**Soil Mechanics**
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**Lecture – 3**

In the previous lecture we have studied about definitions of volumetric ratios and weight volume ratios and their relationships based on two approaches, they are: specific volume approach and unit volume approach. So again in this lecture we will be trying to look into the soil aggregate basic relationships using unit volume approach.

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We will also try to solve the couple of problems and then I will introduce to the mineralogy of fine grained soil particles. If we review that we established different relationships among volumetric ratios and weight volume ratios and we have also defined in the previous lecture. We said that there are two approaches in the phase diagram method, one is the specific volume approach in which the volume of solids is set as 1 and the second one is unit volume approach where the total volume is set as 1.

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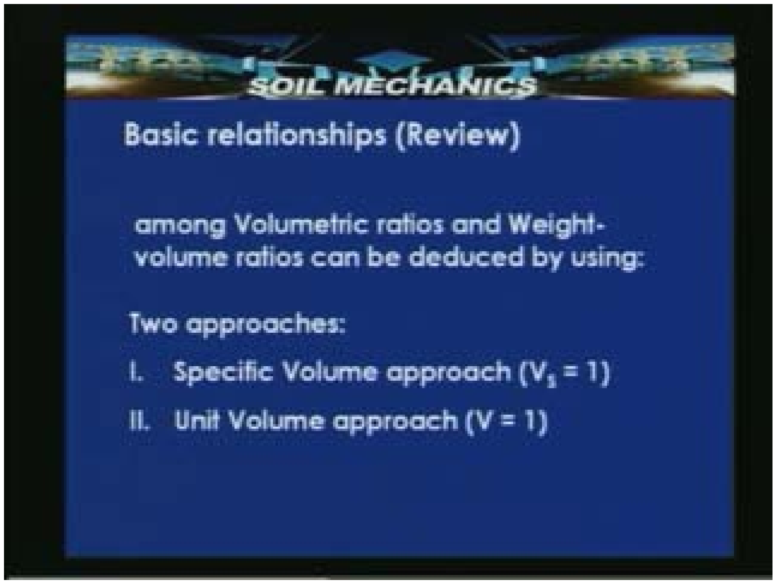


In this lecture let us look into the methodology of the unit volume approach. In the unit volume approach, the total volume v is set as 1 as the phase diagram method requires certain quantity of soil to be specified. So here the total volume is set as 1. Basically the Porosity n is used in place of void ratio here. This approach is used when no weights or volumes are given in the problem statement, so one can select depending upon the problem statement.

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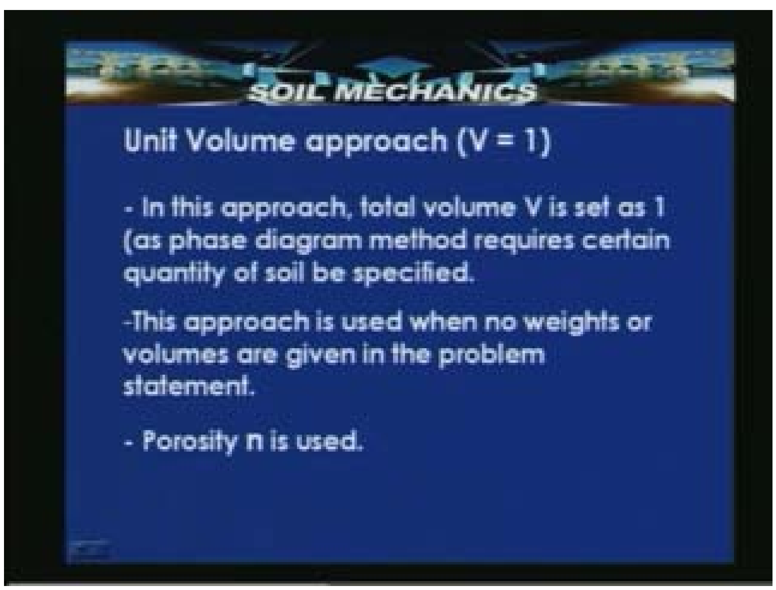


Now let us consider for the unit volume approach V is equal to 1 and for a partially saturated soil a 3-phase system where there are solids, water and air. On the right hand side you are seeing the weights and the left hand side you are seeing the volumes. When we said the total volume as 1, if you look into it these weight of solids is deduced as $G_s$ (1 minus n) into (gamma w) and weight of water is (weight of solids) into (water content), so w times $G_s$ (1 minus n) into (gamma w) and weight of air is assumed to be 0. If definition of volume of voids as n, we can say that the volume of voids is equal to n and the volume of solids is equal to (1 minus n). By knowing the weight of water we can say that the volume of water is equal to w $G_s$ (1 minus n).

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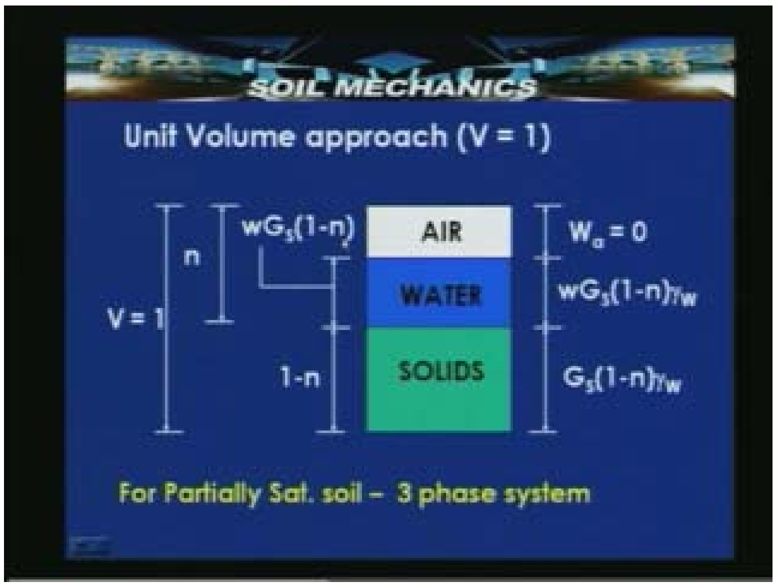


Let us look into the deduction of this particular figure for a partially saturated soil 3-phase system. We know n Porosity is equal to (volume of voids to total volume) with V is equal to 1 in unit volume approach, n is equal to $V_v$ now the volume of voids is set as n. Then void ratio is equal to (ratio of volume of voids to volume of solids), it is nothing but n by (1 minus n).

From the previous deduction gamma d is equal to $W_s$ by V is equal to (1 minus n) $G_s$ (gamma w) by taking V is equal to 1 and because of this gamma d appears like (1 minus n) $G_s$ (gamma w).Then gamma bulk is given as (total weight by volume) which is nothing but (weight of solids portion plus weight of water) by (volume is equal to 1). Percentage air voids can be deduced as $n_a$ is equal to (volume of air to total volume) which is nothing but (volume of voids minus volume of water) by V is equal to [n minus w $G_s$ (1 minus n)] This is for the case of the partially saturated soil, we have deduced expressions for gamma d, gamma bulk and percentage air voids by using unit volume approach.

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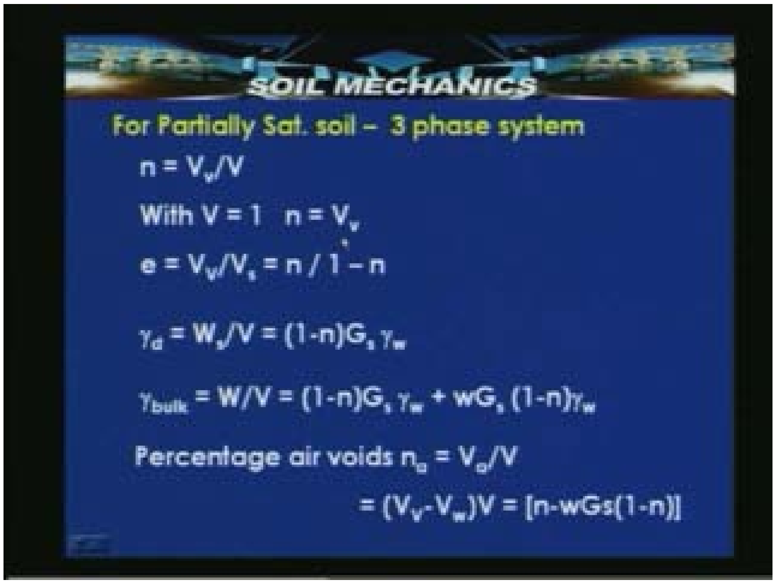


Let us look for a completely saturated soil where gamma sat is equal to $G_s$ (1 minus n) gamma w plus (n into gamma w). This is nothing but for a partially saturated soil, the volume of solids n is 1 minus n and n is the volume of water which is nothing but volume of voids. Then volume of voids times unit weight of water gives the weight of water and weight of solids is $G_s$ (1 minus n) gamma w. So from the definition of water content (weight of water by weight of solids) is given as (n gamma w) by $G_s$ (1 minus n) gamma w) which gives you the relation as w is equal to e by $G_s$ and e is equal to w $G_s$. Here e is a relation between water content, void ratio and specific gravity of solids; this is for degree of saturation is equal to 1. So in a simple way we can deduce relationships by using unit volume approach.

