ENVIRONMENTAL GEOSCIENCES

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Lecture-22

Properties of Common Silicate Minerals

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We are continuing the model four. In the model four, we have already discussed three lectures. Now, today we will discuss lecture four, which is based on the properties of common silicate minerals. In this lecture four, the important concepts will be covered like common rock forming minerals, introduction to silicate minerals, structure of silicate minerals, types of silicate minerals, major silicate families.

Example will be given in terms of olivine, quartz, mica, pyroxene, feldspar and amphibole minerals. Now we will start from the common rock forming minerals. Minerals are the fundamental units of rocks we have seen in the previous lectures which form the earth crust, making the rocks the storehouse of minerals. Based on their usefulness, minerals can be classified into two categories. The first is the economic minerals.

These minerals are valuable due to their industrial, commercial or economic significance. They include metals like gold, iron and copper as well as non-metals like gypsum and halite which are extensively mined and used in various industries. Next is the rock forming minerals. These minerals make up the bulk of rocks and are formed through typical mineral forming processes. Each major category of rocks contain distinct types of minerals which are characterized by their specific mineral assemblages.

Minerals are basic building blocks of rocks which collectively form the Earth's crust. Its different types are group-forming silicates, silicate minerals, non-family silicates, non-silicate minerals. First is the group-forming silicates, silicate minerals. The silicates are the most abundant and significant group of rock-forming minerals. They are classified into groups or families based on their physical, chemical, and optical similarities which arise from their atomic structures.

Second is the non-family silicates. Some silicate minerals do not belong to the structural families mentioned above but are still important as rock-forming minerals. Examples include zircon, sphene, topaz, staurolite, beryl, cordierite, tourmaline, talc, serpentine, dumortierite. Of about 2000 known mineral species, about 50 are considered rock-forming minerals with silicates being the most abundant. Non-silicate minerals are less abundant and are crucial in certain rock formations and geological processes.

The third one is the non-silicate minerals. These are oxides, hydroxides, carbonates, sulphides, sulphates, etc. Among the non-silicates, the oxides are the most important since many of them occur as minor accessories of rocks. Minerals like quartz, feldspar, mica, amphiboles, pyroxenes and olivines are the common constituents of igneous rocks. In case of metamorphic rocks, minerals like kyanite, sillimanite, staurolite, andalusite, chlorite, garnet, etc. are commonly found.

As the sedimentary rocks are formed due to the consolidation of the weathering products of the pre-existing rocks, they may contain any of mineral or assemblages of minerals. Now about the silicate minerals. About 25% of the known minerals and nearly 40% of the common ones are the silicate minerals. The silicates make up 90% of the Earth's crust. Of every 100 atoms in the crust of the Earth, more than 46 are oxygen, over 27 are silicon, and 7 to 8 are aluminium.

The crust has been pictured as a boxwork of oxygen ions bound together by the small highly charged silicon and aluminum ions. The interstices of this more or less continuous silicon-oxygen-aluminum network are occupied by ions of magnesium, iron, calcium, sodium, and potassium. The predominance of alumino silicates and silicates reflects the abundance of oxygen-silicon-aluminum. Now we will discuss the structure of silicates.

Silicon oxygen tetrahedral, silicates are composed of silicon atoms in 4-fold coordination with oxygen forming strong stable tetrahedral units with nearly constant dimensions and shape. Right side you can see the picture also of the silicon oxygen tetrahedral. Bonding and energy distribution if you will see in the silicate structure Each silicon-oxygen bond shares electrons with bonding energy evenly distributed among 4 oxygen atoms, enabling oxygen to bond with multiple silicon atoms and link tetrahedral. Polymerization and connectivity properties there, oxygen sharing between tetrahedral leads to polymerization, forming diverse structural configurations such as chains, sheets, and 3-D frameworks.

Higher formation temperatures result in lower polymerization levels. Crystallization sequence, Silicate minerals in igneous rocks crystallize sequentially like olivine, then pyroxene, then amphibole, then mica, with increasing polymerization of the tetrahedral units. Structural diversity is remaining in the silicate structure. That is, based on the degree of oxygen sharing, silicate structure vary from isolated tetrahedral to interconnected frameworks, influencing the properties and stability of silicate minerals. Now, Types of Silicate Minerals, The silicate structures are categorized into 6 types based on the degree of tetrahedral linking.

The first type is the Nasosilicates, which means independent tetrahedra, Sorosilicates, double tetrahedra, Cyclosilicates ring structures, Inosilicates chain structure, Tectosilicates framework structures. First is the Nasosilicates. Nasosilicate consists of isolated SiO_4 tetrahedral bonded by ionic bonds through interstitial cations. The SiO_4 group has a net charge of -4, requiring cations to balance the charge. Interstitial cations, such as magnesium and olivine, provide positive charges to neutralize the structure.

