ex. Limonite, Hematite
4. **TARNISH:** Change of original colour due to oxidation ex. Bornite
5. **GREASY LUSTRE:** Luster exhibited by grease ex. Talc
6. **DULL OR EARTHY:** No luster said to earthy luster ex.

Kaolin **HARDNESS:** Hardness of mineral depends on chemical composition

Determined by rubbing or scratching a mineral of unknown hardness against one of known hardness. A numerical value is obtained by using the Moh's scale of hardness. Here 10 minerals are arranged in order of increasing

**CLEAVAGE:** It is defined as a tendency of mineral to break more easily with smooth surface along plane of weak bonding. The cleavage can be classified as perfect, good, poor, and indistinct. **PERFECT CLEAVAGE:** Mica, Galena, Calcite **NO CLEAVAGE:** Quartz

**FRACTURE:** The nature of the surface of a mineral is called as fracture. The common types of fracture are

1. **EVEN FRACTURE:** Surface almost flat ex. flint, chert
2. **UNEVEN FRACTURE:** Surface is irregular and rough ex. Fluorite
3. **CONCHOIDAL FRACTURE:** Curved surface showing concentric line like shell ex. Quartz
4. **HACKY FRACTURE:** Rough surface with sharp and jagged points ex. Asbestos
5. **EARTHY FRACTURE:** Smooth, soft and porous ex.

chalk, kaolin **SPECIFIC GRAVITY:**

Its number which represents the ratio of weight of the mineral to the weight of an equal volume of water.

**HABIT (FORM):** The chief habits of minerals are shown as follows,

1. ACCICULAR: Needle like crystal ex.Natrolite
2. FIBROUS: Aggregate of long thin fibre ex.Asbestos
3. FOLIATED: Thin separate sheet ex.Mica
4. BLADED: Occur as small knife blade ex.Kyanite
5. TABULAR: Broad flat surface ex. Gypsum, feldspar
6. COLUMNAR: Columnar crystal ex. Tourmaline
7. GRANULAR: aggregate of equi-dimension grains ex.Magnetite
8. REINFORM: Kidney shaped form ex.Hematite.
9. OOLITIC: Aggregate bodies resembling fish roe ex.Bauxite

10. MASSIVE: Structural less mass

ex.Flint ROCK FORMING MINERALS:

1. SILICATE MINERALS: CONSTITUTE 90% OF EARTH CRUST
2. NON- SILICATE MINERALS: There are 2 groups,
  - I. Stable (quartz group, feldspar group)
  - II. Unstable (pyroxene group, amphibole group, mica group, olivine)

ATOMIC STRUCTURES:

1. Neosilicates
2. Sorosilicates
3. Cyclosilicate (ring structure)
4. Inosilicate (chain silicate)
5. Phyllosilicate (sheet structure)
6. Tectosilicates

QUARTZ GROUP:

1. It is an important rock forming mineral next to feldspar
2. It is a non-metallic refractory mineral
3. It is a silicate group

PHYSICAL PROPERTIES

OF QUARTZ:

CRYSTAL SYSTEM: Hexagonal

HABIT: Crystalline or

amorphous FRACTURE:

Conchoidal HARDNESS: 7

SPECIFIC GRAVITY: 2.65-

2.66 (LOW) STREAK: No

TRANSPARENCY: Transparent/semi-transparent/opaque

POLYMORPHISM TRANSFORMATION:

Quartz tridymite cristobalite melt

COLOURED VARIETIES:

1. *Pure quartz* is always colourless and transparent
2. Presence of impurities the mineral showing colour they

- a. *Amethyst*: purple or violet
- b. *Smoky quartz*: shades of grey
- c. *Milky quartz*: light brown, pure white, opaque
- d. *Rose quartz*: rose