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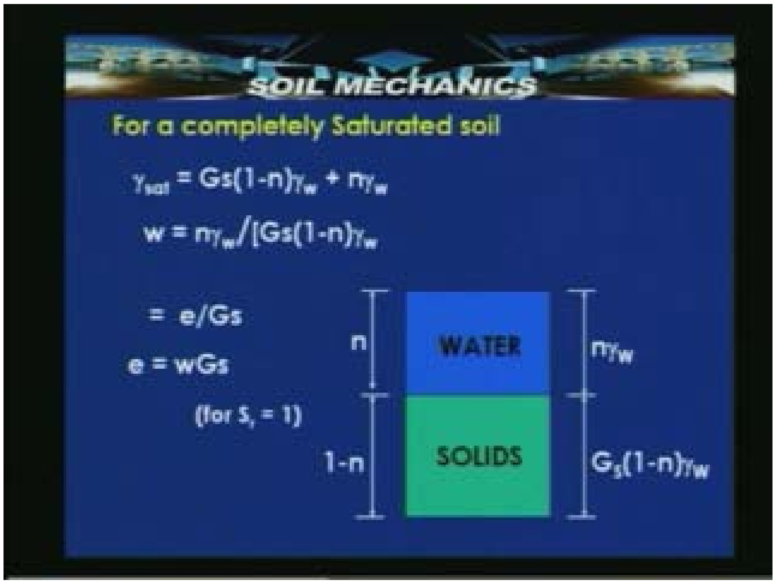


Now let us consider for a dry soil. In the case of dry soil, when total volume v is equal to 1 and volume of voids is equal to n, which is nothing but volume of air and volume of solids is equal to 1 minus n, with this we can say that $G_s$ (1 minus n) gamma w is again weight of solids. So dry unit weight of soil is (weight of solids by total volume) which is nothing but $G_s$ (1 minus n) gamma w. So in this way we can use this unit volume approach to establish the relationship between different volume ratios and weight volume ratios.

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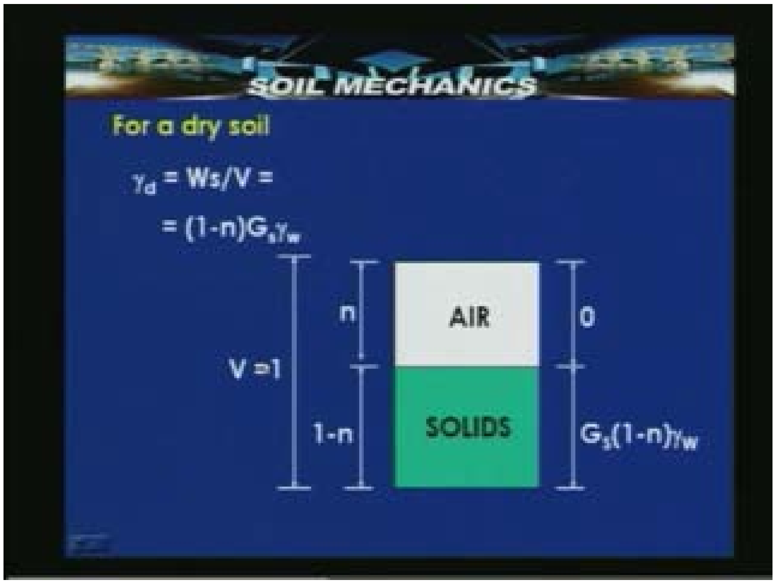

Now let us look into a problem by using this unit volume approach. As you can see, in this problem a saturated soil that means the soil with a 2 phase system in which all the voids are filled with water and has a unit weight of 18.85 kN by m cube. It means that gamma sat the saturated unit weight of a soil mass was given that is 18.85 kN by m cube and a water content of 32.5 percent. So we are required to estimate void ratio and specific gravity of solids.

Now let us solve this problem by using unit volume approach that is V is equal to 1 approach. By drawing the phase diagram for a partially saturated soil, this is nothing but voids which are filled with water so the weight of water is (n gamma w) and weight of solids is (1 minus n) $G_s$ gamma w that is $w_s$ is equal to ($G_s$ $V_s$ gamma w) where $V_s$ is equal to (1 minus n) gamma w is unit weight of water and (1 minus n) is the volume of the solids. By knowing from the definition of water content, water content is equal to (weight of water to the weight of solids) in this weight of water is (n gamma w) and weight of solids is (1 minus n) $G_s$ gamma w. By using this we can write w is equal to (n gamma w) by (1 minus n) $G_s$ gamma w. So, in this problem we knew water content is equal to 0.325 which is expressed as decimals. So 0.325 is equal to n by (1 minus n)$G_s$. So, by using water content is equal to 32.5 percent and substituting here in this equation we will get the relationship between porosity and specific gravity of the solids.

Now, we can write gamma sat that is the saturated unit weight of soil mass is equal to [(weight of water plus weight of solids) by the total volume] which is nothing but (n gamma w plus (1 minus n) $G_s$ gamma w. So by knowing gamma sat is equal to 18.85 kN by m cube, substituting gamma sat for 18.85 we can solve this by using the equation 1 and by substituting the second equation here we get the weight of solids.

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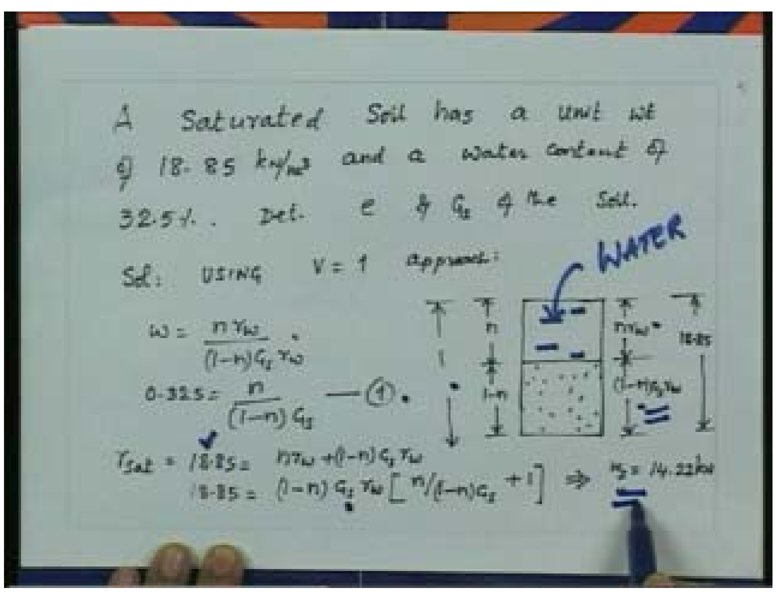


Now we can solve by using this unit volume approach the void ratio as 0.463 and volume of solids is equal to 1 minus 0.463 that is void ratio is equal to 0.86 where e is equal to n by (1 minus n) double dot. Saturated weight was given as 18.85 kN by m cube of soil that means here weight of water is equal to 4.63kNs from the water content. So weight of solids is equal to 14.22kN that's what we have deduced previously. So substituting the void ratio in the previous expression 1 that is w is equal to n by (1 minus n)$G_s$, we will get the specific gravity of the solids as 2.646. So what we did is that we try to use the phase block method in which we set total volume as 1 and we have used the given values in the problem and try to deduce the asked parameters like void ratio and specific gravity of the solids.

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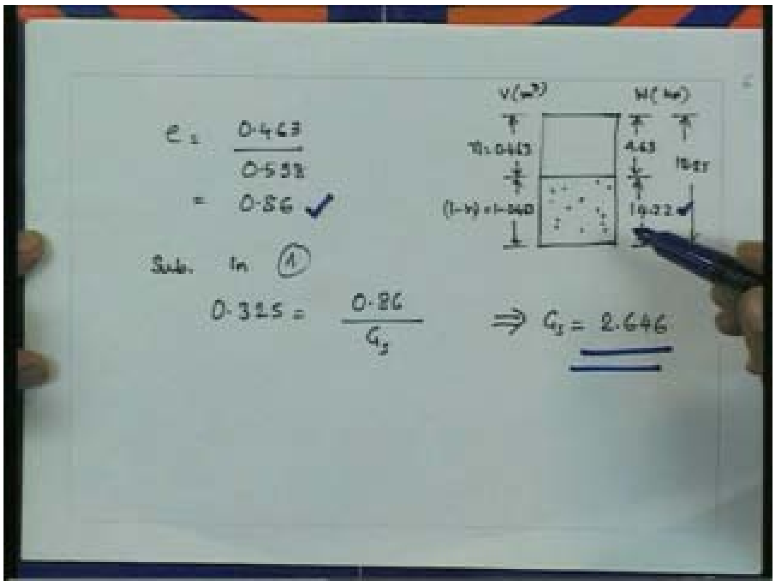


Now let us look another problem by using specific volume approach that is volume of solids is equal to 1. So in this problem the problem statements is as follows: A sample of dry sand having a unit weight of 16.5kN by m cubed that means that the given unit weight is dry unit weight of a given soil mass and specific gravity of solids $G_s$ as 2.7 is placed in the rain. That means that the dry sand is placed in the rain. During the rain the volume of the sample remains constant but the degree of saturation increases to 40 percent. So it is given that the degree of saturation increases to 40 percent. In that case determine the unit weight and water content of soil after being in the rain.

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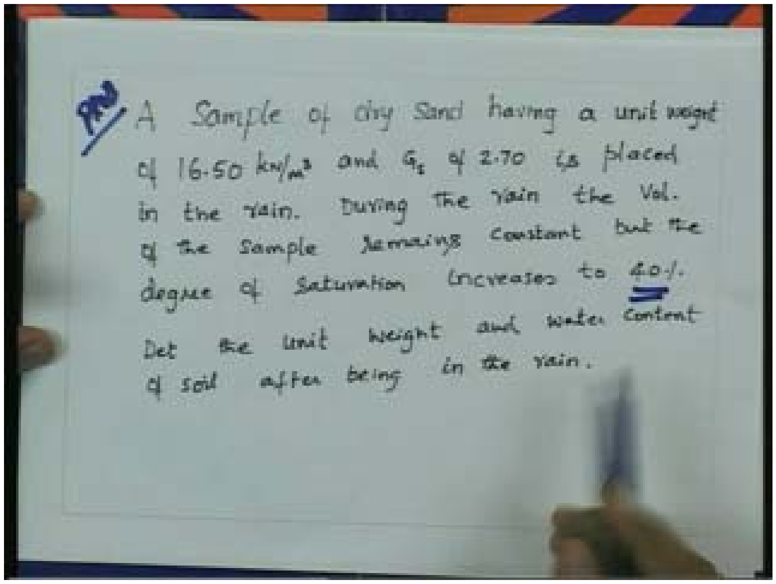


Let us try to look into this problem and solve by using specific volume approach. Given dry unit weight of soil mass gamma d is equal to 16.5kN by m cubed, specific gravity of solids is equal to 2.7 and degree of saturation as 40 percent. So we are required to determine water content and bulk unit weight of soil mass. By using gamma d is equal to ($G_s$ gamma w) by (1 plus e), calculate e that is void ratio as0.636. This can be obtained by rearranging this gamma d equation as [($G_S$ gamma w) by (gamma d)] minus 1. So by substituting the perspective values we will get the void ratio.

