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Lecture-08
Inorganic Soil Components (Contd.)

Welcome friends to this third lecture of module 2, that is inorganic soil components. And in previous 2 lectures we have discussed about different types of crystallographic structure, as well as the Pauling's rule, and 5 different Pauling's rule and how they impact the stability of different crystallographic structures. And we have discussed about the coordination number. And also we have briefly discussed about the classification of the soil silicates.

We have discussed about the difference between primary minerals and secondary minerals. For now in this lecture we will be discussing in details about the primary minerals and also the secondary different types of secondary minerals. So, when we talk about the primary minerals the first mineral which come our mind is basically the feldspars.

Now feldspars are anhydrous 3-dimensional aluminosilicates of linked silica tetrahedra and aluminum, you know, silicon tetrahedra and aluminium tetrahedra that contains the cavities that can hold the calcium sodium you know, potassium, and barium to maintain the electronic neutrality. Remember that these feldspars are the most common primary minerals in the earth's crust. And they are basically found mainly in sand and silt fractions. And they are basically non reactive in nature and the potassium bearing feldspars of the major source of potassium in soils.

So, if you see the classification of the feldspars there are 2 major types, one is called the alkali feldspar, and another is plagioclases feldspar. Now alkali feldspar you know, their composition ranges from these potassium feldspar, sodium feldspar and plagioclase feldspar their composition ranges from sodium feldspar to calcium feldspar. So, if you see some examples, obviously potassium feldspar.

The examples are either orthoclase or microcline. These are 2 major examples of potassium orthoclase potassium feldspar, whereas sodium feldspar example is albite. So, remember again the feldspar is the most common and most widely abundant you know abundant mineral in the earth's crust.

The second most abundant mineral in the earth crust is quartz. So, quartz is basically hard crystalline mineral, which is composed of silicon and an oxygen atom, and the atoms are basically linked in a continuous framework of SiO_4 silicon oxygen tetrahedra with each oxygen being shared between the 2 tetrahedra, giving an overall chemical formula of a SiO_2 , we have discussed this tectosilicate structure in our, in our last lecture when we have discussed about the classification of soil silicates.

Now this quartz you know quartz basically an example of this tectosilicates which is basically a 3-dimensional and stable structure. So, quartz is also the second you know as I have already tell you the second most abundant mineral in that continental crust behind the feldspar. This is an example of the quartz mineral.

Now, there are some other accessory minerals also, which are found in heavy specific gravity fractions. Some examples are olivine, pyroxene, amphiboles, you can see that pyroxene, amphiboles are ferromagnesian minerals that will basically contain iron and magnesium with single and double chain structure respectively of linked silica tetrahedra. So, basically, the present the inosilicates which basically shows the single or double chain of tetrahedra.

Now olivine as you know it is a you know, it is basically nesosilicates. They are basically green nesosilicates within which the magnesium and iron since they are ferromagnesian minerals obviously they will contain iron and magnesium are octahedrally coordinated by oxygen atom. And remember one important fact that these olivines that the ferromagnesian minerals are the major source of magnesium and iron in the soils.

And remember these magnesium added are the one of you know, the major you know micronutrient for plant growth. So, some examples are given here like a tremolite is an amphibole, which has this formula. And it is also contained the calcium and magnesium. Pyroxene examples are given like enstatite, diopside and rhodonite, the formulas are given here, olivine formula as you can see it is a ferromagnesian minerals to iron and magnesium are there. And, you know, this is the formula of olivine.

So, let us see some pictures of these minimal. This is an example of tremolite as you can see this is diopside and olivine all these are primary minerals. So, all these primary minerals basically forms the skeleton of the soil, that means the sand and silt fraction.

And whenever we go from the primary minerals to the secondary soil minerals, the, the chemical nature gets changed. Remember this primary minerals maintain their chemical composition, irrespective of their size. They maintain their original chemical composition from the rocks from which they developed. However, when the chemical composition changes from one mineral to another mineral the secondary soil minerals basically appears.