The structure of neso-silicate depends on the size and charge of the interstitial cations. Common neso-silicate minerals include olivine, garnet, zircon, sillimanite, kyanite, and topaz, etc. soro-silicates, the soro-silicates are characterized by isolated double tetrahedral groups formed by two SiO_4 tetrahedra sharing a single apical oxygen. The resulting ratio of silicon to oxygen is 2:7. They have a net charge of -6.

As the charge is -6, three divalent ions are needed to balance it. Important minerals are idocrase minerals of epidote group, melilite, lawsonite, hemimorphite, etc. Third type is the cyclosilicates. When each SiO_4 tetrahedral shares two of its oxygen with the neighboring tetrahedra, they may be linked into rings. They have a ratio of Si to O is 1:3.

Three possible closed cyclic configuration of this kind may exist. First is each of three tetrahedra shares an oxygen atom. Second is each of the four tetrahedra shares an oxygen atom. Third is each of the six tetrahedra shares an oxygen atom. The simplest is the Si_3O_9 ring represented among minerals only by the rare titanosilicate, benitoite (hexagonal).

The hexagonal rings are arranged in planar sheets parallel to (0001) in beryl. These sheets are so firmly bonded by the small beryllium and aluminium ions with their high surface density of charge and high polarizing power that only poor cleavage results. In tourmaline, however, the rings are polar. This polarity of the fundamental structural unit leads to the well-known polar character of the tourmaline crystal. The cyclosilicates are also known as ring structures.

The fourth one is the chain structure. These are also known as ionosilicates. Here tetrahedra are joined together to form chains of indefinite extent. There are two principal modifications of this structure, yielding somewhat different composition. Single chains, in which Si:O ratio is 1:3, and characterized by the minerals pyroxenes and pyroxenoids.

Double chains, where alternate tetrahedral in two parallel single chains are cross-linked, and the Si:O ratio is 4:11, characterized by the minerals amphiboles. Now the single chain structure. The chain consists of a large number of linked SiO_4 groups each sharing two oxygen atoms. The chain is balanced by the valencies of their cations. The chain runs parallel to the c-axis of the mineral and are bonded together by the calcium and magnesium ions which lie between them.

Double chain, these are also known as band structures. Here the alternate tetrahedra are arranged in two parallel ways and these chains are indefinite in extension and elongated usually in e-crystallographic directions and are bounded by metallic ions. Seed structure is also known as phyllosilicates. It is formed when the SiO_4 tetrahedra are linked by three of their corners and extend indefinitely in a two-dimensional network or seed which has a silicon and oxygen ratio of 4:10. This is the fundamental unit in all micas and clay structures.

The seeds form a planar network responsible for the principal characteristics of the minerals of this type, their pronounced pseudo-hexagonal habit, and perfect basal cleavage parallel to the plane of the seed. Most of the minerals of this class are hydroxyl bearing. Most of the members have platy or flaky habit and one prominent cleavage. They are generally soft of relative low specific gravity and may show flexibility or even plasticity of the cleavage lamellae. Depending on the mode of coordination of the hydroxyl group, there are two types of configuration.

One is called the di-octahedral seed and the other is called the tri-octahedral seed. Next is the tectosilicates. It is also known as framework structures. When each of the four oxygen atoms of each tetrahedron is shared by another tetrahedron, it results in the formation of tectosilicates. Here every SiO_4 tetrahedra shares all its corners with other tetrahedra giving a three-dimensional network in which Si:O ratio remains1:2.

Here the bond is stable and strong and the framework is electrically neutral and does not contain other structural unit. There are eight different ways in which the linked tetrahedra may share oxygen and at the same time build a continuous electrically neutral three-dimensional network. Minerals of the feldspar, feldspathoid, zeolite, quartz group of minerals show this type of silicate structures. Now major silicate families. Silicate minerals can also be grouped into families based on their structural similarities like olivine group.

We have seen the neso-silicates. That example is olivine. Then silica group, example is quartz. Feldspathoid group, framework silicates with lower silica content. Example is nepheline.

Pyroxene group, single-chain inosilicates. Example is augite. amphibole group, double chain ionosilicates, example is hornblende, mica group, seed silicates, example is muscovite biotite. Now, one by one we will discuss the different minerals, that is, olivine, this is a group of rock forming silicates, the minerals are olive green or brown in color, all these minerals crystallize in orthorhombic system. Atomic structure, these are nesosilicates, which essentially consist of a series of isolated SiO_4 tetrahedral, which are linked by means of metal cations.