Now we are drawing the phase diagram for a partially saturated soil. Initially the soil was in 2-phase system after being placed in the rain, the water starts entering. So the soil transforms into a 3- phase system. By drawing a phase diagram for a 3 phase system, here these are the solids, water and air. So by setting the volume of solids is equal to 1 and the rest as volume of voids that is void ratio is equal to 0.636. So total volume is 1 plus 0.636.We knew the volume of solids as 1 and by knowing specific gravity of solids, we can determine weight of solids as $w_s$ is equal to (Gs $V_s$ gamma w) where $V_s$ is equal to 1.

By knowing $G_s$ is equal to 2.7, we can write $w_s$ is equal to 2.7 into10 to 27kN. So the fundamental definition of the degree of saturation is nothing but degree of saturation is equal to volume of water to total volume of voids. So we knew the degree of saturation is 0.4 that is 40 percent. So volume of water is equal to 0.4 times of 0.636, which is set as volume of water as 0.254. Now we obtain the volume of water, it is a component of volume of voids which is 0.254. By knowing the volume of water, we can determine the weight of water as (0.254 into 10) is equal to 2.54.

From the definition of water content w is equal to (weight of water to weight of solids) into 100, we can get the water content for this given problem as 9.42 percent. The gamma bulk that is the bulk unit weight of the soil mass can be deduced as total weight to the total volume. Then weight of solids plus weight of water to the total volume that is [(27 plus 2.54) by 1.636] is equal to 18.05kN by m cube.

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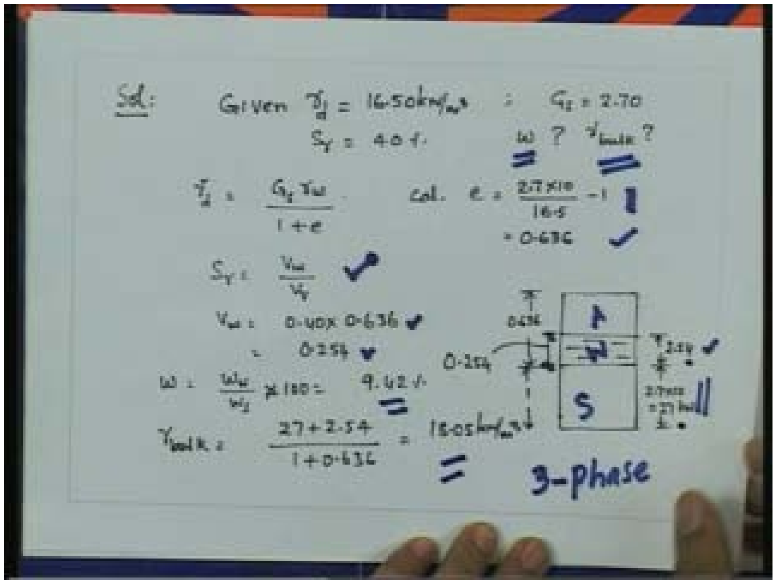


In this we try to solve couple of problems by using this approach and similar problems can be expected and can be solved easily by using either specific volume approach or unit volume approach. Before introducing the types of clay minerals, let us once again look at the geologic processes affecting the origin of soil deposits. As can be seen here, the source is igneous rock and after mechanical and chemical weathering this rock transforms into the residual soil. And this residual soil with the agencies can get transported and deposited in other places and forms sediments which after a process of induration form sedimentary rocks. And then after a process of metamorphism the sedimentary rock transforms into the metamorphic rock, then again it transforms into igneous rock.

A sedimentary rock can also directly transform into igneous rock. So this is the basic cycle which continuous, from igneous rock the residual soils are formed and these residual soils can remain at that place, otherwise the part of the soil can be transported by using wind, water or other agencies to form sedimentary deposits. These sedimentary deposits, in the process of induration can form sedimentary rocks. After undergoing a metamorphism, these sedimentary rocks can transform to a metamorphic rock. And then after due course of time it can transform to igneous rock or a sedimentary rock can transform into igneous rock.

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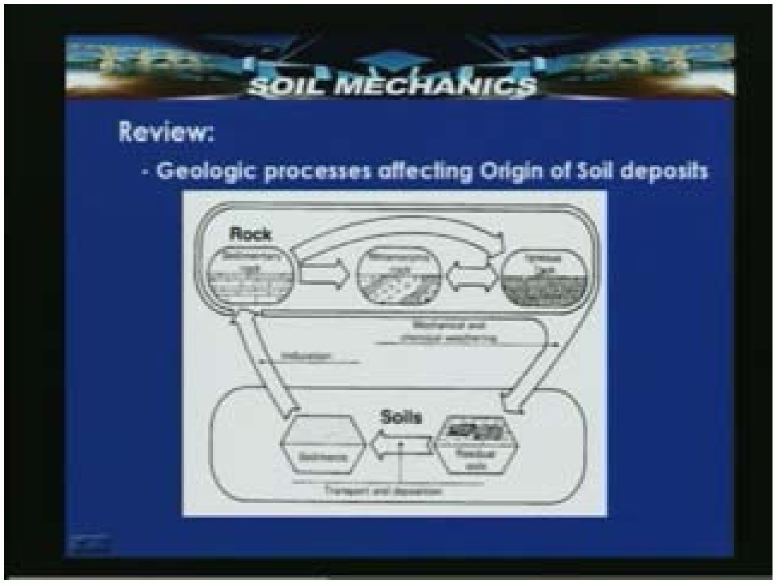


That is what we have seen in the previous slide. The progression of mechanical and chemical weathering that converts all types of rock to residual soils. These soils transport and deposition to form sediments, and the eventual conversion of sediments to sedimentary rock through a process of induration. This is the process which affects the origin of soil deposits.

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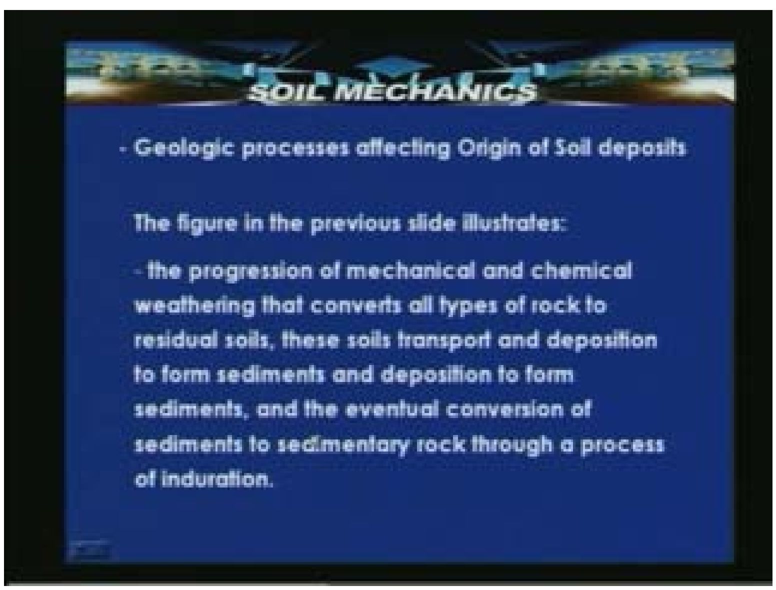


This slide shows a typical residual soil profile. A schematic profile shows an approximate parallelism in weathering zones. You can see a parent rock, a weathered rock and a residual soil profile. As we have discussed this residual soil has the properties pertinent to the parent rock. Here in this slide below, a residual soil profile is shown. It is derived from the volcanic rock in western Oregon USA.

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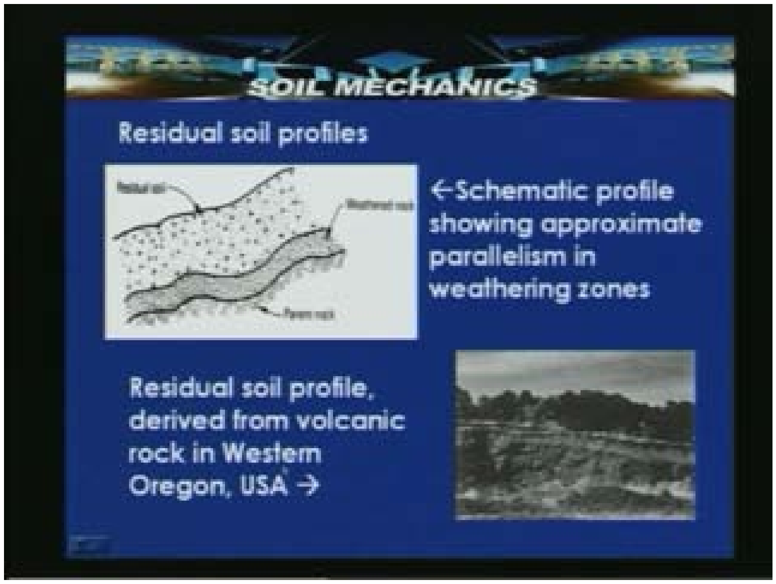


Transported soil profiles and these soils can get transported either by wind, water or weather agency. As you see here a parent rock, a thin weather zone and a transported soil deposit can be seen here. Note that the soil depth bears no particular relationship to rock surface topography and the soil thickness varies according to the physical conditions during the deposition. So the soil conditions are soil thickness is varying according to the physical conditions during the deposition.