#### CRYPTOCRYSTALLINE FORMS

#### OF QUARTZ:

1. CHALCEDONY: Amorphous, waxy lustre
2. AGATE: A banded, variety having different colours
3. JASPER: Dull red, yellow, massive
4. FLINT: Dark grey, conchoidal fracture
5. OPAL: Amorphous
6. QUARTZ FAMILY MINERALS
7. PRIMARY: Recrystallisation process (Si, Al, Fe)
8. SECONDARY: Precipitation (chalcedony, opal, chert, flint)

#### OCCURRENCE:

It occurs in all types of rocks igneous, metamorphic and sedimentary rocks

#### USES:

1. Used as semi-precious stone
2. Form of sand in construction
3. Used as abrasive in industries
4. Used for making watches
5. Piezoelectric crystal for frequency state

#### FELSPAR GROUP:

1. It is most abundant of all minerals
2. It is used for making more than 50% by weight crust of earth
3. It is non-metallic and silicate minerals

#### CHEMICAL COMPOSITION:

Potash feldspar  $KAlSi_3O_8$

Soda-lime feldspar  $NaAlSi_3O_8$  (OR)

$CaAl_2Si_2O_8$  VARIETIES OF POTASH

#### FELSPAR:

1. Orthoclase
2. Sanidine
3. Microcline

#### SODA LIME

#### FELSPAR:

1. Albite
2. Oligoclase
3. Andesine
4. Anorthite
5. Labradorite

#### GENERAL PHYSICAL:

CRYSTAL SYSTEM: monoclinic, triclinic

HABIT: Tabular (crystalline)

CLEAVAGE: Perfect(2- directional)

FRACTURE: Conchoidal or uneven

COLOUR: White, grey, pink,  
green,red LUSTRE: Vitreous

HARDNESS: 6-6.5

SPECIFIC GRAVITY: 2.56-  
2.58(low) STREAK: No

OCCURRENCE: Igneous rock

USES: Ceramics, glass, tableware, enamels, electric porcelain, false teeth

POTASH FELSPAR:

ORTHOCLASE:

CRYSTAL SYSTEM:

monoclinic COLOUR:red

CHEMICAL COMPOSITION:

$KAlSi_3O_8$  MICROCLINE:

CRYSTAL SYSTEM: triclinic

COLOUR: flesh red

CHEMICAL COMPOSITION:  $KAlSi_3O_8$

USES: ceramic

semiprecious SODA LIME

FELSPAR:

ALBITE:

CRYSTAL SYSTEM: Triclinic

COLOR: Whitish or pinkish

white COMPOSITION:  $NaAlSi_3$

$O_8$

USES: Ceramic, ornamental stone

ANORTHITE:

CRYSTAL SYSTEM: Triclinic

COLOR: white

COMPOSITION:  $CaAl_2Si_2O_8$  (90%),  $NaAlSi_3O_8$  (10%)

USES: ceramic, ornamental stone

OCCURRENCE: all types of

rocks PYROXENES GROUP:

It is important group of rock forming minerals. They are commonly occur in dark colours, igneous and metamorphic rocks, they are rich in calcium, magnesium, iron, silicates. It shows single chain structure of silicate. It is classified into orthopyroxene and clinopyroxene. It is based on internal atomic structure.

ORTHOPYROXENE:

Enstatite ( $MgSiO_3$ )

Hypersthene [ $(Mg,Fe)SiO_3$ ]

### CLINOPYROXENE:

Augite [(Ca, Na) (Mg, Fe, Al) (Al,

Si)<sub>2</sub>O<sub>6</sub>] Diopside [CaMgSi<sub>2</sub>O<sub>6</sub>]

Hedenbergite[CaFeSi<sub>2</sub>O<sub>6</sub>]

### AUGITE:

CRYSTAL SYSTEM:

Monoclinic HABIT:

Crystalline

CLEAVAGE: Good ( prismatic cleavage)

FRACTURE: Conchoidal

COLOUR: shades of greyish green and

black LUSTRE: vitreous

HARDNESS: 5-6

SPECIFIC GRAVITY: medium

STREAK :white

OCCURRENCE: Ferro magnesium mineral of igneous rock

(dolerite) USES: rock forming mineral

COMPOSITON: [(Ca, Na) (Mg, Fe, Al) (Al, Si)<sub>2</sub>O<sub>6</sub>

TRANSPARENCY:

Translucent/opaque AMIPHOBLE

### GROUP:

These are closely related to pyroxene group It shows double chain silicate structure Rich in calcium, magnesium, iron oxide and Mn, Na, K and H

CLASSIFICATION:

1. Orthorhombic
2. Monoclinic
  - a. Hornblende
  - b. Tremolite
  - c. Actinolite

### HORNBLLENDE: (COMPOUND-COMPLEX SILICATE)

CRYSTAL SYSTEM:

Monoclinic HABIT:

crystalline

CLEAVAGE: good

(prismatic) FRACTURE:

conchoidal

COLOUR: dark green, dark brown

black LUSTRE: vitreous

HARDNESS: 5 to 6

SPECIFIC GRRAVITY: 3 to 3.5 (medium)

STREAK: colourless or white

COMPOSITION: hydrous silicates of Ca, Na, Mg,

Al TRANSPARENCY: translucent/opaque

OCCURRENCE: found in igneous rocks

USES: road material



Form sheet like structure can be split into very thin sheets along one direction Aluminum and magnesium are rich Occupy 4% of earth crust

Shows basal cleavage

CLASSIFICATION:

LIGHTMICA:

Muscovite- $KAl_2 (AlSi_2O_{10})(OH)_2$ -Potash

mica Paragonite- $NaAl_2 (AlSi_3O_{10})(OH)_2$ -

Soda mica Lepidolite- $KLiAl (Si_4O_{10})(OH)_2$  –

Lithium mica DARKMICA:

Biotite- $K (Mg, Fe)_3 (AlSi_3O_{10})(OH)_2$ . (Fe Mg

mica) Phlogopite- $KMg_3 (Al_3Si_3O_{10})(OH)_2$ - (Mg

mica) Zinwaldite-Complex Li-Fe mica

GENERAL PHYSICAL PROPERTIES:

CRYSTAL

SYSTEM: Monoclinic

HARDNESS: 2-3

LUSTRE: Vitreous

HABIT: Foliated

CLEAVAGE:

perfect (basal)

LIGHTMICA:

MUSCOVITE:

CRYSTAL SYSTEM:

monoclinic HARDNESS: 2-3

LUSTRE: vitreous

HABIT: foliated

CLEAVAGE: perfect

SPECIFIC GRAVITY:

2.7-

STREAK: colourless

COMPOSITION:  $KAl_2 (AlSi_2O_{10})(OH)_2$

OCCURRENCE: in igneous rock (granite and pegmatite) and accessory mineral in sedimentary rock

USES: electrical industry

TRANSPARENCY:

Transparent FRACTURE:

even

COLOUR:

colourless LEPIDOL

ITE:

CRYSTAL SYSTEM:

monoclinic HABIT: granular

CLEAVAGE:

good

FRACTURE:

even COLOR:

colorless

LUSTRE:

pearly

HARDNESS:

2-3

SPECIFIC GRAVITY: 2.8-3.3

STREAK: colorless

COMPOSITION:  $\text{NaAl}_2(\text{AlSi}_3\text{O}_{10})(\text{OH})_2$

TRANSPARENCY:

transparent OCCURRENCE:

In igneous rock USES: fire

proof material DARK MICA:

BIOTITE:

CRYSTAL SYSTEM:

monoclinic HABIT: foliated

CLEAVAGE: perfect

FRACTURE: even

COLOUR: black, deep

green LUSTRE: vitreous

HARDNESS: 2.5-3

SP.GRAVITY: 2.7-3

STREAK: colorless

COMPOSITION:  $\text{K}(\text{Mg Fe})_3(\text{AlSi}_3\text{O}_{10})(\text{OH})_2$

OCCURRENCE: commonly found in igneous rocks, sedimentary rocks TRANSPARENCY: Translucent

