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ADVANCED GEOTECHNICAL ENGINEERING

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Lecture. 04

Module – 1

Clay Mineralogy and Soil-air-water interaction

Welcome to lecture number 4 of module 1 of advanced geotechnical engineering. In the previous lecture we have discussed about the particle arrangement and the grain say grains shapes and their impact. In this lecture we are going to discuss about clay mineralogy and clay water part interaction, in principle clay mineralogy I abhorred the clay minerals prevalent in soils and clay particle water interaction. As we discussed in the previous lectures if you look into it in this slide.

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A typical SEM of silty sand

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A typical slity sand in dry heap which is shown on the left hand side figure, on the right hand side a 500 times magnified SEM photograph which actually shows you know coarse sand particles and some fine silt particles, so this allows us to look into the different particle arrangements with respect to the SEM as concerned.

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Clay mineralogy; Clay-Water Interaction

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So coming to the today's discussion particularly clay mineralogy and clay water interaction.

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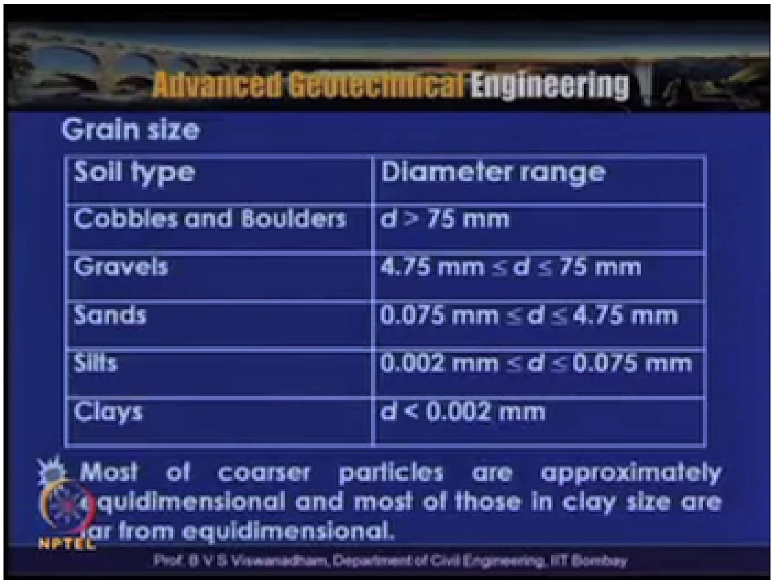

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Grain size

Soil type	Diameter range
Cobbles and Boulders	$d > 75$ mm
Gravels	$4.75 \text{ mm} \le d \le 75 \text{ mm}$
Sands	$0.075 \text{ mm} \le d \le 4.75 \text{ mm}$
Silts	$0.002 \text{ mm} \le d \le 0.075 \text{ mm}$
Clays	$d < 0.002$ mm

- Most of coarser particles are approximately equidimensional and most of those in clay size are far from equidimensional.

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So we actually have discussed that the soils when they disintegrate they get into different shapes and sizes they are classified based on the soil types as cobbles and boulders which size is actually more than 75 mm, gravels size greater than 4.75 less than 75 mm anything which is actually more than 19mm these are treated as cobble or boulder in principle but between 4.75mm to19mm is treated as the bulk sized particles are the gravel particles and sand which is actually greater than75 micron or 0.075mm to 4.75mm that is actually treated as sands and slit size greater than 2 micron to less than 75 micron.

And the clays which are actually fine particles we have introduced and we have told that particles diameter is less than 2 micron that is the clay particle can be as small as 0.002mm. So most of the coarse particles are approximately equal dimensional and most of those in clay size are far from the equdimensional, so most of the coarse particles, coarser particles are approximately equal dimensional that is what we have discussed and most of those in clay size are from equdimensional.

So we are going to discuss about what type of shapes these particles have and what type of minerals they consist and why the clays behave in this particular manner. Before discussing or introducing clay water interaction or climatology let us introduce to a particular term called specific surface area SSK.

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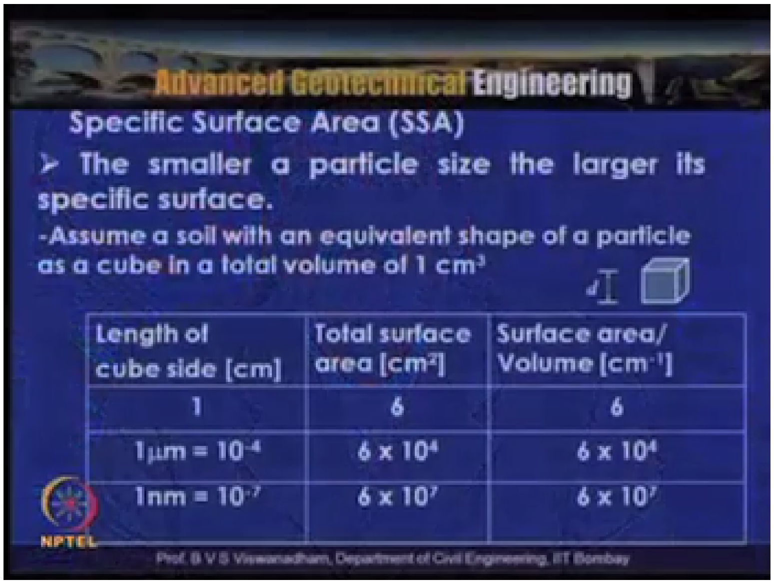

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Specific Surface Area (SSA)

- The smaller a particle size the larger its specific surface.

-Assume a soil with an equivalent shape of a particle as a cube in a total volume of 1 cm^3

Length of cube side [cm]	Total surface area [cm^2]	Surface area/ Volume [cm^{-1}]
1	6	6
1μm = 10^{-4}	6 x 10^4	6 x 10^4
1nm = 10^{-7}	6 x 10^7	6 x 10^7

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The smaller a particle size the larger its surface specific surface, so in this slide if you consider a an equivalent shape of a particle let us assume that you have got a particle of size say d units and which is a cube in dimensions, so assume a soil with an equivalent shape of a particle as a cube in a total volume of one centimeter cube. So if length of the cube side is say one centimeter then we knew that the total surface area is 6cm^2 and surface area per volume is 6.

Similarly if you reduce this particle size cut into very, very small cubes let us say that we consider 1 micrometer that is 10^{-4}cm in that case if you look into the total surface area works out to be 6x10^{-4}cm^2 and surface area per volume is 6x10^4. If you cut further is something like 1 nano meter is equal to10x10^{-7}cm the total surface area works out to be 6x10^{7}cm^2 so this works out to be a surface area per volume is 6x10^{7}cm to the power raised minus 1, that means that if you observe here length of this side is decrease then the surface area is actually increasing.

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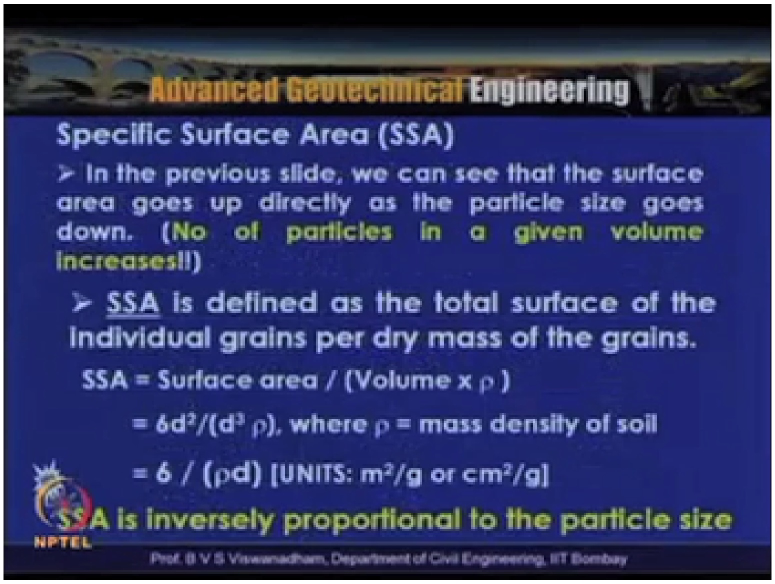

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Specific Surface Area (SSA)

- In the previous slide, we can see that the surface area goes up directly as the particle size goes down. (No of particles in a given volume increases!!)
- SSA is defined as the total surface of the individual grains per dry mass of the grains.

SSA = Surface area / (Volume x ρ)

= $6d^2/(d^3 \rho)$, where ρ = mass density of soil

= $6 / (\rho d)$ [UNITS: m^2/g or cm^2/g]

SSA is inversely proportional to the particle size

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So in the previous slide we have observed that the surface area, as the surface area we can see that the surface area goes up directly as the particle size or the cube size goes down, that means that the number of particles in a given volume are increasing. So we can define with this background the SSK as SSK is defined as a total surface area of individual grain per drive mass of the grains, so SSK is nothing but surface area divided by volume into ρ, ρ is nothing but the mass density of the particular soil.

So surface area if you indicate if d is the size then $6d^2$/ volume of that particular cube let us say that d is the size $d^3x\rho$ that means that specific surface area gets simplified to 6/ρd that units works out to be either m^2/g or cm^2/g. So if you observe here the specific surface area is inversely proportional to the particle size that means that larger particles have low specific surface area and finer particles have higher specific surface area.

So the observation is that the specific surface area is defined as the total surface of individual grains per dry mass of the grains and SSK is inversely proportional to the particle size. Now the property of the very fine soil fractions.