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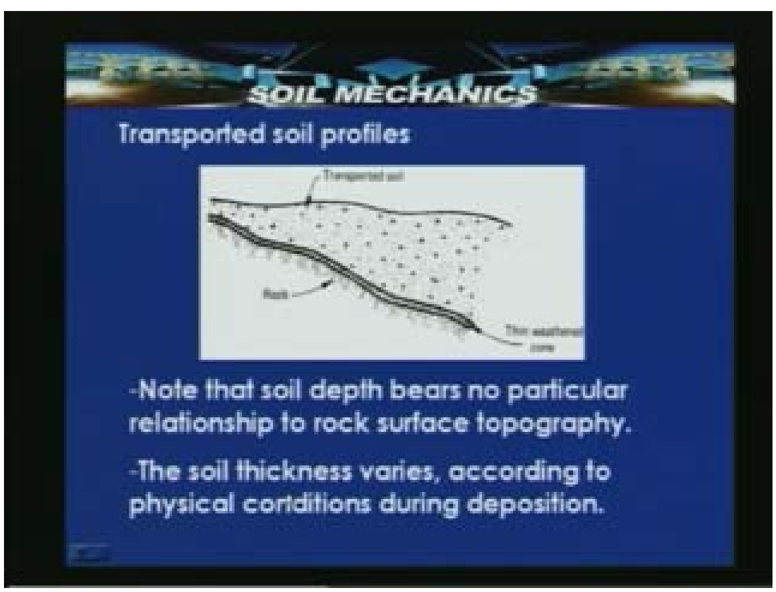

This is a typical distribution of the predominant soil deposits in India. This map is showing different types of soils that are superimposed on the map of India. As you see here, this particular type of legend which indicates alluvial deposits and these are the desert soils. This particular portion here and then here, parts of kerala and here is shown the laterites and lateritic soils. The majority of portion shown here, this particular one is black cotton soils. The coastal beds we can see the different types of soils which is called marine soil that is marine deposits. The boulder deposits occur along this particular region here and foot Himalayas and all are the boulder deposits.  So different type of soils form complicates or necessitates the requirement for understanding the soil mechanics.

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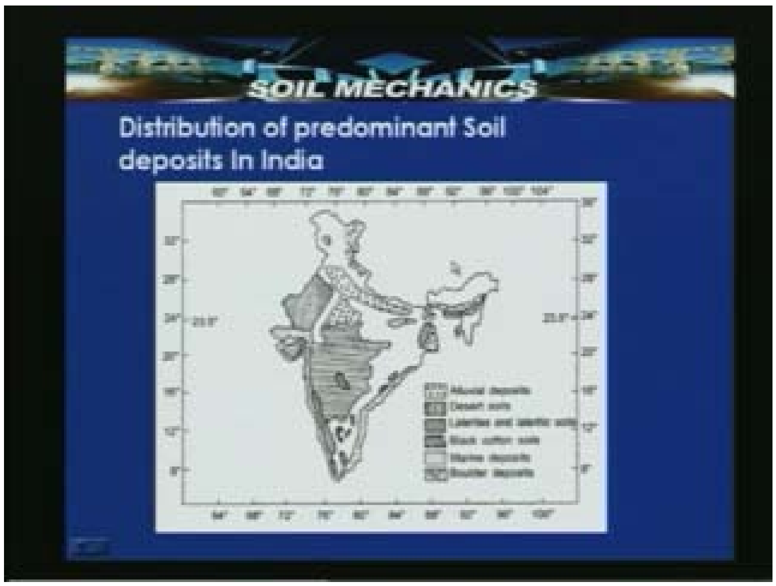


Before looking into the different types of mineral, another important property we should look up on is the grain shape. We said that once the soil forms from the disintegration by chemical or mechanical weathering, it undergoes or it gets disintegrated into small particles. So during the process of breaking either due to mechanical weathering or due to transportation either by wind, water and other agencies, it undergoes changes in the shape. So the shape of the soil grains is a useful grain property in the case of coarse-grained soils and it is important in influencing the engineering behavior of soils. In the previous lecture we had also seen different types of coarse grain particles like coarse sand and medium coarse sand where the shape of the coarse grain can be seen with the naked eye whereas fine grained soils require microscopic examination. So the grain shape is an important property for the coarse grain soils.

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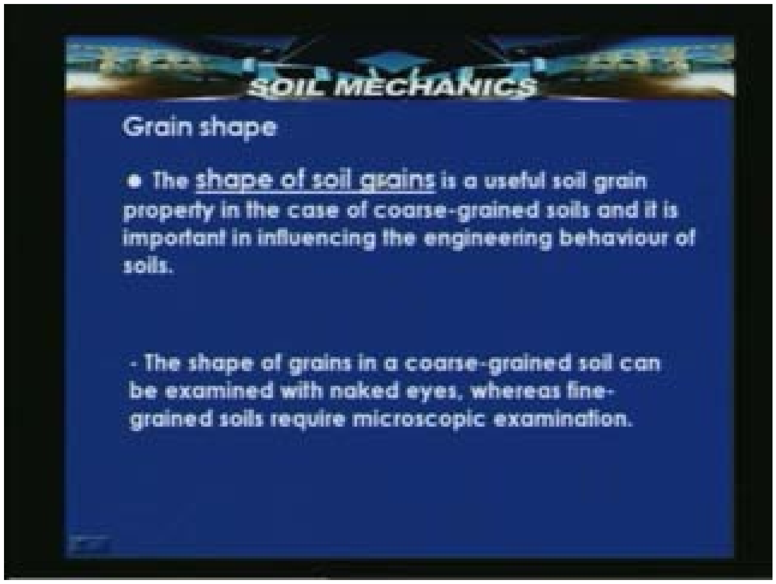


Actually a general classification can be set for soil grains based on the grain shape. So the soil grains can be classified as the bulky grains, flaky grains and needle shaped grains. Bulky grains are soil grains where all dimensions of a grain are more or less the same. So these are the characteristics of sand and gravel soils.

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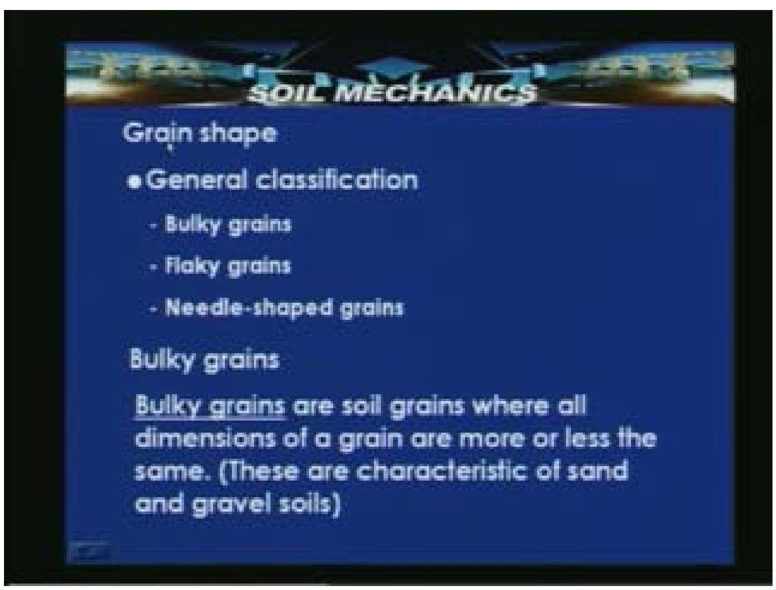


Now let us look here, the source of this bulky grains are mechanical breakdown of parent rocks. During their transportation by wind or water, the sharp edges of the grains may get worn out and the grains may become rounded. For example gravels which are found along the river beds like river gravels or wind blown sands like dune sands the grain shape will be rounded in nature. Alluvial sands that are along the river deposits can have sub-angular to sub-rounded shapes.

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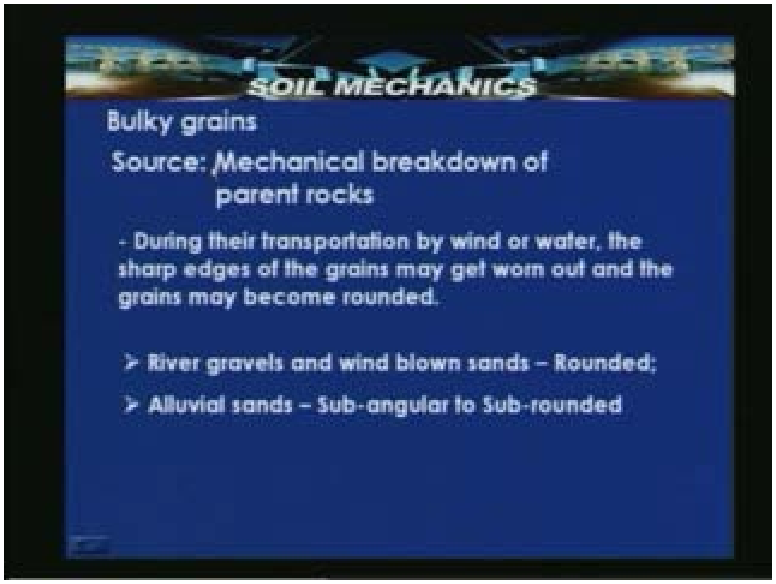


This slide shows different shapes of bulky particles. Here we can see a sub-angular grain shape where edges are distinct but fairly well rounded. These are the two different types of angular bulky particles: the sharp edges in the crushed stone are shown and very rounded or sub-rounded and rounded bulky grains can be seen here. So soils containing particles with high angularity tends to resist displacement and hence possesses higher shearing strength compared to those with less angular particles.