USES: electrical industries

PHLOGOPITE:[LIMITED

OCCURNECE]

CRYSTAL SYSTEM:

Monoclinic HABIT: foliated

CLEAVAGE: perfect

STREAK: The streak of the mineral is the true colour of the mineral is quite helpful in mineral

The streak is obtained by rubbing a mineral against an unglazed porcelain plate

Example: Magnetite, black in color and give blackish brown colour as streak

LUSTRE: General appearance of a mineral surface in reflected light

METALLIC: Metallic appearance ex. Magnetite, hematite

SUB-METALLIC: Feebly displayed metallic luster ex. Chromite

ADAMANTINE: Hard brilliant luster ex. Diamond

VITREOUS LUSTRE: Lustre exhibited by broken glass ex. Quartz, gypsum

PEARLY LUSTRE: Lustre exhibited by pearls ex. Talc, calcite

SILKY LUSTRE: Lustre exhibited by silk fibers ex. Asbestos

RESINOUS LUSTRE: Exhibited by resin ex. Sphalerite, nephiline

FRACTURE: even

COLOUR: yellow, brown red

LUSTRE: vitreous

HARDNESS: 2.5-3

SP.GRAVITY: 2.7-3

STREAK: colourless

COMPOSITION:  $K Mg_3(Al_3Si_3O_{10})(OH)_2$

TRANSPARENCY: translucent

OCCURRENCE: in igneous rock, metamorphic rock and rarely in sedimentary

rock USES: electrical industries

### IRON OXIDE MINERALS:

#### 1. MAGNETITE:

Crystal system: cubic

Habit: crystalline, massive or granular

Fracture: uneven

Cleavage: absent

Lustre: metallic

Hardness: 6-7

Sp.gravity- 5.18(high)

Streak: brown

Composition:

$Fe_3O_4$  Transparency:

translucent

Occurrence: as a accessory in igneous rock

Uses: it is important ore of iron

#### 2. HEMATITE:

Crystal system: hexagonal

Habit: massive

Cleavage: absent

Fracture: uneven

Color: reddish brown to black

Lustre: metallic

Hardness: 5-6

Sp. Gravity: 5.26(high)

Streak: dark red

Composition:

$Fe_2O_3$  Varieties: red ocher

Transparency: translucent

Occurrence: thick beds of sedimentary rocks

Uses: as iron ore and pigments

#### 3. PYRITE:

Crystal system: cubic

Habit: cube or granular

Cleavage: absent

Fracture;

conchoidal Colour:

brass yellow Lustre:

vitreous Hardness: 6-

6.5

Sp. Gravity: 5.02

Streak: greenish or brownish black

Transparency: translucent

Occurrence: common sulphide minerals found in hydrothermal veins of metamorphic rock

Uses: used in manufacture of sulphuric acid

#### **4. SIDERITE:**

Crystal system: hexagonal

Habit: crystalline, fibrous also granular

Cleavage: perfect

Colour: light to dark brown

Lustre: vitreous

Streak:

Fracture:

Hardness: 3.5-4

Sp. Gravity: 3.96 (medium)

Composition:

$\text{FeCO}_3$  Transparency:

translucent

Occurrence: massive in sedimentary deposited

Uses: in steel industries

#### **CARBONATE MINERAL:**

##### ***1. CALCITE:***

Crystal system: hexagonal

Habit: tabular

Cleavage: perfect

Fracture: even

Colour: milky white, grey, green, yellow, colorless

etc Lustre: vitreous

Hardness: 3

Sp. Gravity: 2.71 (low)

Streak:

colourless Composition:

$\text{CaCO}_3$  Transparency:

transparent

Uses: used for manufacture of cement and lime it is also used as fertilizer

Occurrence: rock forming mineral in sedimentary rocks.