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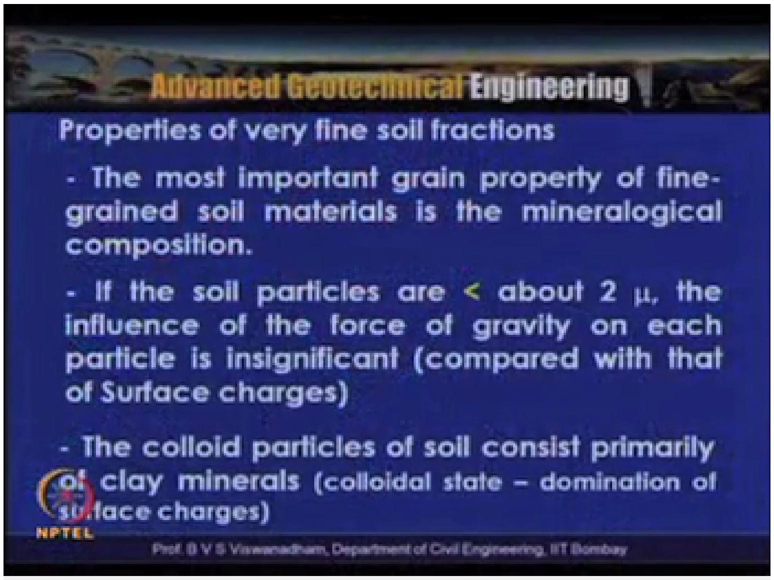

Properties of very fine soil fractions

- The most important grain property of fine-grained soil materials is the mineralogical composition.
- If the soil particles are < about 2 μ, the influence of the force of gravity on each particle is insignificant (compared with that of Surface charges)
- The colloid particles of soil consist primarily of clay minerals (colloidal state – domination of surface charges)

The most important property of fine-grained soil materials is the mineralogical composition this we have been discussing and if the soil particles are less than about 2 micron the influence of force of gravity of each particles is insignificant, so we have discussed in the previous class that if the particles are less than 2 microns the influence of the force of gravity in each particle actually is insignificant of delicious compared to that of the surface are just the pitch that the surface just dominate the you know the finer particles.

So the colloid particles of soil consists primarily of clay minerals the colloid state is nothing but the domination of the surface charges.

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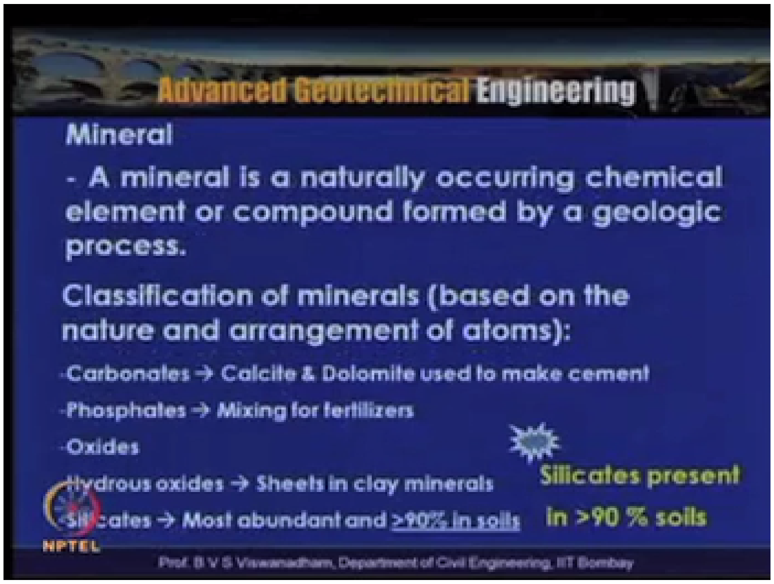

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Mineral

- A mineral is a naturally occurring chemical element or compound formed by a geologic process.

Classification of minerals (based on the nature and arrangement of atoms):

- Carbonates → Calcite & Dolomite used to make cement
- Phosphates → Mixing for fertilizers
- Oxides
- Hydrous oxides → Sheets in clay minerals
- Silicates → Most abundant and >90% in soils

Silicates present in >90 % soils

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So what is the mineral, a mineral is a naturally occurring chemical element or a compound formed by geological process. Once the rocks disintegrate they possessed certain minerals and they transfer that mineral property to the soil from which actually it has been generated. The classification of minerals based on the nature and arrangement of atoms carbonates the typically carbonates, phosphates, oxides, hydrous oxides and silicates, carbonates some soils the dew consists of carbonates calcite and dolomite basically used to make cement.

Phosphates mixing for fertilizers and hydroxides sheets in clay minerals and silicates most abundant and more than 90% soils consist of this silicate minerals. So silicates present in more than 90% of soils, so a plum minerals are classified based on the crack as based on the nature and arrangement of the atoms as carbonates, phosphates, oxides and hydroxides and silicates most abundant and most prevalent element most prevalent mineral is silicates.

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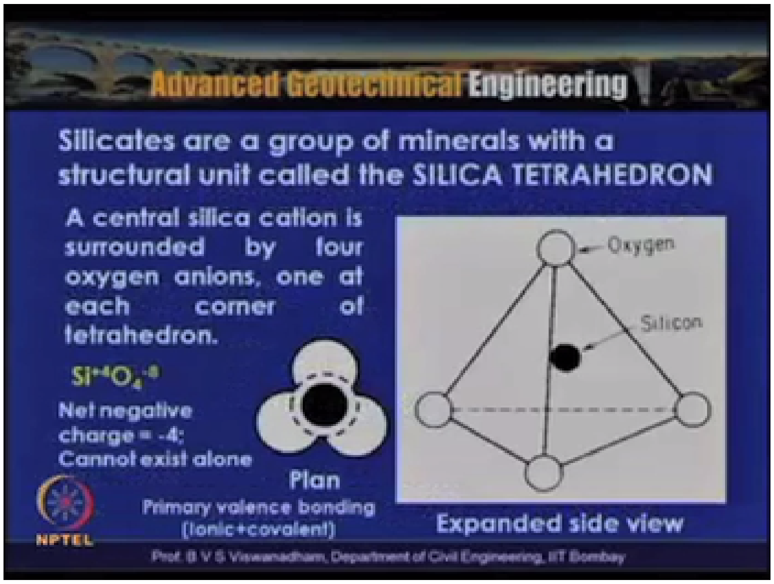

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Silicates are a group of minerals with a structural unit called the SILICA TETRAHEDRON

A central silica cation is surrounded by four oxygen anions, one at each corner of tetrahedron.

$Si^{+4}O_4^{-8}$

Net negative charge = -4; Cannot exist alone

Primary valence bonding (Ionic+covalent)

Expanded side view

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So what is the silica silicates are been nothing but groups of minerals with a structural unit called the silica tetra hydrate, so Interviewer: his case you have seen one silica silicon and the four oxygen anions. So the a central silica cation is surrounded by four oxygen anions and one of each corner of the tetrahedron so SI+4 and O4-8 with that the net negative charge is -4 and this cannot exist alone in the sense that the net charge is actually neutral so it tries to net charge is not neutral and it actually has got a net negative charge of -4 so it tries to combine with other minerals.

So this primary valence bonding which is prevalent here and here the plan view of the arrangement of the oxygen anions and the silicon cation which is actually shown and this is the expanded side view, so silicates are a group of minerals with a structural unit called silica tetrahedron a central silica cation is surrounded by four oxygen anions one of each corner of the of the tetrahedron, okay. So net native charge is -4 and they cannot exist along.

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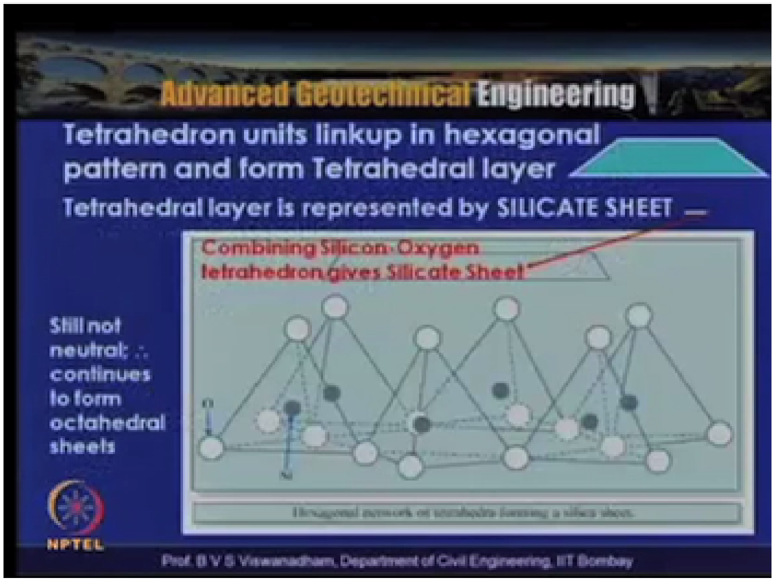

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Tetrahedron units linkup in hexagonal pattern and form Tetrahedral layer

Tetrahedral layer is represented by SILICATE SHEET

Combining Silicon Oxygen tetrahedron gives Silicate Sheet

Still not neutral; ∴ continues to form octahedral sheets

Hexagonal network of tetrahedra forming a silica sheet.

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So because of this they form tetrahedrons units linked up in hexagonal pattern and form tetrahedron layer, so combining silicon axes silicon oxygen tetrahedron gives silicate sheet so if you have a several silicon-oxygen tetrahedrons and it forms silicate sheet and even with the formation of silicate sheet still it is not neutral and continues to form octahedral sheets. So, tetrahedron units link it up in exogenous pattern and form tetrahedral layer so tetrahedral layer is nothing but represented by a silicate sheet.

So the silicate sheet is actually represented as in this particular shape which is actually shown here, so combining silicon and oxygen tetrahedron gives this silicon silicate sheet.