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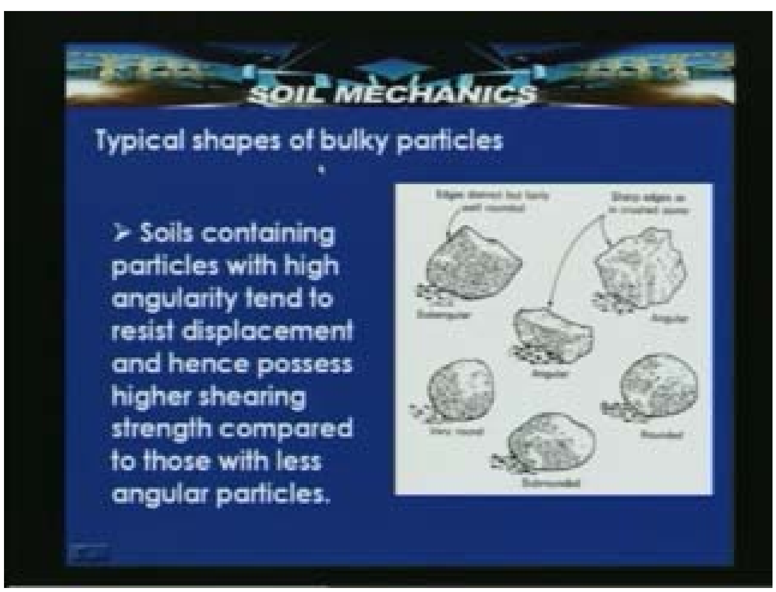

As we said, the shape of the grain is very important for coarse grained particles. Let us look some photomicrographs of sand particles. Here, this first picture on the left hand side shows a photomicrograph of beach sand where the contacts between different grain particles can be seen. Here photomicrograph of Quartz sand which is in the middle figure can be seen here and the Dune sand where the loss of contact because of the uniformity in gradation can be seen here. The important point to be noted is area of contact between grains is extremely small and even small forces between grains produce very high contact pressures and they can induce very high contact stresses between the grain particles.

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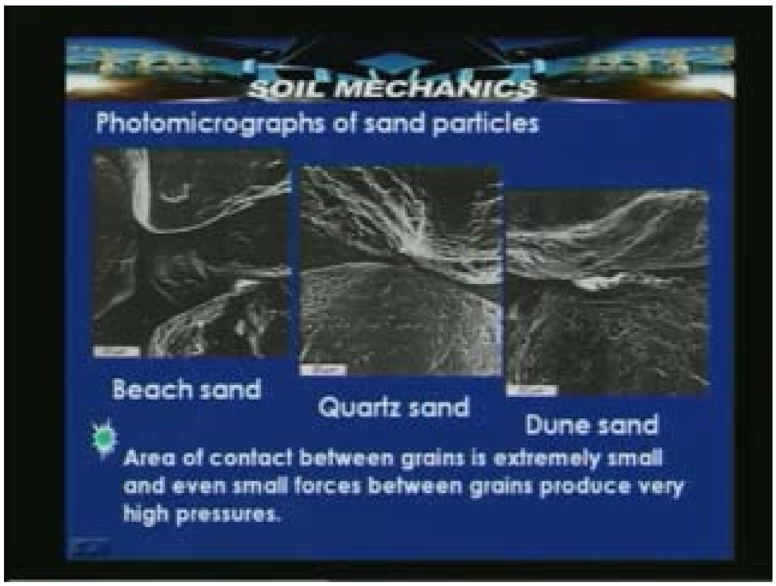


Now, let us look at the second type of the grains based on their shape, it is called the flaky grain or plate-shaped grains. They will be there predominantly in the fine-grained soils and they are the ones in which one dimension of grain namely its thickness bears no relationship with the other two lateral dimensions which are much bigger. The lateral dimensions are very very large and the thickness is very very small. This resembles a sheet of a paper or a leaf or a platelet. On the bottom corner of the figure, a submicroscopic crystals of clay minerals usually exhibit a flaky grain shape can be seen here. This is a microphotograph of a Kaolinite particle.

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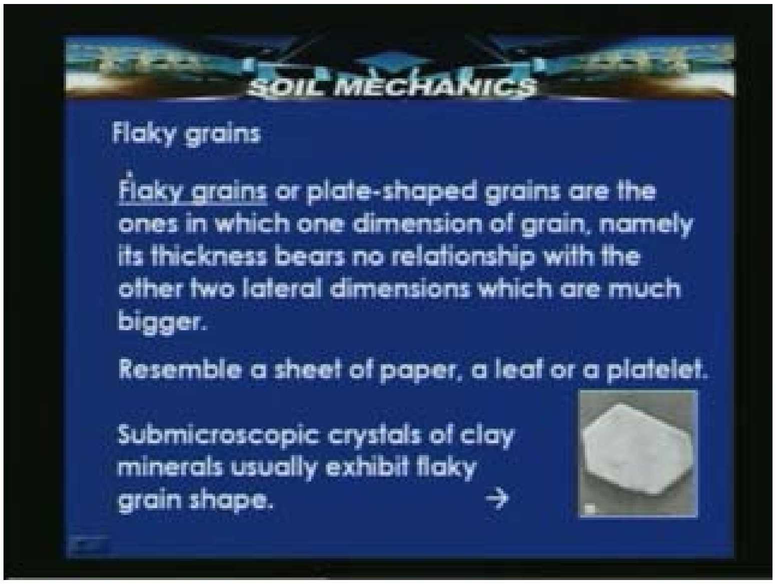


The other shape we define is like Needle-shaped grains; the one dimension of the grain is fully developed and is much larger than the other two dimensions. In this slide, a photomicrograph of a clay mineral Attapulgite is shown, where a needle shaped grains can be seen. This needle shaped grains are the characteristics of the clay mineral Attapulgite. What we have seen from this discussion is that the different shapes of the grains like, we have got Rounded, Sub-rounded, Angular or Sub-angular grains for bulky particles, some flaky grains have got plate shaped particles or platelet particles and needle shaped grains where one dimension of the grain is fully developed and it is much larger than the other two dimensions. One important thing you noted is the different shape of grains for the soil.

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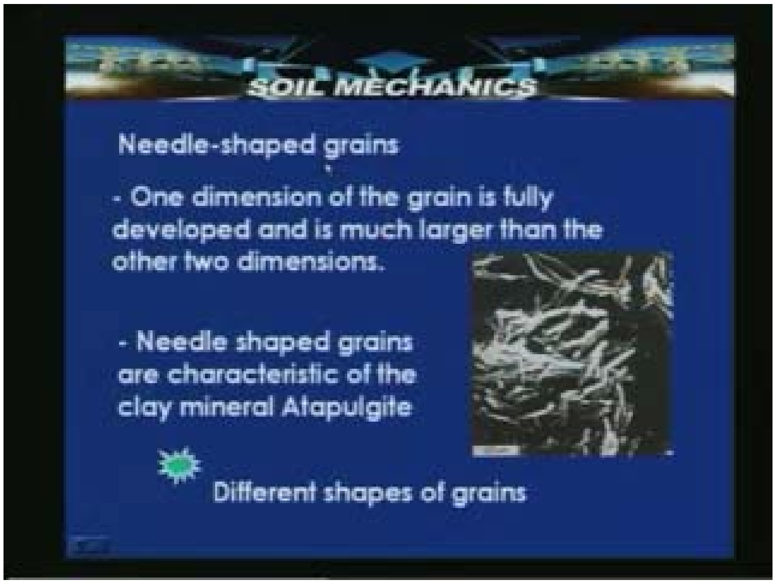


Let us now try to look into the mineralogy which influences the soil behavior, like the properties of very fine soil fractions. The most important grain property of fine grained soil materials is the mineralogical composition. If the soil particles are less than about 2 microns that is 0.002 mm, the influence of the force of gravity on each particle is insignificant that means the surface charges overcome the weight gravity forces here. The colloid particles of soil consist primarily of clay minerals, the colloidal state is nothing but the particles in which the domination of the surface charges takes place.

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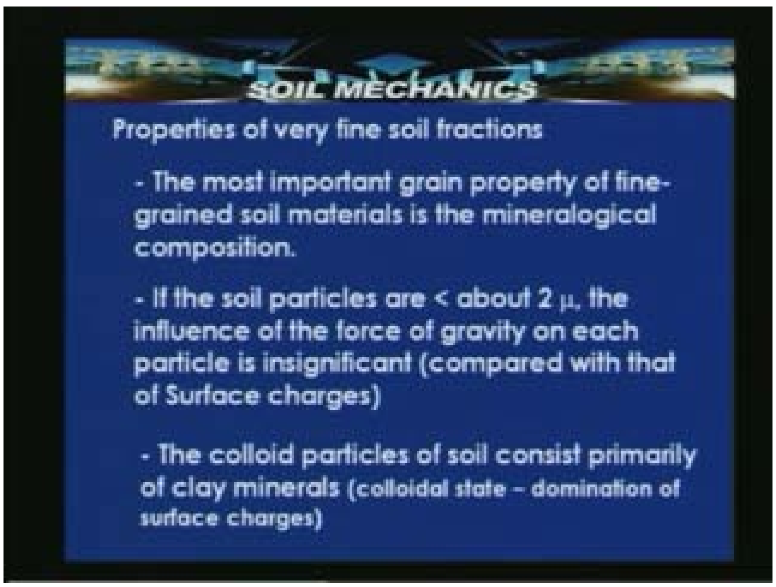

Before defining clay mineral, let us define a mineral. A mineral is a naturally occurring chemical element or compound formed by a geologic process. Classification of minerals based on the nature and arrangements of atoms can be in the following ways: Carbonates, Phosphates, Oxides and Silicates.