The another name of secondary soil minerals are secondary clay minerals. We have already discussed about the phyllosilicates, which are the major, you know clue you know, one of the major class of soil silicates and also known as the soil clay minerals. So, apart from Phyllosilicates the secondary soil minerals also consist of interstratified clay minerals, oxides, hydroxide, oxyhydroxides and also carbonates and sulfate minerals. So, as you can see you you will see here the structure of the phyllosilicates with the basic structural formula of Si_2O_5 and now we will see different types of phyllosilicates.

So, phyllosilicates as you know, the secondary clay minerals or simply the clay minerals are the best example of phyllosilicates which occur, primarily in the clay sized fractions, why they are called clay minerals, because they are occurring in the clay sized fractions. And they play a major role in various soil chemical reactions. Clay minerals remember they are the assemblages of tetrahedral and octahedral sheets basically they are combination of different tetrahedral sheet and octahedral sheet in different stacking fashion or different defining stacking arrangement.

And remember that the clay minerals are, you know, the tetrahedral are bonded point to point which I have already discussed and whereas the octahedral are bonded from edge to edge. So, it is basically characterized by the typical layer or sheet like structure. Remember the phylo means phylum or leaf like structure. So the name came from this leaf like shape. So, this is the clay minerals as you can see here this is a structural unit of the phyllosilicates.

So, let us start with discussion with the first one building block, the first building block of soil that is silica tetrahedral. Now silica tetrahedral, you can see the aluminium, you know the silicon cation is surrounded by 4 oxygen, anions and internal angle is 109 degrees. So, when these silica individual silica tetrahedra share their oxygen between 2 surround 2 adjacent tetrahedral they form the shape you know sheet like structure.

And we call this a tetrahedron sheet. Now as you can see it is an individual tetrahedral sheet, and this is in sorry this is the individual silicate tetrahedral 3-dimensional figure. And this is basically the tetrahedral sheet which is generated by sharing their sharing their points. So, let us see how they basically joined together. So, these are the individual silica tetrahedra silica tetrahedra.

So, when this individual silica tetrahedron comes together and share their oxygen the corner oxygen. Then they basically form this sheet like structure. And it is known as a tetrahedral sheet. This is the tetrahedral sheet. Similar in case of aluminium octahedron you know that aluminium octahedron is basically composed of aluminium at the center surrounded by 4 surrounding by 6 hydroxyl anions forming a pedal like shape. So, when these octahedral share their edges, they form this octahedral sheet.

So, let us see this is a signal aluminum or magnesium octahedron. And when they share their edges they will form. This structure called octahedral sheet. Now this tetrahedron sheet and octahedral sheet are the basic building blocks of any clay mineral structure, because all the clay minerals are basically, most of the crystalline clay minerals are basically, developed by this specific stacking arrangement of the tetrahedral sheets and octahedral sheet in a single clay crystal.

So, if we see the overview of a clay mineral structure we will have this picture. So, let us discuss how these different sheets. That means octahedral sheets and tetrahedral sheets joined together to form a total clay mineral lattice. So, as you can see that a tetrahedral sheet. This

is basically a 2 is to 1 type of clay mineral. Why is call 2 is to 1 type of clay mineral well basically because you seeing that there are, there is a 1 octahedral sheet, which is sandwiched between 2 tetrahedral sheet.

So, that that is why it is known as the 2 is to 1 type of structure, now the 2 is to 1 type of structure as you can see how they are joined together. So, this is basically a tetrahedral sheet. If we consider the tetrahedral sheet inverted, then obviously the basal cations will be a basal anions will be oxygen plane. So, the basal plane will be basically oxygen plane followed by these silicon plane, which is the major cation.

And epical oxygen for each of these, you know, tetrahedra will be basically shared with this adjacent octahedral sheet, and these adjacent octahedral sheet is basically composed of this aluminum and magnesium plane in the middle. And in this shared layer it will be basically either oxygen or hydroxyl. So, as you can see this is a hydroxyl and oxygen will be shared between these tetrahedral sheet as well as this octahedral sheet.