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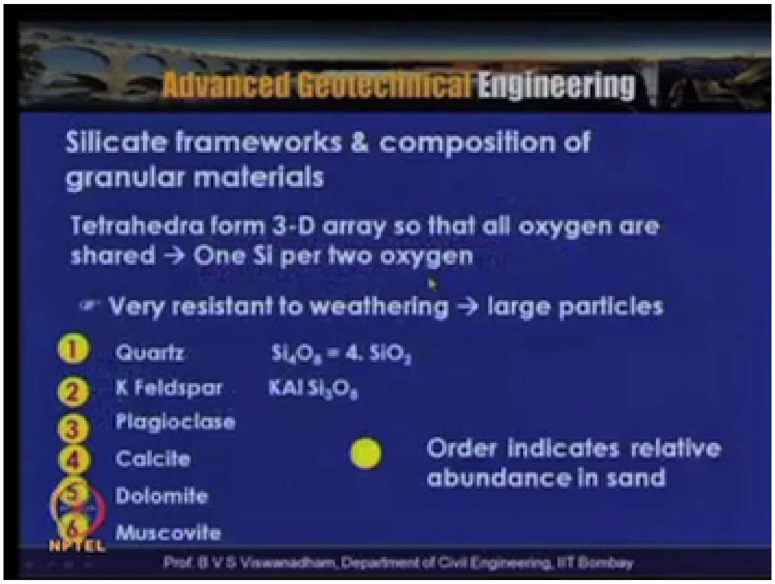

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Silicate frameworks & composition of granular materials

Tetrahedra form 3-D array so that all oxygen are shared → One Si per two oxygen

- Very resistant to weathering → large particles

① Quartz $Si_4O_8 = 4. SiO_2$
② K Feldspar $KAl\,Si_3O_8$
③ Plagioclase
④ Calcite
⑤ Dolomite
⑥ Muscovite

● Order indicates relative abundance in sand

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So the silicate frameworks and composition of granular materials if you look into YZ tetrahedra form 3D array so that all oxygen are shared and one SI/2 oxygen and Young's very resistant to weathering and it form it actually has large particles. And here some typical minerals are shown here quartz K feldspar, Palgiociase and the calcite, dolomite and muscovite. So if you look into here the order which is actually shown here indicates the relative abundance in the sand that means the the cards is actually most abundantly available in the sand then followed by feldspar and Palgiociase, calcite, dolomite and then followed by muscovite.

So tetrahedral form the 3D array so that all oxygens are actually shade and 1 silica / 2 oxygen and they are very resistant to weathering and have tendency to have large particles.

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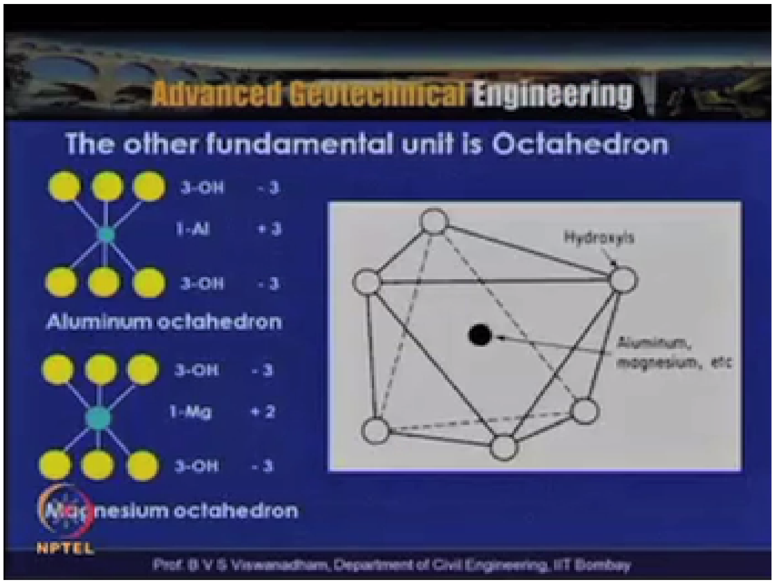

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The other fundamental unit is Octahedron

Aluminum octahedron

Magnesium octahedron

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The other fundamental unit we have discussed about the silicate sheet now in order to discuss the further there are other fundamental unit that is actually called octahedron, here there are two here in this particular slide an expanded side view which is actually shown here where you have what add octahedron at each corner and either aluminum or magnesium cation which is actually shown here. So here this shows aluminum octahedron where in you have three hydroxides with 3 native charge 1 aluminum 3 and 3 OH that is with -3 valence here.

So if you have a central cation which is aluminum then that is called aluminum octahedron, if you have a central cation magnesium then it is called magnesium octahedron. So in this slide a fundamental unit of octahedron is introduced where in we have aluminum octahedron or magnesium of octahedron.

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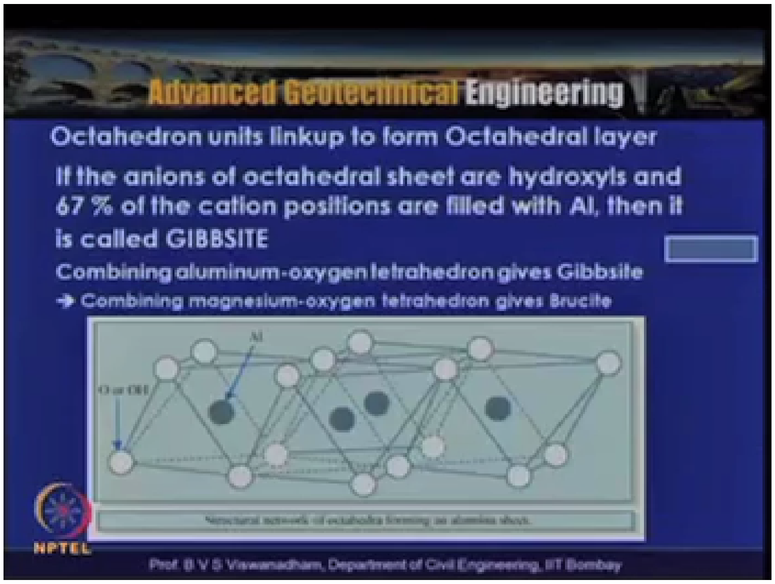

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Octahedron units linkup to form Octahedral layer

If the anions of octahedral sheet are hydroxyls and 67 % of the cation positions are filled with Al, then it is called GIBBSITE

Combining aluminum-oxygen tetrahedron gives Gibbsite

→ Combining magnesium-oxygen tetrahedron gives Brucite

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When you link up these several octahedron layers then it forms a octahedron layer if the anions of octahedral sheet or hydroxides and 67% of the cation positions are filled with aluminum then it is called gibbsite, so it is indicated as a in a rectangular feet which is actually known as gibbsite. Combining aluminum oxygen tetrahedron gives gibbsite if you happen to find or you have combining magnesium oxygen tetrahedron then it gives a mineral called brucite, so combining aluminum oxygen tetrahedron that is called a gibbsite and combining magnesium oxygen tetrahedron use brucite.

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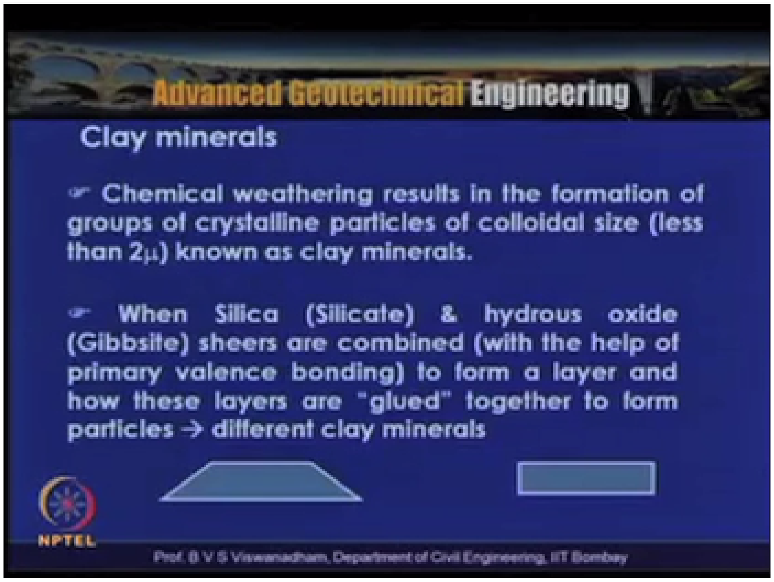

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Clay minerals

- Chemical weathering results in the formation of groups of crystalline particles of colloidal size (less than 2μ) known as clay minerals.
- When Silica (Silicate) & hydrous oxide (Gibbsite) sheers are combined (with the help of primary valence bonding) to form a layer and how these layers are "glued" together to form particles → different clay minerals

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So the clay minerals then silicates are hydroxide, hydroxide that is gibbsite sheets are combined with the help of primary valency bond to form a layer and how these layers are glued to that to form particles and they form different clay minerals. Chemical weathering results in the formation of groups of crystalline particles of colliding size less than two part two microns they are basically defined as K minerals and these clay minerals are formed when we have silica and silicates and gibbsite sheets are glued to form a layer and these are actually resulting into the different clay minerals.

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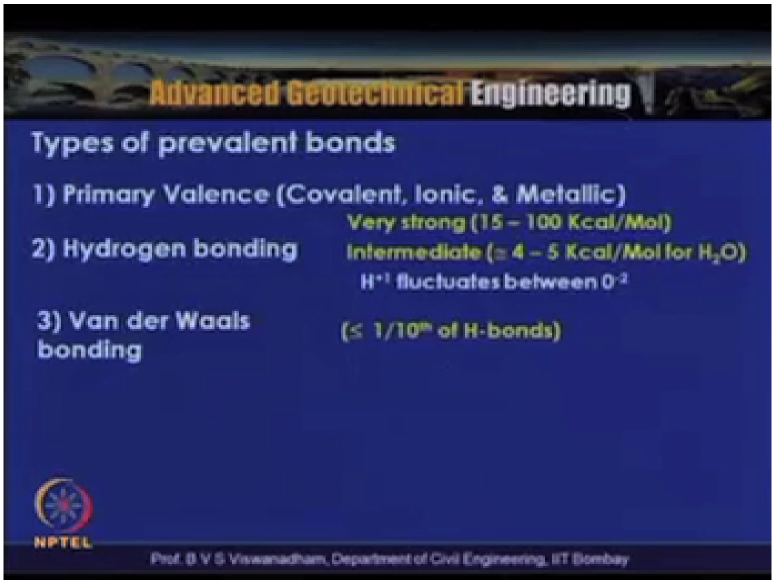

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Types of prevalent bonds

1) Primary Valence (Covalent, Ionic, & Metallic) Very strong (15 – 100 Kcal/Mol)

2) Hydrogen bonding Intermediate ($\approx$ 4 – 5 Kcal/Mol for H_2O) H^{+1} fluctuates between O^{-2}

3) Van der Waals bonding ($\leq$ 1/10th of H-bonds)

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And these sheets are bonded primarily by you know predominantly by three different types of bonds they are actually primary balance that is covalent, ionic and metallic very strong which is has, which has actually has a capacity 15 to 100 kilocalories per molecule and hydro then it is followed by hydrogen bonding which is intermediate in nature and which is actually has got a 4 to 5 kilocalories per mole for H2O and hydrogen cation fluctuates between O2, O-2 and then followed by a Van Der Waals is relatively weak morning where which is the strength is 1/10th of the hydrogen bond.