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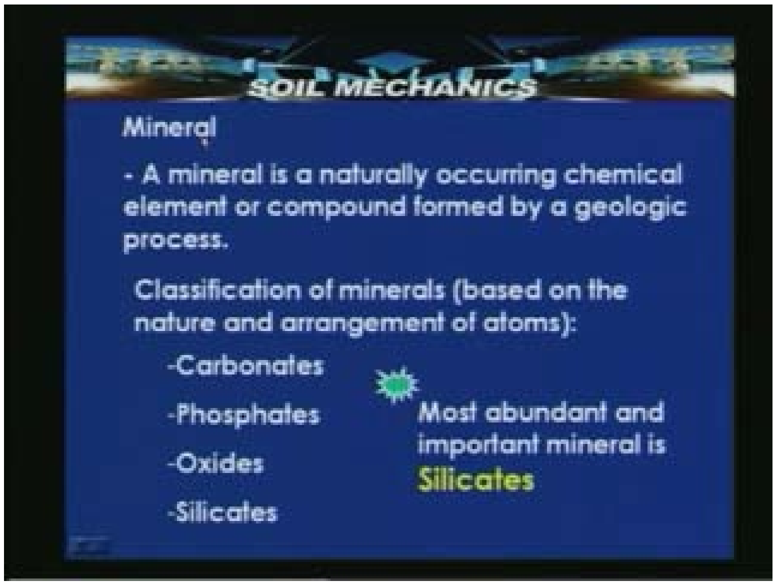


Most of the clay minerals formed in soil mechanics by using two abundant elements in the earth called silicon and oxygen. It was reported that 90 percent of the soil predominantly has silicates. So the most abundant and important mineral is silicates which is very important as far as soil is concerned. Two elements like silicon and oxygen forms silicates. The silicates are nothing but a group of minerals with a structural unit called the SILICA TETRAHEDRON. A slide here shows oxygen at the corners of a tetrahedron and silicon at the centre. A central silica cation is surrounded by four oxygen anions, one at each corner of tetrahedron. This is called a SILICA TETRAHEDRON.

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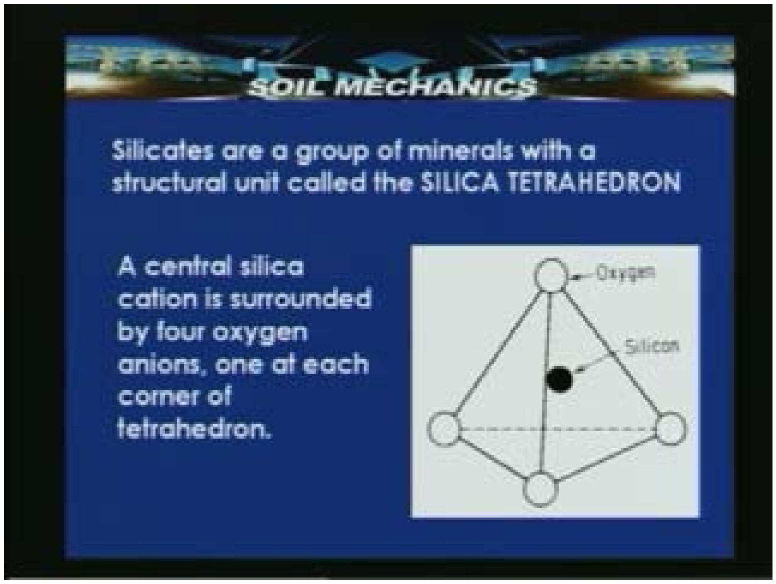


Several Silica Tetrahedrons link up in hexagonal pattern to form tetrahedral layer. This tetrahedral layer is represented by Silicate Sheet. Here the hexagonal network of tetrahedra forming silicate sheets can be seen. Now, different Silica tetrahedral units forming silica tetrahedral layer that is silicate sheet can be seen here.

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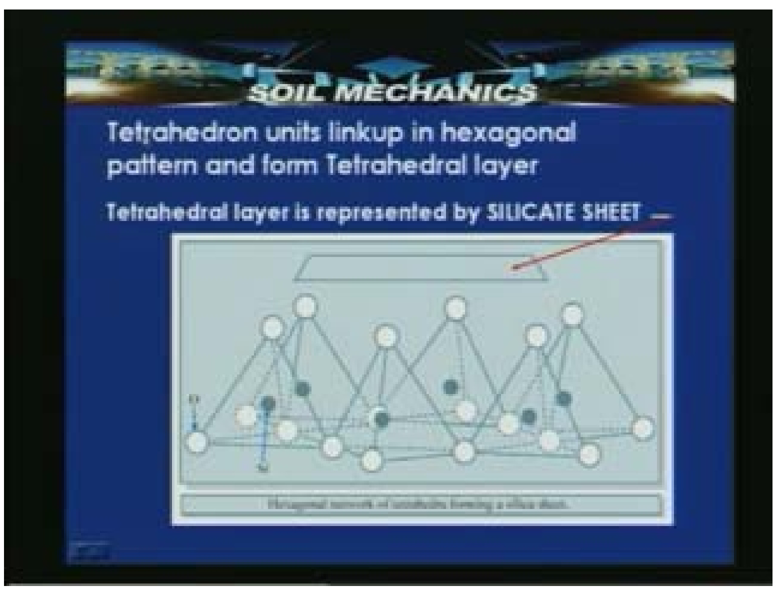


Another fundamental unit formed by using aluminum or magnesium and hydroxyls is the octahedron. In this slide, another fundamental unit is shown where aluminum or magnesium is at the center and they are surrounded by hydroxyls or oxygen.

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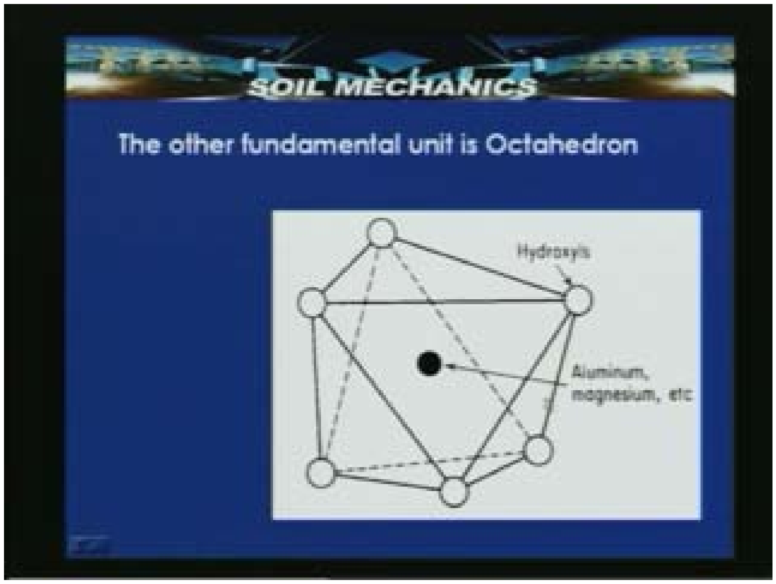


Octahedron units will linkup to form octahedral layer. If the anions of octahedral sheet are hydroxyls and 67 percent of the cation positions are filled with aluminum, then it is called GIBBSITE sheet or alumina sheet. It is indicated with this particular shape. If the cations positions are filled with magnesium, then it is called BRUSIDE sheet but several clay minerals are formed with the combination of silicate and GIBBSITE sheets only. In the below figure, the structural network of octahedra forming an alumina sheet and the combination of different octahedra units linkup to form octahedral layer or a GIBBSITE layer or alumina layer can be seen here.

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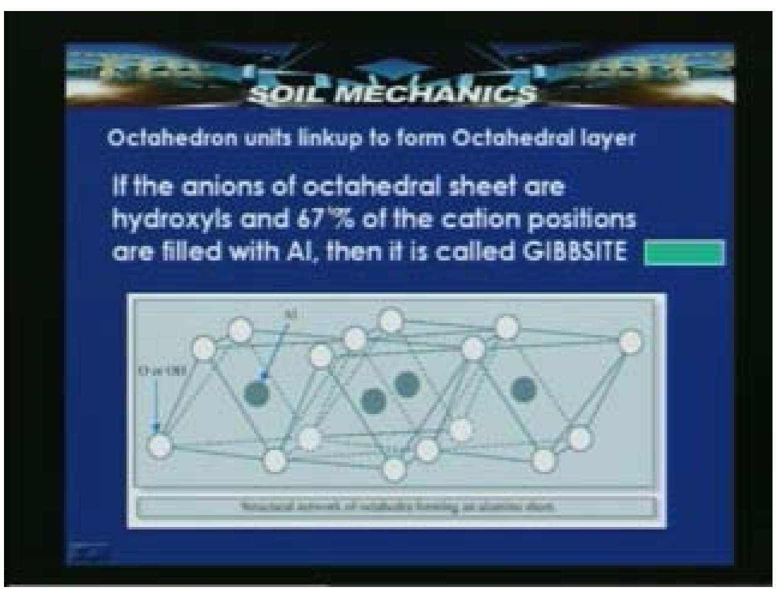

Having defined the fundamental units and they become the source for forming the clay minerals. Let us try to define clay mineral; we have already given that clay mineral is a constituent for the fine grained soil. The clay mineral is defined as chemical weathering, which results in the formation of group of crystalline particles of colloidal size for the particles finer than 2 microns that is less than 0.02 mm. In the previous slides, we have seen that how the silicate sheets and GIBBSITE sheets can be evolved? These silicate sheets and GIBBSITE sheets join together to form fundamental sheet structures and they form different types of clay minerals. This is basically a silicate sheet and this is GIBBSITE sheets or an alumina sheet.

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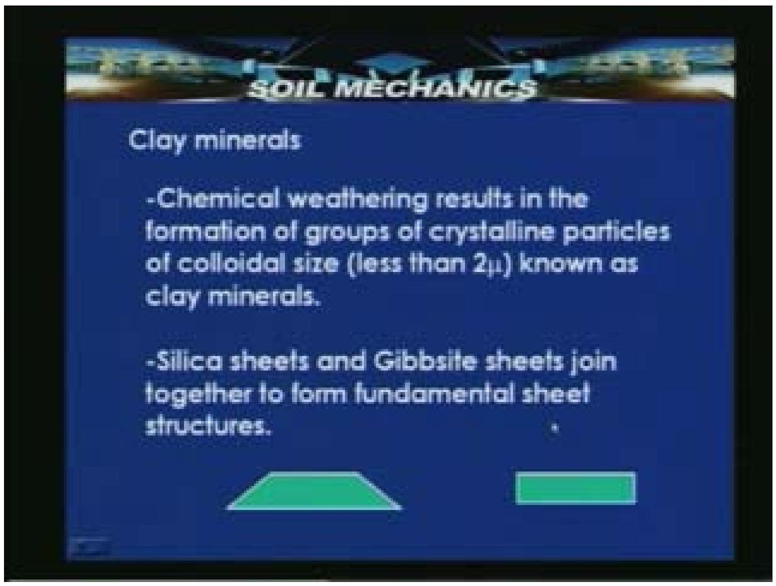


The three basic clay minerals are Kaolinite, Illite and Montmorillonite. Kaolinite is generally prevalent in sedimentary and residual soils. Illite is common in stiff clays and shales as well as in post glacial marine and lacustrine soft clay and silt deposits. Montmorillonite is the third mineral; it is the dominant clay mineral in some clays and shales and in some residual soils derived from volcanic ash like Bentonite. Other minerals form Halloysite, Chlorite, Attapulgite and Allophane.