#### **CLAY MINERAL GROUP:**

These are phyllosilicates minerals  
Essentially hydrous aluminium silicates  
These are common weathering products  
Very common in sedimentary rock

#### CLASSIFICATION:

There are four group,

##### **A. Kaolin**

- a. Kaolinite
- b. Dicitite
- c. Nacrite
- d. Halloysite
- e. Smectite
- f. Montmorillonite
- g. Nontronite

##### **B. Hectorite**

- a. Illite
- b. Chorite

#### PHYSICAL PROPERTIES:

IES:

##### KAOLIN GROUP:

##### KAOLINITE:

It is formed by weathering of aluminate- silicate minerals. The feldspar rich rocks are commonly weathered to kaolinite.

Crystal system: Triclinic

Habit: Massive

Colour: White sometimes brown

Cleavage: Perfect

Fracture: Even

Streak: White

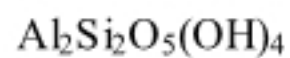
Lustre: Dull earthy

Hardness: 2

Specific gravity: 2.6(low)

Transparency: Translucent

Composition:



Occurrence: secondary mineral formed by alteration of alkali feldspar

Uses: ceramic industries, medicine, cosmetics and main components in porcelain

##### HALLOYSITE:

Crystal system: Monoclinic

Habit: Massive

Colour: white, grey, green, yellow, red, blue

Streak:

Cleavage: imperfect

Lustre: waxy or dull

Fracture: conchoidal

Hardness: 2-2.5

Sp. Gravity: 2-2.5 (low)

Transparency: Translucent

Composition:

$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$

Occurrence: secondary mineral formed by alteration of alkali feldspar

**SMECTITE GROUPS:**

**MONTMORILLONITE:**

It is derived from weathering of volcanic ash. In contact with water it expands several times its original volume. Act as drilling mud and it is main constituents as petronite

Crystal system: Monoclinic

Habit: Lamellar/ Globular

Colour: White, blue or yellow

Streak:

Lustre: Dull Earthy

Fracture: Uneven

Cleavage: Perfect

Hardness: 1-2

Sp. Gravity: 1.7-2 (low)

Transparency: Translucent

Composition:  $(\text{Na}, \text{Ca})_{0.33}(\text{Al}, \text{Mg})_2 \text{Si}_4\text{O}_{10}(\text{OH})_2 \cdot n\text{H}_2\text{O}$

Occurrence: derived from volcanic ash also weathering of muscovite, illite, kaolinite

Uses: Mainly used for oil industry (drilling mud)

**ILLITE:**

The illite clay have a structure similar to that of muscovite. They form by alternate minerals like muscovite and feldspar.

Chemical composition:  $(\text{K}, \text{H}) \text{Al}_2(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_2$

$\text{XH}_2\text{O}$  Uses: in oil industry

**CHLORITE:**

Crystal system: Foliated Monoclinic

Habit: Foliated

Colour: Grey, Green

Streak: White

Cleavage: Good

Fracture: Even

Lustre: Vitreous

Sp. Gravity:

Low Hardness:

2-3

Transparency:

**ENGINEERING CONSIDERATIONS OF CLAY MINERALS:**

Montmorillonite is a dangerous type of clay cut it when found in road or tunnel since it has expandable nature which causes slope or wall failure.

Kaolinite is used in ceramic industry, it is not expandable and won't absorb water

Clay is used as important material in construction industries both as building material and as foundation or structure. It has poor drainage because the soil tends to stay wet and soggy when it is affected by water, while it is wet it can be easily compacted. It has poor aeration because the soil particles are small and closely spaced, it is very difficult for air to enter or leave the soil. It has very high nutrients reserves, reducing the need for fertilization also because clay retains water plants growing in it often more drought tolerant than plants growing in sandy soil.