The similar thing will be repeated here also. So, this is how we will get it total 2 is to 1 type of structure. So, basically one thing is clear that to join 2 differentiates, we need to know they need to share their epical oxygen, specifically the epical oxygen of the tetrahedral sheet. And that is why they join. So, obviously, based on the structure, they will get an O plane followed by silicon plane.

And then they will get an O that means oxygen as well as hydroxyl plane, followed by aluminium and magnesium plane, then again oxygen hydroxyl plane. Then again silica plane, and then followed by an oxygen plane. So, as you can see, this basically defines how these 2 is to 1 fracture is composed of. Now, in the clay crystal these individual layer is repeated several times, thousands and thousand times.

So, these individual layer will be stacked over another individual layer, and ultimately they will create this clay crystal. And the space between these individual layers are known is basically known as the inter layer space. And these inter layer space is the area where they absorb for basically adsorb different types of cations and water. So, this is the basic structure of a clay mineral 2 is to 1 type of clay mineral.

Now when we call it as a 1 is to 1 type, obviously, when there will be 1 tetrahedral sheet and 1 octahedral sheet it will be called a 1 is to 1 type of clay mineral. However, since here the octahedral sheet is sandwich within 2 tetrahedral sheet it is known as the 2 is to 1 type of ah clay mineral.

So, phyllosilicates nomenclature as I have just told you that phyllosilicates nomenclature based on the number of tetrahedral sheet and octahedral sheet joined together. As you can see here the 1 is to 1 layer is basically composed of 1 tetrahedral sheet and 1 octahedral sheet, whereas 2 is to 1 layer is basically composed of 1 octahedral sheet sandwiched between 2 tetrahedron sheet.

So, what are the basics of distinguishing crystalline silicate clays, there is several you know criteria based on what we can distinguish different types of crystalline silica clays based on the number and combination of structural units, that means tetrahedral, octahedral sheets planes combines, sheets combine, layers and crystal which you have seen just and then there are 2 different general categories like 1 is to 1.

And 2 is to 1, there is an intermediate category, also known as it is known as the 2 is to 1 is to 1 or 2 is to 2 example is chlorite we will see it in in our lecture, and also based on the number of cations in the octahedral sheets so either it is a tri octahedral or di octahedral depending on size the location of layer search, depending on the type of bonding between the layers, because you know that ionic.

There are different types of bonding like the ionic bonding. Then hydrogen bonding Van der waals bonding. So, based on these different types of bonding and their strength also we can distinguish different types of silicate clays, and also based on the absence or presence of cationic interlayers. We can also distinguish different types of clay minerals is like fine grained mica.

So, let us first discuss the types of clay minerals, obviously as you know that there are 2 main groups of crystalline clays 1 is to 1 type of clay. And, which is basically composed of 1 octahedral and 1 tetrahedral and basically this is the, you know, the structural formula where these 4 denotes basically the tetrahedral coordination and 6 denotes the 6 fold coordination for this aluminum or octahedral coordination for aluminium.

And the 2 is to 1 type of clay where 1 octahedral sheet you know, 1 octahedral sandwich is you know 1 octahedral between 2 tetrahedral sheet it will get a formula like this, where the silica will show the tetrahedral coordination aluminum will show the octahedral coordination. And this is basically a shorthand representation of this 1 is to 1 and 2 is to 1 type of mineral.

So, one more thing comes into our mind while we discuss about the structure of clay mineral that is di octahedral and tri octahedral, you will encountered this terms you know frequency in the coming slides while we discuss the different types of clay mineral structure di octahedral and tri octahedral, so what is the difference. Now, remember that clays can be divided into di and tri octahedral depending on the number of cations.

Number of cationic positions in the octahedral sheet that are occupied. For example, if aluminium is present in the octahedral only two third of the cation positions are filled. If we go to the next slide, it will be more clear. So, this is an example of a tri-octahedral structure, these are an example of a di-octahedral structure. Now you can see this is a tetrahedral sheet. This is another silica tetrahedral sheet.

And this is an octahedral sheet sandwich in between. So, the octahedral sheet has 3 octahedral positions, 1 2 3, here you can see 1 2 3. So, if all the octahedral positions are filled by cations then it is called the

tri octahedral structure. Example is phlogopite. And remember one thing that if there is a divalent cations present like magnesium, then it will give this di-octahedral structures.