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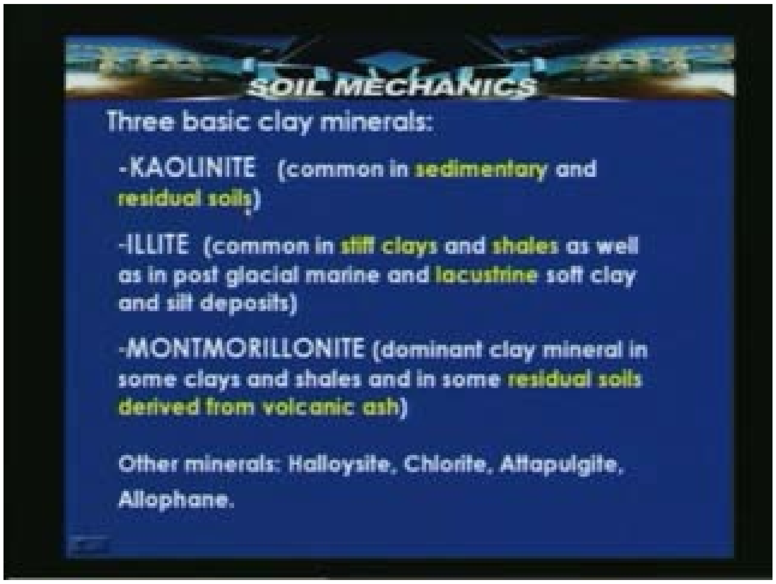


In this slide, we have seen different clay minerals. Let us discuss one by one about the different clay minerals. Three important clay minerals which should be introduced in this particular lecture are Kaolinite, Illite and Montmorillonite. As discussed the Kaolinite is basically formed with the repeating layers of one silicate sheet and one GIBBSITE sheet or alumina sheet. Here the elementary layer of Kaolinite is shown; GIBBSITE sheet or alumina sheet is strongly attached to a silicate sheet. The repeating layers of alumina and silicate sheet forms Kaolinite layer.

Here in this figure Kaolinite layer is joined to form Kaolinite particles which is shown. Here as you said a group of silica tetrahedrons forms silica sheets and a group of octahedrons forms alumina sheet. These two get attached through a bonding and forms elementary layer of Kaolinite. Several elementary layers of Kaolinite form Kaolinite particles. In Kaolinite particles, basically the elementary layer is 7.2 Angstroms thick where 1 Angstrom is equal to 10 minus 10 m. Kaolinite is basically a repeating layer of one silicate sheet and one GIBBSITE sheet or alumina sheet. Kaolinite is also called 1:1 clay mineral which means that one silicate sheet and one alumina sheet forms an elementary layer of Kaolinite.

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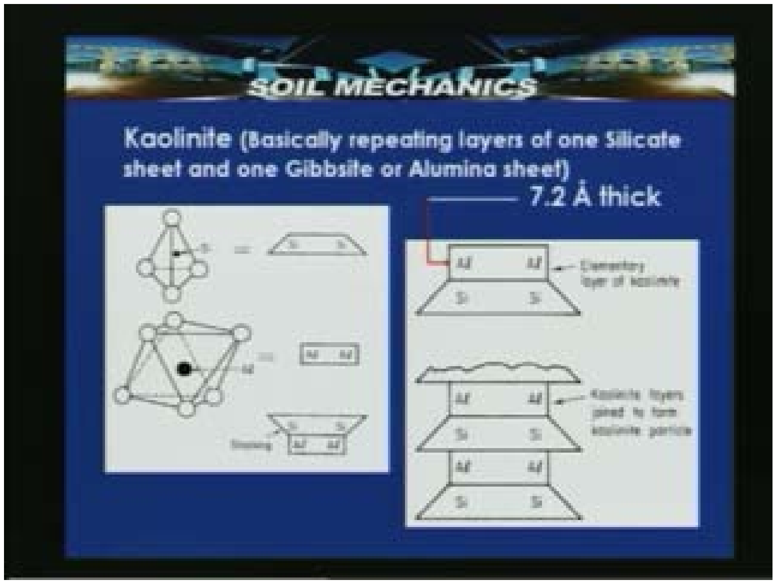


Here the nature of bonding in Kaolinite elementary layer is shown and how the silicate sheet and alumina sheet are attached is also shown in this slide. This is an alumina sheet and this is the silicate sheet.

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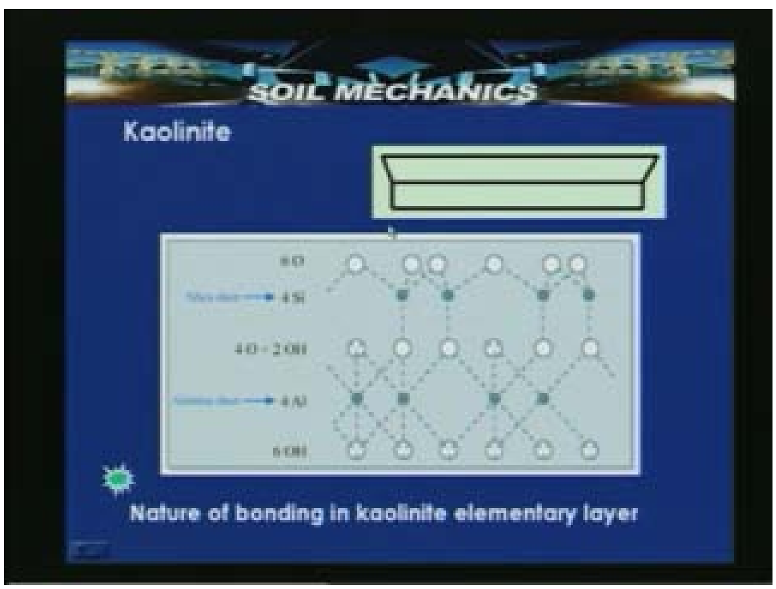


A Kaolinite crystal or particle consists of a stack of several layers of the basic 7.2 Angstrom thick layers. Here a typical Kaolinite particle has a length equivalent to 1000 to 20,000 Angstrom units and its thickness is 100 to 1000 Angstrom units. This Kaolinite particle is formed typically by 70 to 100 elementary layers. This forms strong hydrogen bonds between the hydroxyls of the GIBBSITE sheet and oxygen of the silicate sheet.

Because of this particular nature of bonding, there is a little tendency in the inter layers to allow water and to swell. Kaolinite has got less affinity for water. So Kaolinite crystal or particle consists of a stack of several layers of basic elementary layers.

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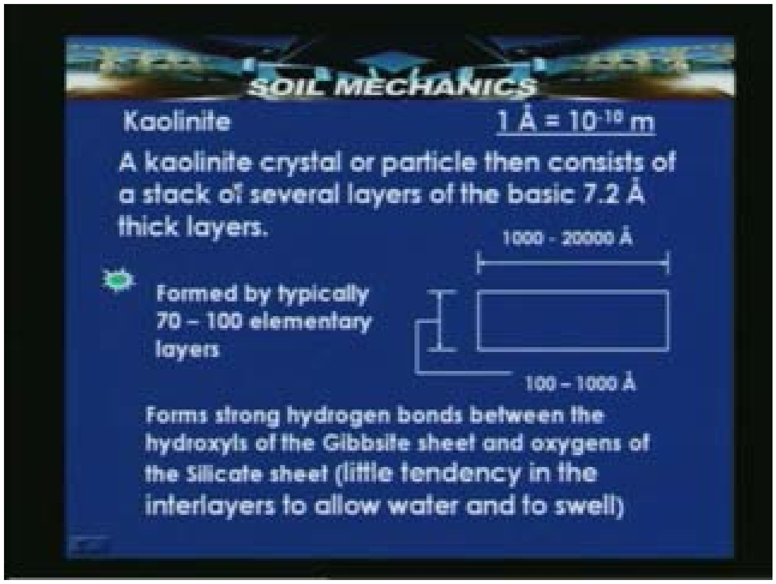


Here is the photomicrograph of Kaolinite and these photographs are obtained from the Scanning Electron Microscope that is called SEM. Here a cluster of the plates can be seen in the Kaolinite particle which resembles pages in a book. You can see the stacks of the plate shaped particles in a Kaolinite.