So these silicate sheets and gibbsite sheets are connected either by two sheets or three sheets and they are connected by three product bonds predominantly they are primary valence bond which is actually consists of covalent, ionic and metallic and very strong bond and which actually has got a strength of 15 to 100 kilo call calories per molecule followed by hydrogen bonding which is intermediate in nature and which is actually relatively weak compared to primary balance and but it has actually got an energy of our 4 to 5 kilocalories per molecule for a water.

And then Van Der Waals bonding which is 1/10th of the hydrogen bonding as far as the strength is concerned. So the three basic clay minerals are pure night basically these minerals are found in sedimentary and residual soils.

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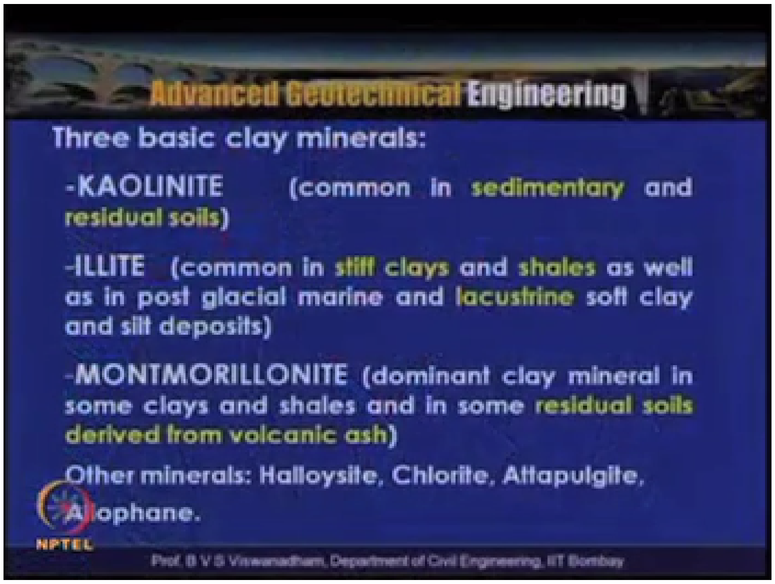

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Three basic clay minerals:

-KAOLINITE (common in sedimentary and residual soils)

-ILLITE (common in stiff clays and shales as well as in post glacial marine and lacustrine soft clay and silt deposits)

-MONTMORILLONITE (dominant clay mineral in some clays and shales and in some residual soils derived from volcanic ash)

Other minerals: Halloysite, Chlorite, Attapulgite, Allophane.

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And then illite which is actually formed in stiff clay and shales as well as post glacial marine and lacustrine soft clay and slit deposits so this illite can actually occur in summer enrollment and it common in the stiff clays and shales as well as in the post glacial marine and lacustrine soft clay and slit deposits. Montmorillonite dominant clay mineral in some clays and shales in some residual soils derived from the volcanic ash.

So the other minerals are halloysite, chloride, attapulgite, allophane so there are some other minerals also but we discuss primarily in this lecture about the kaolinite, illite and montmorillonite.

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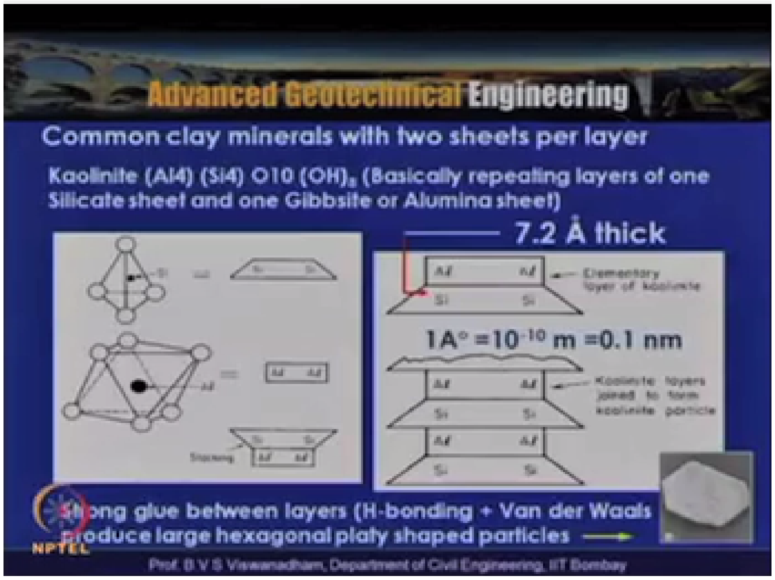

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Common clay minerals with two sheets per layer

Kaolinite (Al4) (Si4) O10 $(OH)_8$ (Basically repeating layers of one Silicate sheet and one Gibbsite or Alumina sheet)

7.2 Å thick

1A° =10^{-10} m =0.1 nm

Strong glue between layers (H-bonding + Van der Waals produce large hexagonal platy shaped particles →

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Here in this particular slide what you see is a kaolinite is a scientific formula is nothing but Al4 SI4 O10 and OH8 basically repeating layers of one silicate sheet and one gibbsite sheet or alumina sheet, so it is actually has got repeating layers of one silica tetrahedron that is the silicate sheet and alumina. So when they are glued when they are formed when they are actually attached with the bonding then it forms actually alumina sheet and silicate sheet will get attached.

So the structure of the kaolinite particle is actually written with several layers like this and this is actually about 1% 7.2 angstrom thickness one one angstrom is equal to 10^{-10}cm=0.1 nanometers so when the kaolinite layers join to form the kaolinite particle so here the strong glue between the layers hydrogen bonding and Van der Waals produce large hexagonal platy shaped particles which is actually typically shown here in this particular slide this is a platy shaped particle.

So one of the common clay mineral which we have discussed is kaolinite basically which actually has got a repeating layers of silicate sheet one silicate sheet and one gibbsite sheet and which is about 10 to 1 about 7.2 Armstrong thickness and the strong glue between the layers which actually there is a strong bonding betray is prevalent between the high that is nothing but hydrogen bonding and Van Der Waals produce Van Der Waals bonding produced large hexagonal lattice shaped particles.

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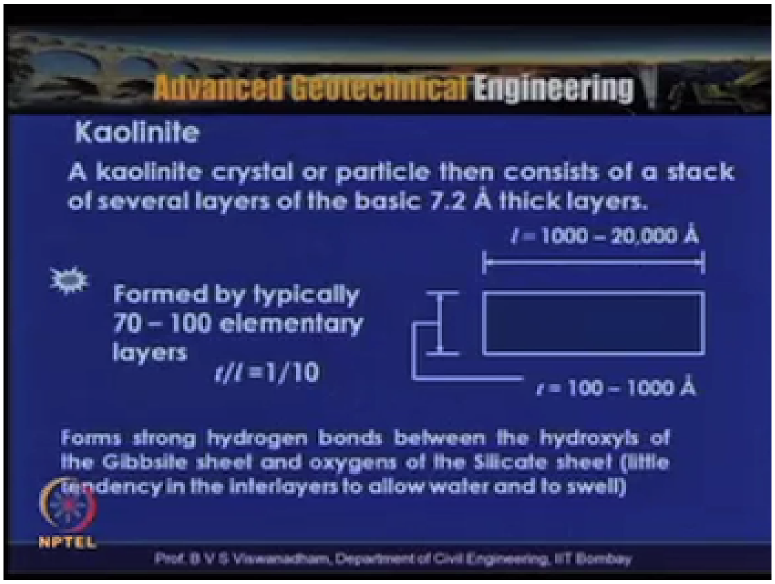

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Kaolinite

A kaolinite crystal or particle then consists of a stack of several layers of the basic 7.2 Å thick layers.

$l = 1000 - 20{,}000$ Å

Formed by typically 70 – 100 elementary layers

$t/l = 1/10$

$t = 100 - 1000$ Å

Forms strong hydrogen bonds between the hydroxyls of the Gibbsite sheet and oxygens of the Silicate sheet (little tendency in the interlayers to allow water and to swell)

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If you the kaolinite particle if you look into the length and thickness if this is the length dimension and if the thickness dimension it form would by typically 7 to 100 elementary layers the ratio of thickness to length is about 1/10 that means that the thickness to length ratio is about 1/10 a colored crystal or particle then consists of a stack of several layers of the basic 7.2 angstrom meter thick layers.

For the kaolinite crystal or particle consists of a stack of several layers of basic 7.2 angstroms thick layers, so this forms the strong hydrogen bonds between the hydraulic science of gibbsite sheet and oxygen of the silicate sheet and little tendency to the inter layers and allow water and to swell, so these particular characteristics of this mineral is that there is a little tendency to allow water and then so there is little possibility to swelling of a soil which consists of this mineral. So the thickness to length ratio is about 1/10.