And if 2 out of these 3 octahedral positions are filled, due to the presence of aluminium, that is Al^{3+} . Then we will see, this is a di-octahedral structure. So, this is called tri-octahedral structure. This is a di-octahedral structure. Example is muscovite. So, this is a different little tri-octahedral and di-octahedral structure.

So, for every 6 hydroxyl ions 2 aluminium ion satisfied that anionic charge as aluminum 3 is trivalent which you have just seen here. So, that is why it is called di-octahedral. And if magnesium is present in the octahedral sheet 3 of them would satisfy the anion, anionic charge of 6 hydroxyl ions since it is called the tri-octahedral which we just which we just have seen.

So, this is the difference between di-octahedral structure and tri-octahedral structure. Another important feature we want to want to discuss that is called the isomorphous substitution. Isomorphous substitution means a substitution of 1 atom by another atom of similar size in a crystal lattice without disrupting the crystal structure. So, let us first, let us consider the example that a cation with the coordination number of 4 can substitute silica in tetrahedral and a cation of coordination number of 6 can substitute aluminium and octahedral sheet, without disrupting the crystal structure.

And the first and foremost criteria for doing that is they have to be almost similar size, and that is why there is this phenomena is known as isomorphous, iso means similar, morphous means similar in morphology or similar in size. So, a silica can be substituted by another cation in a tetrahedral coordination, which can show a coordination number of 4, for example, aluminium.

So aluminium can replace silica in a tetrahedron in a tetrahedral coordination and still maintain its structural integrity because aluminium has similar almost similar size then you know almost similar size as of silica. Similarly in octahedral layers aluminium get replaced by either Fe^{2+} or Mg^{2+} and because they have the similar coordination number of 6. So, these type of substitution is known as isomorphous substitution.

Now what is the implication of this isomorphous substitution. Now remember when we are substituting iron cation with another cation of different valency. That means, in case of tetrahedral sheet when we are substituting a silica cation, which has 4 valency with aluminium cation with the 3 valency, then obviously, there will be a charge imbalance that means we are reducing the positive charge that means we are increasing.

In other way, we are increasing the negative charge development. Okay, so this charge imbalance basically develops due to this isomorphous substitution and this charge is also known as a permanent charge because this is the feature of its crystalline structures. It is not variable, so that is why this charge, which has developed due to this structural you

know arrangement or isomorphous substitution is known as a permanent charge.

So, when the aluminium replaces silica tetrahedral sheet or tetrahedral coordination a charge of negative one is created in an 1 is 1 type of obviously silica is 4 valence aluminium is 3 valence when they are replacing each other. There will be 1 negative charge generation.

So, this thing will be more clear here as you can see this is a tri-octahedral structure where these. For example, let us considered this a magnesium with the 2 valency so 3 magnesium will satisfy all the 6 you know anion so producing a net negative charge. So, all 6 anions are basically as you can see it is 3, negative here, 2 negative here. So, 6 negative, and 6 positive from 3 cations.

So, we are getting a net charge of 0 okay. In case of di-octahedral obviously as you know 3 out of 2 positions are filled. Sorry 2 out of 3 positions are filled by aluminum so as you can see here $3+ 3+$, and here $6+$ and $3-$, so 2 aluminum will be required to satisfy this charge to get a net charge of 0. So, when these isomorphous substitution occurs in this octahedral sheet. Suppose we are replacing 1 aluminium iron with 1 magnesium, with a valency of $2+$ will get a di-octahedral structure with isomorphous substitution.

And when we are getting a di-octahedral structure with isomorphous substitution obviously, here total positive charges $+ 5$ and total negative charges $- 6$ ultimately we are getting in excess of negative charge. Why we are getting the substitution base, because you can see here, aluminum and iron and magnesium has similar almost similar radius. So, this is called the isomorphous or isomorphous substitution.

And isomorphous substitution is the reason behind producing the negative charge in the clay mineral, and that is why clay mineral is very reactive. The sand and silt are not reactive because they are electro neutral. However, due to the presence of this type of negative charge on the surface the clay minerals are highly reactive.