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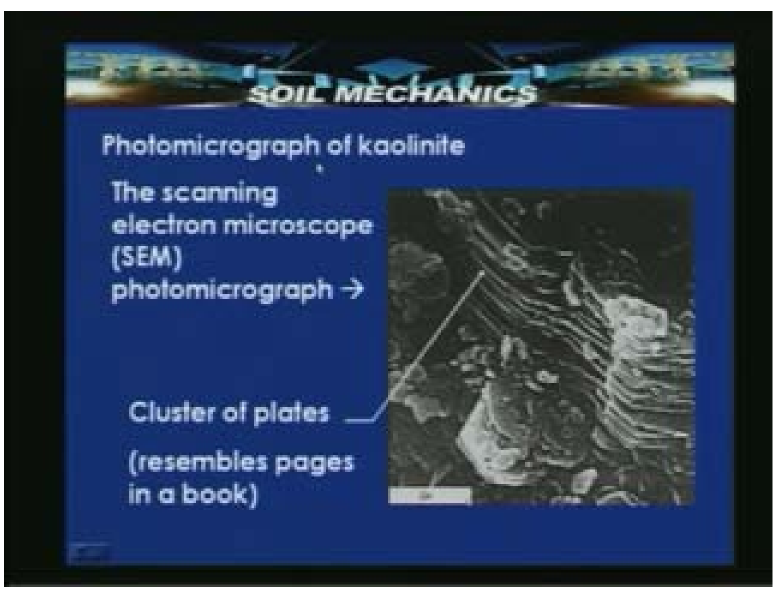

As we said another mineral is Montmorillonite mineral. This is called 2:1 clay mineral and it is also known as Smectite. Pure seams of Montmorillonite can exist in Wyoming Bentonite in Australia and because of this one alumina sheet and two silicate sheets form an elementary layer in case of Montmorillonite. These elementary layers are separated by several water layers and cations, which get separated because of the weak Vander Waals forces. The spacing between silica, GIBBSITE and silicate sheets depend upon the amount of water available to occupy the space. Each elementary layer can get separated and can get extended up to 400 Angstrom distance. This is because of the weak bonding due to weak Vander Waals forces. Predominantly this mineral will be there in black cotton soil. It is one of the transported soils that we have introduced earlier. In this figure a several layers of alumina sheet and silicate sheets are shown here.

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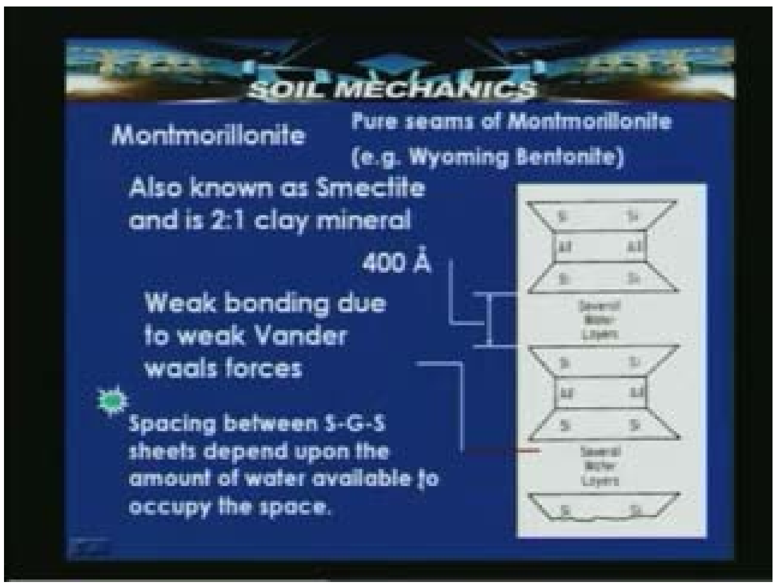


The nature of bonding in Montmorillonite elementary layer can be seen here, where alumina sheet get sandwiched with the help of silicate sheet and another silicate sheet at the bottom. This is represented here in this slide: alumina sheet or GIBBSITE sheet and silicate sheet at the top and silicate sheet at the bottom.

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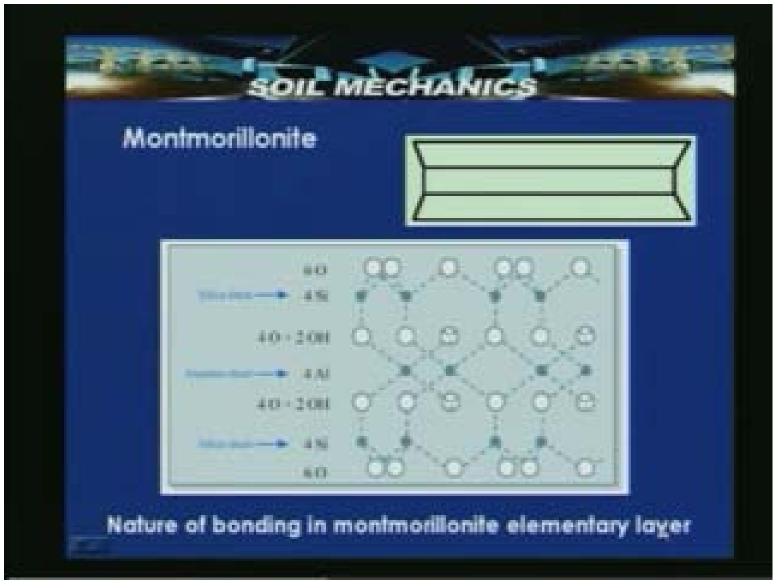


This slide shows photomicrograph of Montmorillonite. Among the clay minerals Sodium Montmorillonite, that is predominantly the cations here are sodium. Here you can see the gel type appearance of the photomicrograph for the Montmorillonite. The approximate Montmorillonite particle has sizes from 1000 to 5000 Angstrom units and its thickness is only 10 to 50 Angstrom units. 1 Angstrom unit we said as 10 minus 10 m. Among the clay minerals, Sodium Montmorillonite has the smallest and very very tiny particles and it has got filmy particles.

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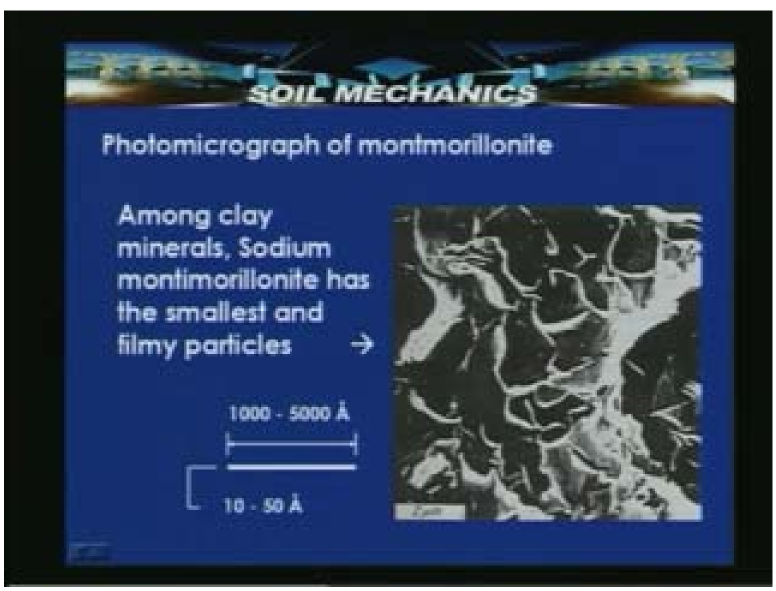

The third clay mineral that we introduced today is Illite which is nothing but repeated layers of GIBBSITE sheet sandwiched by two silicate sheets. It is similar to Montmorillonite except that the adjacent silica layers are bonded with potassium ions instead of water. So these potassium ions bond the two negative surfaces of silicate sheets tightly. With that it has got less affinity for water than Kaolinite as well as more affinity for water than Kaolinite, then less affinity for water than Montmorillonite. This slide shows the elementary layer which is similar to Montmorillonite, one GIBBSITE sheet is sandwiched between two silicate sheets. The only difference is that the water layers are replaced with potassium ions and these potassium ions hold the silicate sheets tightly with an ionic bond. With these the potassium ions bond the two negative surfaces of this elementary layer to prevent any ingress of water.

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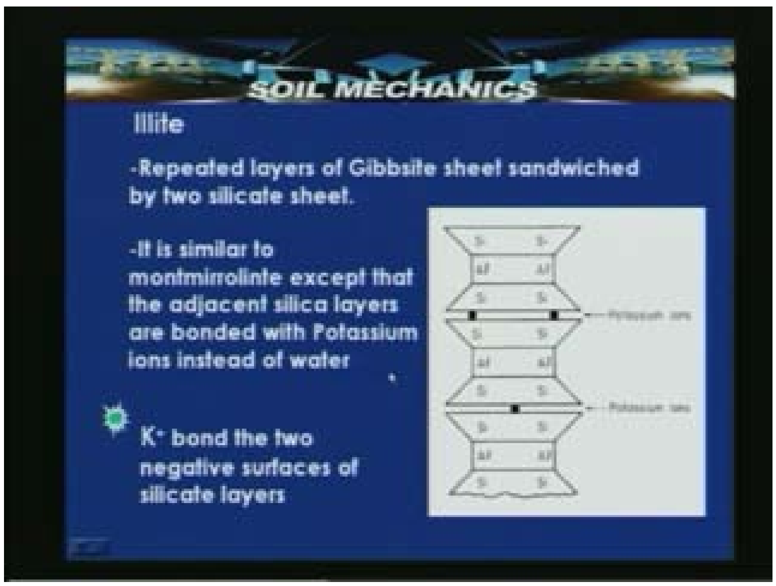


The particle size of Illite is reasonably larger than Montmorillonite which is slightly smaller than Kaolinite where 1000 to 5000 Angstrom is the lateral dimension width and thickness is 50 to 500 Angstrom units. The swelling potential of Illite will be greater than Kaolinite but less than Montmorillonite. If we look into it the Kaolinite clay mineral has got larger particle size than Illite and Montmorillonite. The swelling potential of Montmorillonite mineral is very high compared to Illite and Kaolinite. So that is the reason why the soils contain Montmorillonite exhibit high shrink swell characteristics.

The soils containing 100 percent or 85 percent Montmorillonite are also used very widely in soil engineering construction for supporting the bore holes etc. In this lecture we try to understand about the unit volume approach and then its application for establishing relationship between the weight volume ratios and volumetric ratios. We have also seen the importance of grain shape and different grain shapes like bulky shape, flaky shape and needle shape. We also try to introduce different types of clay minerals, basically we said that three clay minerals will form with the fundamental units silicate sheet and GIBBSITE sheets. Kaolinite forms with one silicate sheet and one GIBBSITE sheet. We have seen different structures of Kaolinite clay mineral, Illite mineral and Montmorillonite mineral. We also discussed about the influence of this mineralogy on the properties like swelling potential and its particle size etc.