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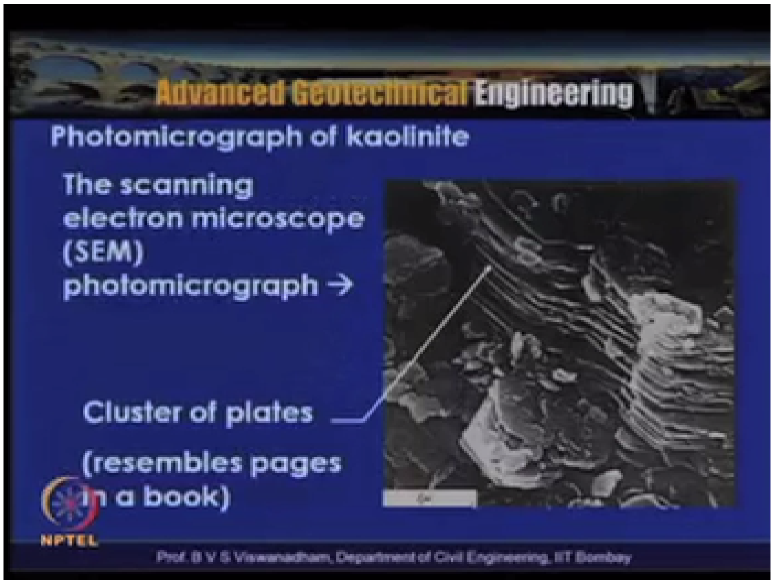

Photomicrograph of kaolinite

The scanning electron microscope (SEM) photomicrograph →

Cluster of plates

(resembles pages in a book)

Here in this a photo micrograph of kaolinite is shown the scanning electron micro photograph of the kaolinite is shown as can be seen here a cluster of the plates there assembling a pages of a book which actually is the analogous example for the kaolinite particle.

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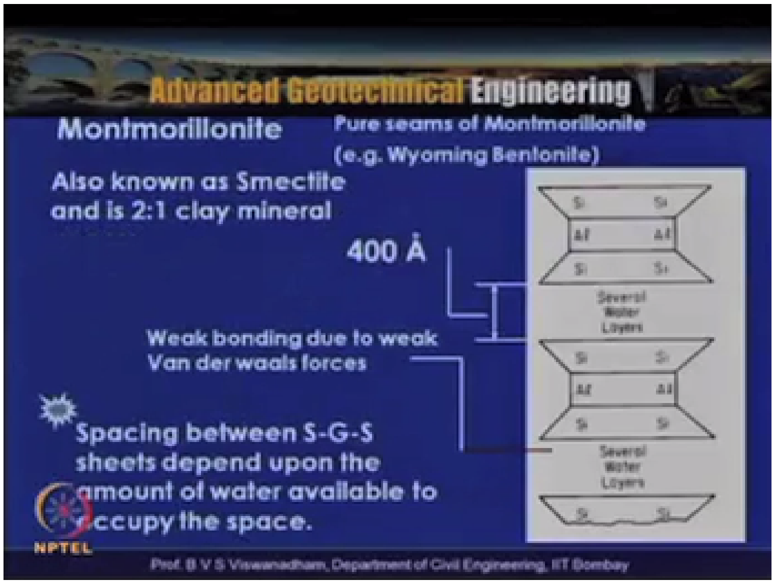
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Montmorillonite

Pure seams of Montmorillonite
(e.g. Wyoming Bentonite)

Also known as Smectite
and is 2:1 clay mineral

400 Å

Weak bonding due to weak
Van der waals forces

Spacing between S-G-S sheets depend upon the amount of water available to occupy the space.

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Montmorilonite is another mineral way you have got this is basically a 2:1 clay mineral is called a three sheet mineral and is also known as a smectite and is 2:1 clay mineral, so here we have 1 gibbsite sheet and 2 silicate sheets and they are separated by a several water layers, so we have a structure which is actually formed by two silicate sheets and one gibbsite sheet or one alumina sheet or one silica two silicate sheets forms a structure like this and which are actually strongly attached and they montmorilonite actually has got several layers of such type of this thing and they have a tendency to actually keep with the availability of the water up to 400 angstroms thick of water that means that between each inter layers between inter layer they can actually keep our have a tendency to store up to 400 angstroms thickness.

This indicates that this is actually due to weak bonding due to the weak Van Der Waals forces we have discussed that because of the weak bonding due to weak nature of the Van Der Waals forces the weak bonding is prominent. So the spacing between silica and silicate sheet and gibbsite and silicate sheet dependent upon the amount of water available to occupy the space. So in case of you know availability of the water there is a tendency for the water to enter in between these inter layers.

So montmorilonite is nothing but a 2:1 clay mineral which actually has got two sheets of silicate and one Gibson sheet separated by the possibility of can have a several water layers some water layers. So pure seems of montmorilonite one of the examples is dynamic Montmorilonite.

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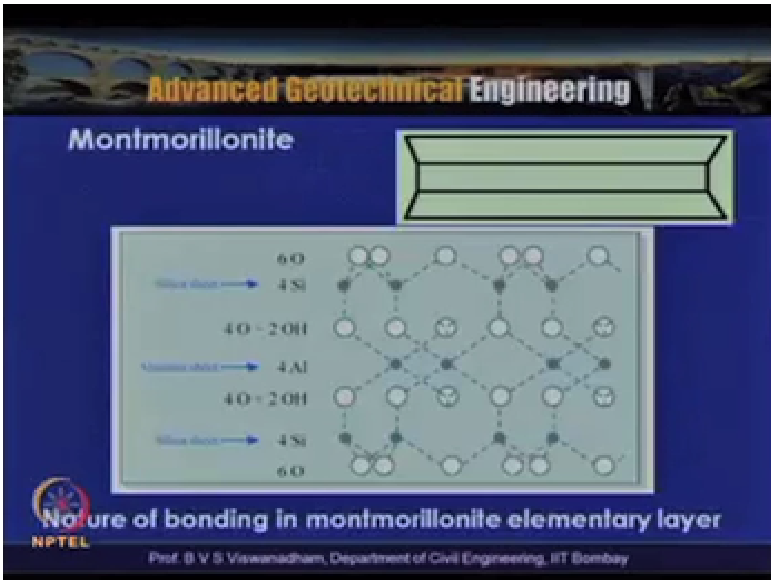
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Montmorillonite

Nature of bonding in montmorillonite elementary layer

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So here a typical the structure of the montmorilonite elementary layer is shown where in you have actually got silicate sheet and silicate sheet attached it actually between by using this gibbsite sheet so you have got two silicate sheets and one gibbsite sheet in between there is a possibility of the lot of you know water molecules to enter, so that is air at this junction at this surface and at this surface then it can actually have what several inter layers, a several layers of water.

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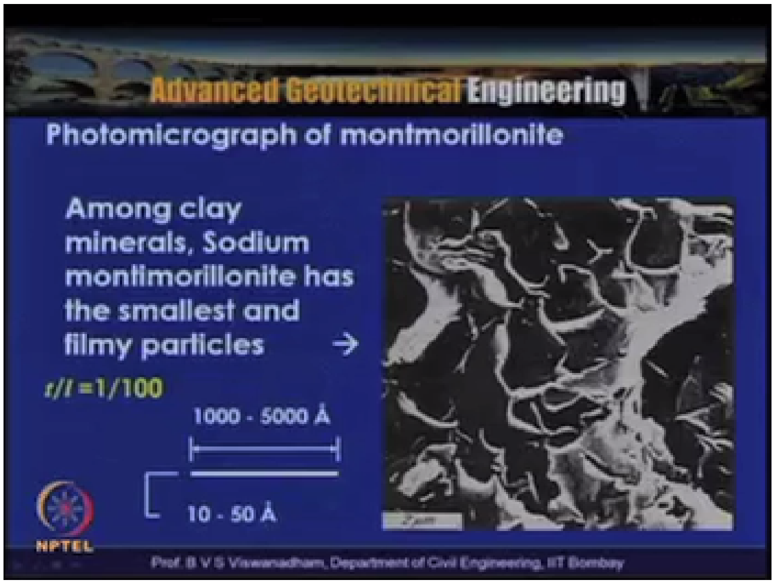

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Photomicrograph of montmorillonite

Among clay minerals, Sodium montimorillonite has the smallest and filmy particles →

$t/l = 1/100$

1000 - 5000 Å

10 - 50 Å

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So here this particular slide shows the photo micrograph of the montmorilonite among clay minerals sodium montmorilonite has the smallest and filmy particles, so what you can see is a gel type of you know tendency so which actually shows that the among the clay minerals sodium based montmorilonite that means that the montmorilonite which is actually has got sodium ion has the smallest and filmy particles if it is shown here the length ratio that is 1000 to 5000 angstroms the thickness is 10 to 50 angstroms.

So if you look this one that t/l ratio is about 1/100 that means that the t/l is 1/100 for montmorilonite.

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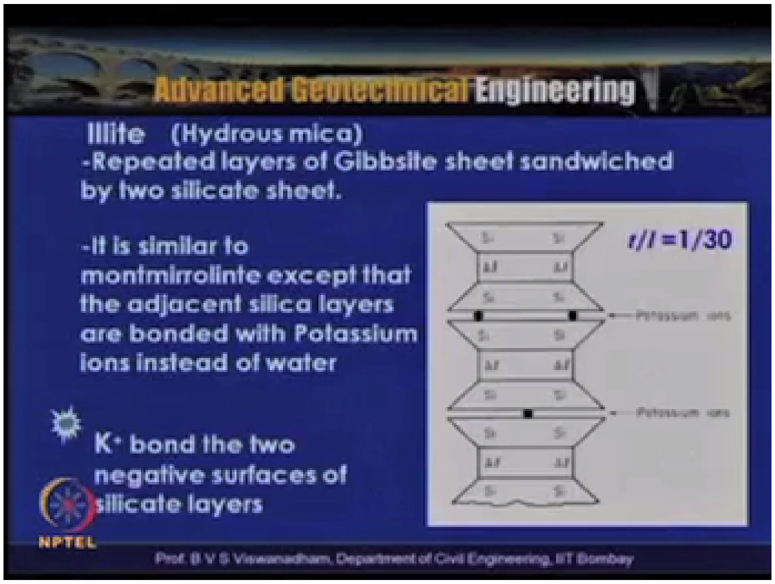

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Illite (Hydrous mica)

-Repeated layers of Gibbsite sheet sandwiched by two silicate sheet.