So, let us start with discussing different types of clay minerals. Let us start with the 1 is to 1 type of clay which is called the Kaolin-serpentine group. So, basically it is called 1 is to 1 type of clay because it is composed of 1 tetrahedral sheet, and 1 octahedral sheet. So, 1 tetrahedral sheet, 1 octahedral sheet linked together to form these 1 is to 1 type of layer by sharing their apical oxygen atom.

And it can be divided into di-octahedral Kaolin as well as tri-octahedral Kaolin. As you can see here the examples are di-octahedral Kaolin or Kaolinite, dickite, nactite, halloysite. And also we can see some tri-octahedral Kaolin, and their composition their composition that is half cell chemical formula unit are also given here.

So, this is basically the kaolinite structure. One silicate tetrahedral sheet, and 1 aluminum octahedral sheet. So, 1 silica tetrahedral sheet and 1 aluminum octahedral sheet are basically joined together by sharing a apical oxygen. Here you can see, sharing the apical oxygen of the tetrahedral layer. And then, it is falling this layer structure of 1 is

to 1 layer structures. The one thing is very clear from this structure that these 2 adjacent layers.

So, this basal layer from these from this. So, the basal plane of atoms is basically representing hydroxyl here. And the next layer of atoms in this next layer adjustment layer is basically the oxygen atom. So, you can see hydroxyl ionic layer is basically, you know, coexisting with the oxygen layer, and as a result of these difference in the electronegativity, there will be formation of hydrogen bonding.

As a result of this hydrogen bonding the interlayer space between kaolinite is very limited. And that basically explains why kaolinite is you know it is nutrient poor we will discuss that later. But one thing is clear from this structure that 1 tetrahedral layer share their apical oxygen with the octahedral layer producing a 1 is to 1 layer structure and when you compare when you when you see the 2 adjacent 1 is to 1 layer will see the coexistence of close existence of 1 hydroxyl atomic layer with 1 oxygen atomic layer producing the hydrogen bond.

So, as a result interlayer space is basically collapsed. And when their interlayer space is collapse, there is no chance of getting other ions in the interlayer space. And so the kaolinite is most common in 1 is 2 you know it is one of the you know the kaolinite is the most common 1 is to 1 dioctahedral kaolin, and it is basically synthesis under equal concentration of aluminium and silica you know that it has got low little or no isomorphous substitution. So, there is no negative charge the excess negative charge development here.

Because there is no isomorphous substitution in case of kaolinite. As a result of that, there is no shrinking and swelling properties in kaolinite, because of hydrogen bonding between the adjacent layers. And that is why these type of mineral kaolinite is nutrient poor, and the ideal full cell chemical formula is given here.

So, another important mineral is called halloysite, which is a 1 is to 1 di-octahedral kaolin. And this has the similar structural unit that as we have seen in case of kaolinite, however, only difference is, it has gotten interlayer water into you know inter layer water molecules. So, basically, there is a layer of water molecules in the interlayer space in between this 1 is to 1 layer.

So, drying, when we dry this water these mineral, basically, produce collapse and produce a you know tubular like structure a tube like structure because of rolling. As a result of dehydrox I mean, dehydration, of these water layer from this interlayer space, the hexagonal plate like structure will basically roll and produce this tubular like structure and this tube like structure is the most distinguishing feature of halloysite.

So guys, we have discussed about the prime different types of primary minerals, we have discussed about the, we have started discussing about the different types of secondary minerals. We have discussed you know how these 1 is to 1 layer and 2 is to 1 layer basically forms. And we

have started discussing about the individual clay mineral, we have completed kaolinite and halloysite.

And in the next lecture, we will start discussing about 2 is to 1 type of clay mineral, we will be discussing pyrophyllite, we will be discussing talc, we will be discussing illite, mica, vermiculite and 2 is 2 type of clay minerals and other types of clay minerals and other types of secondary minerals, we will be discussing. So, thank you for your attention and let us meet our next lecture, to discuss the rest of the clay minerals. Thank you very much.