#### ENGINEERING CLASSIFICATION OF MINERALS:

Minerals have been classified based on their influence on the performance of rocks/ soil. A partial listing of potential minerals are as follows,

##### SOLUBLE MINERALS:

Calcite ( $\text{CaCO}_3$ ), Dolomite ( $\text{CaMg}(\text{CO}_3)_2$ ), Gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ), Anhydrite ( $\text{CaSO}_4$ ), Halite ( $\text{NaCl}$ ), Zeolite

##### UNSTABLE MINERALS:

Marcasite, pyrrhotite

##### POTENTIALLY UNSTABLE MINERALS:

Nontronite (iron rich montmorillonite), Nepheline, Lucite, mica rich in iron

##### MINERALS WHICH RELEASE $\text{H}_2\text{SO}_4$ ON WEATHERING:

Pyrite, pyrrhotite, other sulphide minerals

##### MINERALS WITH LOW COEFFICIENT

##### FRICITION:

Clay minerals, talc, chlorite, serpentine, mica, graphite, molybdenite

##### POTENTIALLY SWELLING MINERALS:

Clay minerals (illite, kaolinite, bentonite, montmorillonite) Anhydrite, vermiculite

##### ALKALI REACTIVE MINERALS (INTERFERE WITH CEMENT):

Opal, volcanic glass, chert, chalcedony, gypsum, zeolite, mica, amorphous quartz

##### MINERALS WITH HIGH DENSITY:

Iron oxide, sulphide minerals, other metallic minerals, barites

##### MINERAL CONTRIBUTING ARSENIC TO

##### GROUNDWATER:

Arseno-pyrite, arsenolite, proustite

##### MINERALS RELEASE FLUORIDE INTO GROUNDWATER:

Fluorapatite

**Definition of Crystallographic :** A crystal is defined as a solid body bounded by plane natural surfaces, which are the external expression of a regular arrangement of its constituent atoms or ions (Berry, Mason and Dietrich 1983). **Crystal structure:** This is the orderly arrangement of atoms or group of atoms (within a crystalline substance) that constitute a crystal (Figure 1.1). Figure 1.1. Crystal structure of Halite. Left: Ions drawn proportional to their sizes. Right: Expanded view to show the interior of the unit cell.



Morphological crystals are finite crystallographic bodies with finite faces that are parallel to lattice planes. Lattice – This is an imaginary three-dimensional framework that can be referenced to a network of regularly spaced points, each of which represents the position of a motif (Figure 1.2). Unit Cell – This is a pattern that yields the entire pattern when translated repeatedly without rotation in space. The repetition yields infinite number of identical unit cells and the pattern is regular. In order to fill space without gaps, the unit cell must at least be a parallelogram in 2D (2-dimensional) space.

**SYMMETRY ELEMENTS** : Symmetry is the most important of all properties in the identification of crystalline substances. In this section we shall be concerned with the symmetrical arrangement of crystal faces, an arrangement which reflects the internal symmetry of the lattice. Symmetry may be described by reference to symmetry planes, axes, and the centre of symmetry as discussed here below

**1. Plane of Symmetry** – This is defined as a plane along which the crystal may be cut into exactly similar halves each of which is a mirror image of the other. A crystal can have one or more planes of symmetry. A sphere for example has infinite planes of symmetry.

**2. Axis of Symmetry** – This is a line about which the crystal may be rotated so as to show the same view of the crystal more than once per revolution, e.g. a cube. Alternatively it can be defined as a line along which the crystal may be rotated such that the crystal assumes a position of congruence i.e. the crystal presents the same appearance to a fixed observer. If a position of congruence occurs after every 180 How many planes of symmetry does a cube have? Lecture Series: SGL 201 – Principles of Mineralogy 15 degrees of rotation, the axis is said to be a diad or two-fold symmetry axis. Other axes may be

called triad, tetrad or hexad (three-fold, four-fold, or six-fold) axes depending on whether congruence is attained every 120, 90, or 60 degrees respectively. Symmetry axes for a cube are shown in Figure 1.10. Note also the symbols used to denote axes in diagrams.

**3. Center of Symmetry** – Center of symmetry is the point from which all similar faces are equidistant. It is a point inside the crystal such that when a line passes through it, you'll have similar parts of the crystal on either side at same distances. A cube possesses a centre of symmetry.