Chemical composition, the group includes minerals, which may be represented by the formula R_2SiO_4, where R is Mg or Fe. The member of this group belongs to a continuous series of solid solutions between forsterite, Mg_2SiO_4, and fayalite, Fe_2SiO_4. Common olivine is intermediate between them with excess Mg and formula represented by $MgFe_2SiO_4$. Physical properties of this olivine is crystal system is orthorhombic, color is olive green, streak, colorless, lustre, vitreous lustre. Twinning, orthoclase, simple twinning, microcline, cross-hatched twinning, plagioclase, polysynthetic or lamellar twinning.

Extinction angle remains 15° to 30°. Michael-Levy method is used to determine these varieties. Sanidine, a high-temperature potassium feldspar, generally present in the volcanic rocks. Adularia, low-temperature orthoclase, moonstone, opalescent, adularia or albite, aventurine, gem variety of albite, amazon stone, bright green microcline. Now, next mineral is the quartz.

Quartz is a member of the silica group of minerals which have tekto-silicate structure and the chemical composition in SiO_2. The atomic structure as is found in the crystalline varieties does not apply to the silica glass i.e. lechatelierite. The crystalline variety occurs in these forms Quartz, Tridymite, Cristobalite, Coesite, Stishovite, Keatite. There are three crystalline polymorphs of silica, while quartz is a low-temperature polymorph formed below 870°C, trydimite is formed between eight 870°C to 1470°C, and cristobalite is formed at a temperature above 1470°C. The non-crystalline variety of silica occurs as lechatelierite, opal, and chalcedony.

Now physical characteristics. The form Quartz is a member of hexagonal system. Tridymite belongs to orthorhombic system and Cristobalite belongs to isometric system. Streak, white, lusture remains vitreous to sub-vitreous. Hardness remains 7.

Cleavage, no cleavage. It is an important characteristic of Quartz. Specific gravity is low, that is 2.65. Electric property, Quartz is piezo as well as pyro-electric. Quartz is colorless, but the non-crystalline varieties are colored.

Optical properties, first is non-pleochroic colorless. Refractive index low positive, birefringence 0.009, polarization color first order gray or yellow, extinction, wavy, glassy varieties are isotropic. Polymorphs of quartz, besides tridymite, cristobalite, coesite, stishovite, there are two modifications of quartz which are as: Alpha-quartz, low temperature quartz formed below 573°C. Beta quartz, high temperature quartz formed between 573 and 870°C, generally found in volcanic rocks at Phenocrysts.

Variety of quartz based on color are rock crystal, clear and transparent, amethyst, violet, citrin, pale yellow, morion, black quartz. Next is the Mica, mica constitute an important group of rock-forming minerals as ferromagnesian silicates. Next in abundance to the amphiboles and pyroxenes, they form a link between felspar and felspathoids, the light-colored constituents of the igneous rocks and the dark-colored minerals. Atomic structure, these are phyllosilicate which possess the Si_4O_{10} sheet structure. Chemical composition, these are hydrated alumino silicates of potassium, sodium or lithium with magnesium or Fe in darker members.

Classification, some classification of mica groups are: Dioctahedral group, example is muscovite. Trioctahedral group, example is phlogopite and biotite. According to the other classification, the composition of micas are taken into account and as they are of muscovite group. These are alumino silicates of alkali metals without Mg or Fe and are colorless. Muscovite group includes members like muscovite, paragonite, lepidolite.

Biotite group, in addition to the alkali metals, they also contain Mg, Fe and are dark in color. They contain minerals like biotite, phlogopite, zinnwaldite. Physical properties of the mica is they crystallize in monoclinic system but the forms are pseudo-hexagonal. Muscovite mineral is colorless, biotite, dark colored, lusture, pearly, splendant, cleavage, perfect basal cleavage, hardness 2 to 3, specific gravity low, twinning rarely seen. Special characteristics, they possess unique combination of properties of elasticity, toughness, flexibility, transparency, resistance to heat and property of splitting into thin films.

Optical properties, muscovites colorless to pale green, biotites dark brown, colored varieties are pleochroic. Refractive index is high, bi-refringence strong, extinction parallel. Varieties of the mica is, sericite, secondary mica, muscovite, fuschsite, chromium-bearing mica, Gilbertite, fluoride-rich muscovite, roscoelite, vanadium-bearing muscovite, damourite, secondary muscovite by hydrothermal alteration of feldspar, lapidomelane, an iron-rich biotite, vermiculites, altered biotite. Mineral is Pyroxene.

Pyroxenes form an important group of rock-forming minerals. They have a general formula $X_2Si_2O_6$ in which X is usually Mg, Fe, Al, Ca or Na. Some aluminum may partly replace silicon. The common pyroxenes are calcium, magnesium and Fe silicates. They are characterized by two cleavages which intersect almost at right angles.