-It is similar to montmirrolinte except that the adjacent silica layers are bonded with Potassium ions instead of water

K^+ bond the two negative surfaces of silicate layers

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Another mineral which is illite which is also called as hydrous mica, which actually has got repeated layers of gibbsite sheet sandwiched between two silicate sheets it is similar to montmorilonite except that the adjacent silicate layers are bonded with potassium ions instead of water. So this presence of potassium ions actually bonds these 2 silicate sheets strongly so these potassium ions which are actually shown and this is particularly nothing but 2:1 clay mineral which is nothing but very similar to multiple light.

But the adjacent silicate sheets are actually bonded by with the help of potassium ions with a strong bond in case of montmorilonite adjacent and silicate sheets have a possibility to have several layers of water that is water molecules can be stored. And the t/l the thickness to length ratio is about 1/30 so potassium bond the two negative surfaces of the silicate layers, so the potassium ion wants the two negative surface of the silica sheets so this ensures that if you look the swelling tendency montmorilonite swells higher and if you compare illite it is followed by illite and then that swelling tendency of the kaolinite will be much more low.

Now having discussed about the three minerals then if you discuss along with the kaolinite then we can actually also link with whatever we have defined the specific surface area, we also discussed that the specific surface area is inversely proportional to the particle size.

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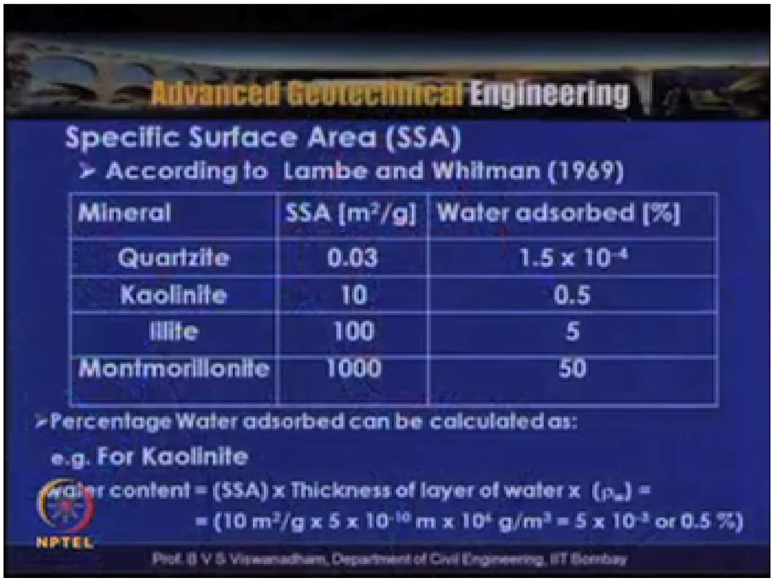

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Specific Surface Area (SSA)

- According to Lambe and Whitman (1969)

Mineral	SSA [m^2/g]	Water adsorbed [%]
Quartzite	0.03	1.5×10^{-4}
Kaolinite	10	0.5
Illite	100	5
Montmorillonite	1000	50

- Percentage Water adsorbed can be calculated as:

e.g. For Kaolinite

water content = (SSA) x Thickness of layer of water x (ρ_w) =

$= (10\ m^2/g \times 5 \times 10^{-10}\ m \times 10^6\ g/m^3 = 5 \times 10^{-3}$ or 0.5 %)

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Now here according to Lambe and Whiteman 1969 the quartzite actually has got specific surface area of $0.03m^2/g$ and the present is water absorbed is $1.5x10^{-4}$ kaolinite 0.5% illite 5% and montmorilonite 50%, so the percentage water absorb, adsorbed but it can be calculated as follows for say for example for kaolinite which is nothing but specific surface area into thickness of the layer of water into ρW the mass density of water.

So here a specific surface area of kaolinite is $10m^2/g$ $x5x10^{-10}m$ that is the thickness layer of the water and into $10^6g/m^3$ which is nothing but $5x10^{-3}$ or 0.5%. So here you know one can one thing can be observed is that the kaolinite as we go towards quartzite, kaolinite, illite and montmorilonite the specific surface area is increasing and present is what water absorbing tendency is also increasing.

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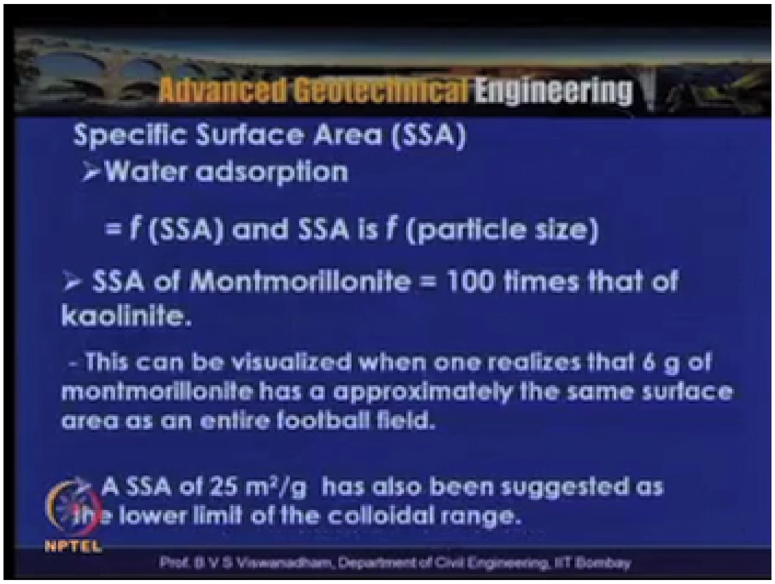

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Specific Surface Area (SSA)

- Water adsorption

  = *f* (SSA) and SSA is *f* (particle size)

- SSA of Montmorillonite = 100 times that of kaolinite.

  - This can be visualized when one realizes that 6 g of montmorillonite has a approximately the same surface area as an entire football field.

- A SSA of 25 m^2/g has also been suggested as the lower limit of the colloidal range.

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Now the specific surface area the water absorption is a function of the specific surface area and a specific surface area is a function of the particle size, so a specific surface area of montmorilonite is 100 times that of kaolinite, if you look into this the specific surface area of montmorilonite 100 times that of the kaolinite, so this can be visualized when one realizes that say 6 grams of montmorilonite has approximately has a surface area of an entire football field.

So and in a specific surface area of through $25m^2/g$ has also been suggested as the lower limit for the colloidal range, so if you take a 6 grams of montmorilonite its surface area is equivalent to be that of a football play field, so the specific surface area of the montmorilonite is 100 times that of the kaolinite.

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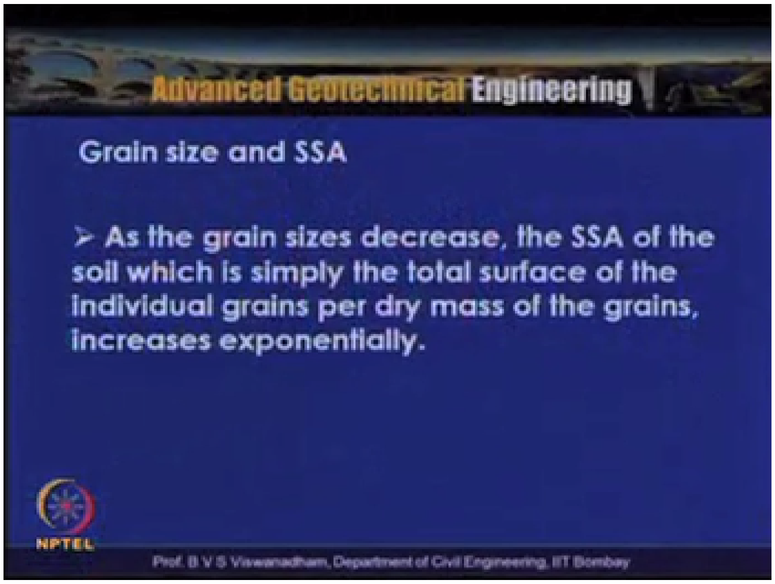

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Grain size and SSA

- As the grain sizes decrease, the SSA of the soil which is simply the total surface of the individual grains per dry mass of the grains, increases exponentially.

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So if you look this grain size and specific surface area as the grain size decreases the specific surface of the soil which is simply the total surface of the individual grains but dry mass of the grains increases exponentially.

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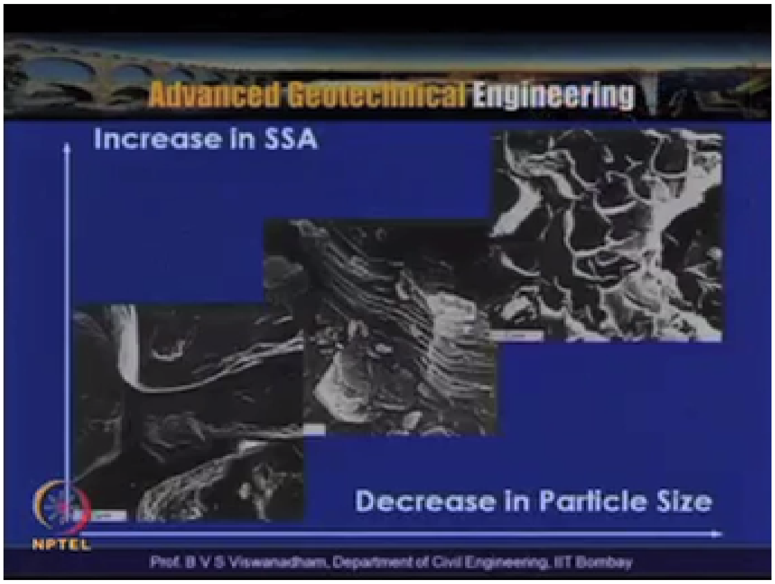

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Increase in SSA

Decrease in Particle Size

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So if you compare here the in this slide the quad site, kaolinite and montmorilonite pictures are shown micrographs are shown, so in this direction with an increase in specific surface area there is actually decrease in the particle size. So here this is prevalent in sandy type of soils this is in certain type of clay soils and then this is actually nothing but in montmorilonite type of soil.

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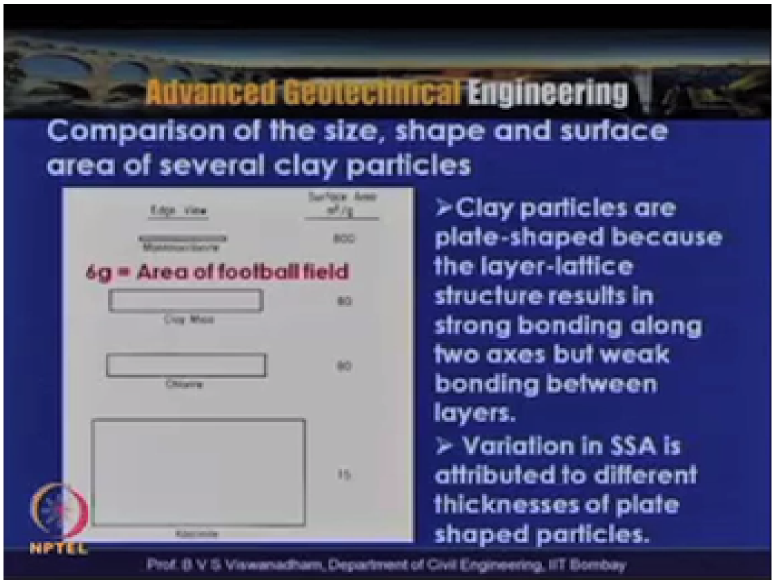

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Comparison of the size, shape and surface area of several clay particles

- Clay particles are plate-shaped because the layer-lattice structure results in strong bonding along two axes but weak bonding between layers.
- Variation in SSA is attributed to different thicknesses of plate shaped particles.

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So comparison of the size, shape, and the surface area of several clay particles if you look into it as we discuss cure light it can have a specific surface area in the range from 10 to 15 meter square per gram and then you have chloride and clay mica montmorillonite it actually has got the tendency of 60 and 80 and 800 meter square per gram. So clay particles are plate shaped particles which is evident from the discussion here and the layer lattice structure results in a strong bonding along the two axes but weak bonding between the layers and variation specific surface is attributed to different thickness of the plane shape of particles.

So the specific surface area is actually varying drastically because of the decrease in thickness of the displaced shape particles now having discussed about the clay minerals present in soil typical minerals present in soils, now let us discuss that clay and water interaction now we have discussed that.

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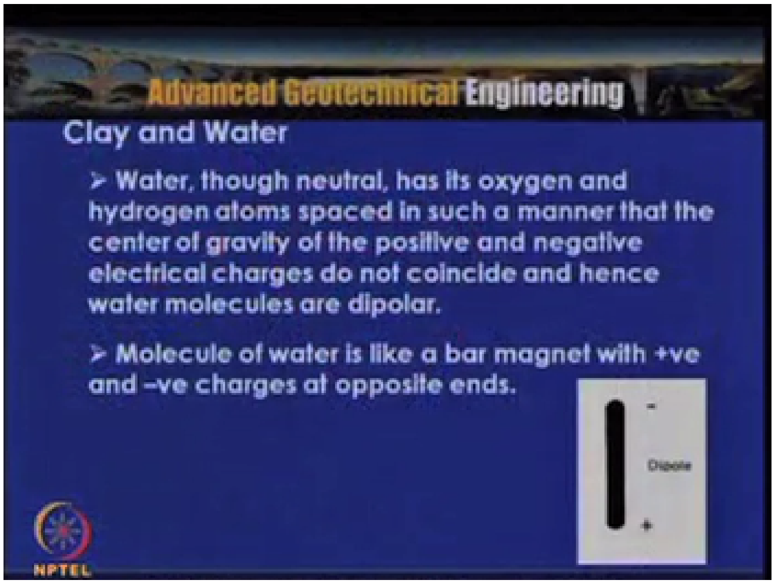

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Clay and Water

- Water, though neutral, has its oxygen and hydrogen atoms spaced in such a manner that the center of gravity of the positive and negative electrical charges do not coincide and hence water molecules are dipolar.
- Molecule of water is like a bar magnet with +ve and –ve charges at opposite ends.

The clay particle surface which is actually nothing but it negatively charged surface, so the water which is actually dipole in nature has actually has got positive we has got you know which is in the is a dipole nature water door neutral has its oxygen and hydrogen atoms specially in such a manner that the central center of gravity of the positive negative electric charges do not coincide hence water molecule is said as dipolar.

And molecular molecule of water is like a bar magnet with the positive and negative charges at the opposite ends, so the molecule of water is indicated or in is analogous to the bar magnet where positive and negative charges of Bat the opposite ends.

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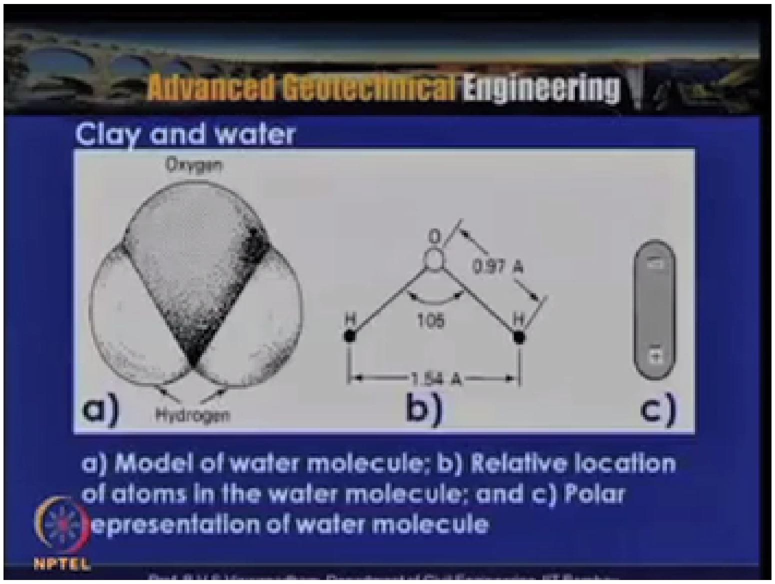

Clay and water

a) Model of water molecule; b) Relative location of atoms in the water molecule; and c) Polar representation of water molecule

So here which is actually shown atypical dipole nature model of water molecule where you have got two hydrogen cations and one oxygen anion and which is actually with the distance of 1 point4 angstroms between hydrogen and oxygen point nine seven angstroms and this polar representation of the water molecule is indicated as a the typical bar magnet.

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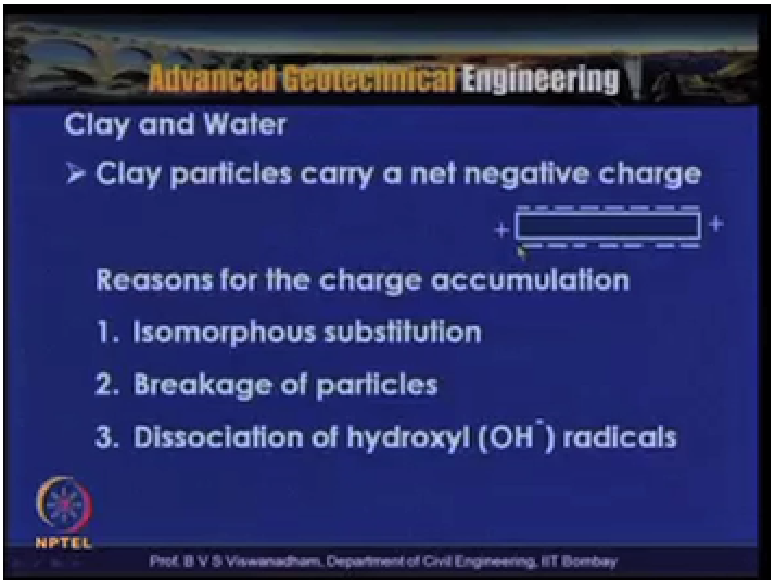

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Clay and Water

- Clay particles carry a net negative charge

Reasons for the charge accumulation

1. Isomorphous substitution
2. Breakage of particles
3. Dissociation of hydroxyl (OH^-) radicals

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So clear particles are have in net negative charge on the both the edges and is a tendency that on the at the edges they can have the positive charges there are when the particles break then they have a tendency of having also at particular breakage points they have a tendency of having the positive charges. So the reasons for this charge accumulation is one is because of the isomorphous substitution which actually takes place then I said another one is that the breakage of particles and this was disassociation of hydroxide yh-radicals.

So the reason for having clay a negative charge is that one predominant reason is that isomorphous substitution that second one is the breakage of particles and the dissociation of the hydroxyl radicals. The processes are the method the isomorphous substitution it is nothing but replacement of a cation in the mineral structure by another cation of lower valance.

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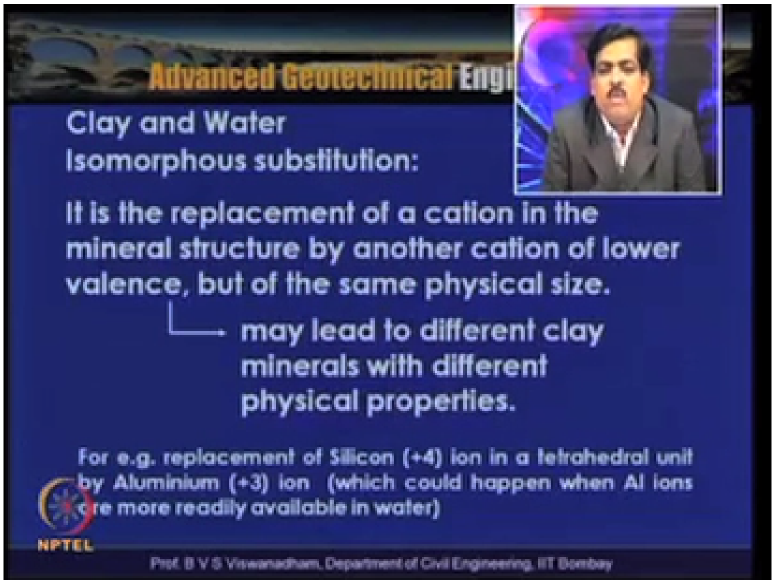

Clay and Water

Isomorphous substitution:

It is the replacement of a cation in the mineral structure by another cation of lower valence, but of the same physical size.