Pyroxenes are broadly divided into two groups, orthopyroxenes and clinopyroxenes. Orthopyroxenes These pyroxenes crystallize in orthorhombic system and contain very little calcium. The enstatite and hypersthine belong to this group. Clinopyroxenes, these pyroxenes crystallize in the monoclinic system and contain calcium or sodium, aluminum, iron or lithium.

Diopside, hedenbergite and augite are the members of this group. Crystal system, orthorhombic, cleavage, good. Specific gravity 3.2 to 3.6, lusture vitreous, color grayish, yellowish or greenish, habit massive or lamellar, occurrence magnesium-rich orthopyroxenes are a common constituents of peridotites, gabbros, norites, and basalts. They are found associated with augite, olivine, and plagioclase. Orthopyroxenes alter to serpentinous products or fibrous amphibole.

Now next is the feldspar. The feldspar are the most abundant of all minerals. They fall into two main series, potassium-sodium feldspars called as the alkali feldspar and calcium-sodium feldspar called as the plagioclase feldspar. Cleavage remains good in two directions at an angle of 90° approximately. Specific gravity 2.55 to 2.63.

Lusture vitreous. Color white, gray, pink or green. Habit generally tabular. Use in the manufacture of porcelain. Now potassium feldspars.

The important member of this group are orthoclase and microcline. Each of these has the composition $KAlSi_3O_8$. But orthoclase crystallizes in the orthorhombic system and microcline in the triclinic system. Potash feldspars alter readily into the clay minerals, especially kaolinite. Plagioclase feldspar, the plagioclase feldspar form a complete solution series from pure albite to pure anorthite.

The plagioclase feldspar crystallize in the triclinic system and are distinguished from K-feldspar by the presence of repeated albite-twin striations visible on cleavage surfaces. The properties of the various members of the plagioclase series vary in the uniform manner with the change in the chemical composition. The plagioclase feldspar usually alter to clay minerals or sericite, fine-grained, micaceous material. Occurrence, the alkali feldspar, which include orthoclase, microcline, and albite, have a similar occurrence. They are commonly found in igneous rocks, such as granites, pegmatites, syenites, rhyolites, and trachytes.

Oligoclase is commonly found in granodiorites and monozonites. Labradorite is commonly constituent of gabbros, basalts, and anorthosites. Next is the amphibole, the amphibole contains hydroxyl groups in the structure the angle between two sets of cleavage is one twenty four degree and is characteristic of amphiboles. Tremolite hydrous silicate of calcium magnesium. Actinolite hydrous silicate of calcium magnesium and iron and hornblende hydrous silicate of sodium, calcium, iron and aluminium are the important members of the amphibole group. Crystals system remains monoclinic, cleavage perfect, specific gravity 3.0 to 3.33, lusture vitreous or silky, color white or gray in tremolite and green in actinolite, habit tremolite is often bladed and sometimes in silky fibrous, actinolite is often in radiating aggregate and fibrous. Occurrence, these minerals are commonly found in metamorphic rocks.

Tremolite occurs in metamorphosed, dolomitic limestones and actinolite is a characteristic mineral of greenish facies of metamorphism. The fibrous varieties are used as asbestos. So summary of the lecture is, first of all we have discussed the common rock forming minerals. Common rock forming minerals essential for earth crust. These include silicates, oxides, sulfates, and many more.

Then the abundant minerals such as quartz, feldspar, mica, pyroxene, amphibole, these play a significant role in rock formation and earth's surface processes. Their unique properties determine their importance in geology and their applications in various industries. Then we have discussed the silicate minerals. Silicates are the dominant mineral group in Earth's crust, making up 90% of its composition. They are composed of silicon and oxygen with diverse structures built around the silicate tetrahedron.

These minerals are found in a wide range of rocks, from igneous to sedimentary. Then we have discussed the structure of silicate minerals. The structure of silicate minerals is based on tetrahedra which are linked in various ways to form isolated units, chains, sheets or frameworks. These linkages influence physical properties such as hardness and cleavage. Cations like magnesium and iron bond with the tetrahedron to stabilize the mineral structures. Then we have discussed the type of silicate minerals. Silicate minerals are classified based on the arrangement of their tetrahedron. In isolated tetrahedra, no oxygen atom are shared as seen in olivine.

Chain silicates include single or double chains such as pyroxene and amphibole, as the example. Sheet silicates like mica have tetrahedron arranged in layers. Framework silicates such as quartz and feldspar form a three-dimensional network by sharing all oxygen atoms. Then we have discussed the major silicate families. The major silicate families include olivine characterized by isolated tetrahedra.

found in mafic rocks, pyroxene with single chains commonly present in volcanic rocks, amphibole featuring double chains with hydroxyl groups, and feldspar, a framework silicate that is abundant in Earth's crust. Thank you very much to all.