→ may lead to different clay minerals with different physical properties.

For e.g. replacement of Silicon (+4) ion in a tetrahedral unit by Aluminium (+3) ion (which could happen when Al ions are more readily available in water)

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But of the same physical size so the isomorphous substitution is nothing but replacement of a cation in the mineral structure by another cation of lower valance but of the same physical size. So this may lead to different clay minerals with the different physical properties because of this isomorphous substitution there is a tendency to form different clay minerals with different physical properties, so consider for example replacement of silicon that is +4 valence ion in a tatrail had a unit by aluminum plus 3 ion which could happen when aluminum ions are more abundantly available in water when aluminum cations are more abundantly available then this process of this isomorphous substitution can take less.

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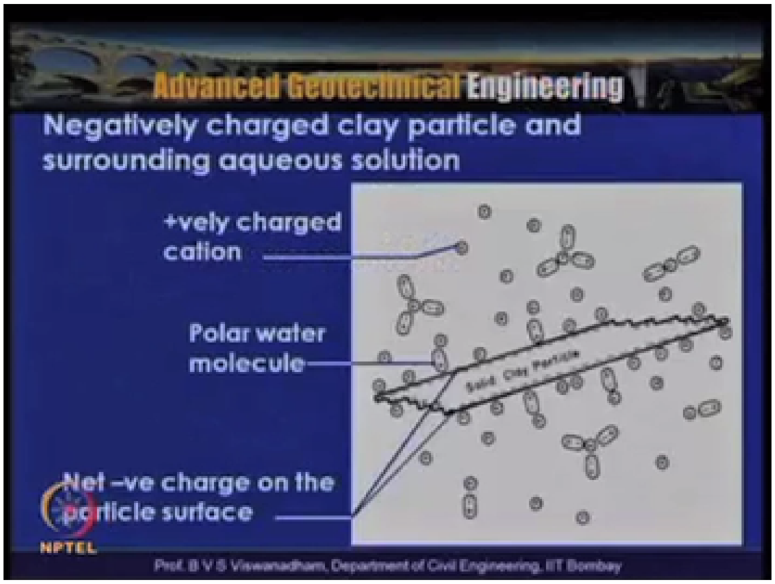

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Negatively charged clay particle and surrounding aqueous solution

+vely charged cation

Polar water molecule

Net –ve charge on the particle surface

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Because of this the typical exclave particle which is actually shown here has a negative surfaces on these edges and some positive on these along these surfaces and along this at the breakage points the positive charges are actually shown and the polar water molecule if it is represented as positive and negative so it is actually attracted towards the clay particle surface because of the negative charge here and the positive charge here and the cations which are actually present in water are the positively charged cations and prior charged water they are also attracted towards the you know clay particle.

So the net negatively charged charge on the clay surface is actually shown here and here these are the positive charged cations present in the water, and this is because of the polar water molecules they are also arranged in this because of this attraction.

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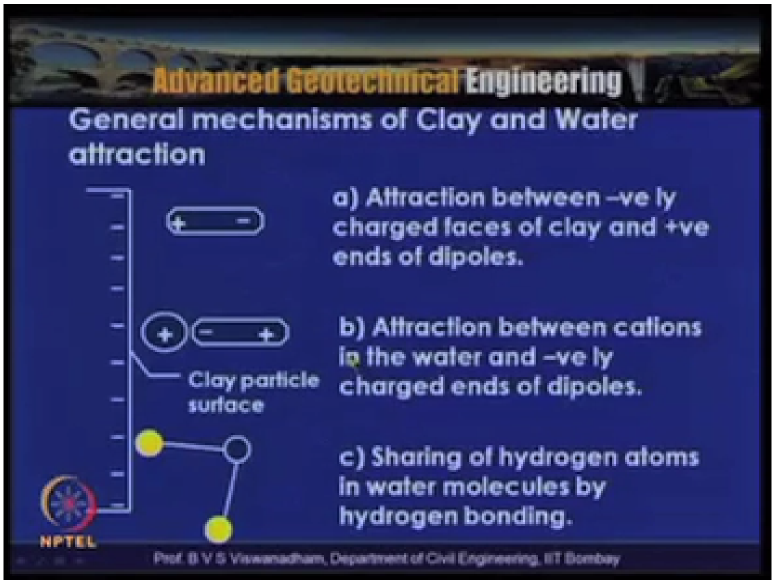

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General mechanisms of Clay and Water attraction

a) Attraction between –ve ly charged faces of clay and +ve ends of dipoles.

b) Attraction between cations in the water and –ve ly charged ends of dipoles.

c) Sharing of hydrogen atoms in water molecules by hydrogen bonding.

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So the mechanism of clay and water interaction can be explained by the three heads one is the attraction between natively charged interfaces of clay and positive and soft dipoles that is attraction between neatly charged clay surface and positively positive end of the dipole that is negative charged with laser face and a positive end of the dipole and attraction between cations in the water and negatively charged the end of dipoles that is attraction between cations in the water cations in the water.

And negatively charged ends of the dipoles and sharing of the hydrogen atoms in water molecules by hydrogen bonding sharing of these hydrogen atoms in water molecules but in the form of the hydrogen bonding. So this actually explains the general mechanism of the clay water attraction.

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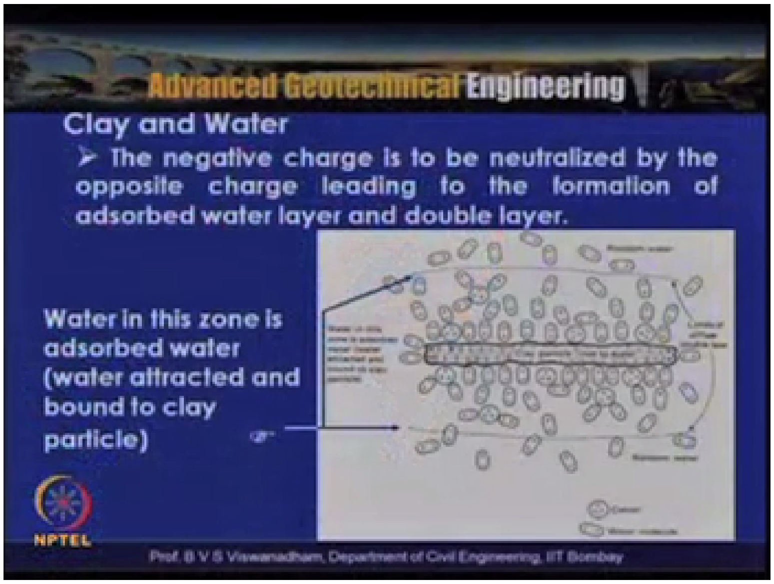

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Clay and Water

- The negative charge is to be neutralized by the opposite charge leading to the formation of adsorbed water layer and double layer.

Water in this zone is adsorbed water (water attracted and bound to clay particle)

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So if you look into this the negative charge is to be neutralized by opposite charges leading to the formation of a absorbed water layer and double layer, so here because of this particular observation what we made in the previous slides, so the water molecules are arranged in a some fashion here and here up to certain distance you will see that the positive cations and these are actually attracted and attached closely and this particular zone is actually called adsorbed water layer or a double water layer so water in this zone is absorbing water attracted and that bound to the clay particle very strongly.

And the water this is the boundary of that water layer and this water is actually nothing but which is called a free water array the absorber water and this is called adsorbed water the water which is actually strongly attached to the clay particle surfaces.

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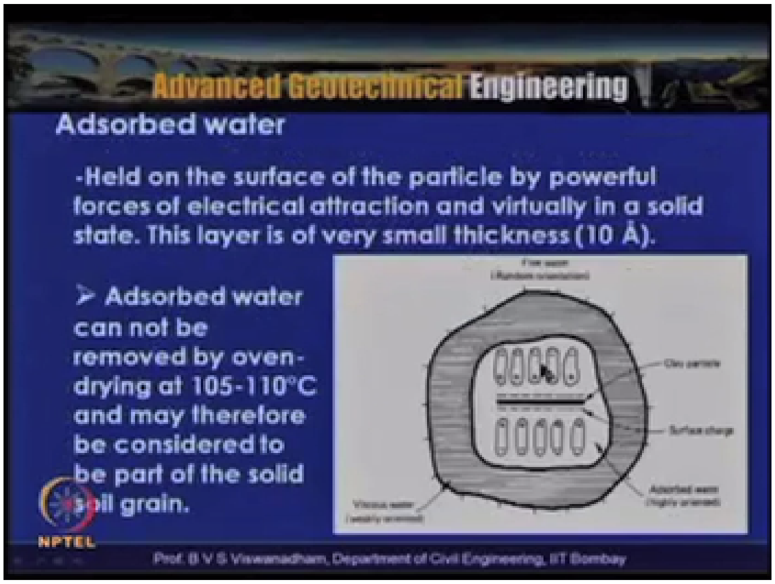

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Adsorbed water

-Held on the surface of the particle by powerful forces of electrical attraction and virtually in a solid state. This layer is of very small thickness (10 Å).

- Adsorbed water can not be removed by oven-drying at 105-110°C and may therefore be considered to be part of the solid soil grain.

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So here the typical cross-section of the other you know more explanation it is actually given here where you have what clay particle a cross-section which of the clay particle is shown here there is neatly charges and here the polar water molecules which are actually arranged and then this particular water is this is the absorber water and this is weakly oriented or low viscous or free water molecules in this case it is said that the viscosity is so high or isolate structure where the water molecules are strongly attached to the clay surface.

So the absorber water cannot be removed by oven drying at one not phi2 110^0 centigrade and may therefore be considered as a part of the solid soil grain and the these absorber water is generally held to the surface of the particle by powerful forces of electrical attraction and virtually in a solid state, and this is actually this thickness of this a draws a absorbed layer on one side of the clay particle or define the one edge of the clay particle is said as about 10 angstroms thickness.

So this cannot be removed by oven drying and if the if the temperature actually increases then there is a possibility that the structure of the soil has a tendency to get distorted or change.

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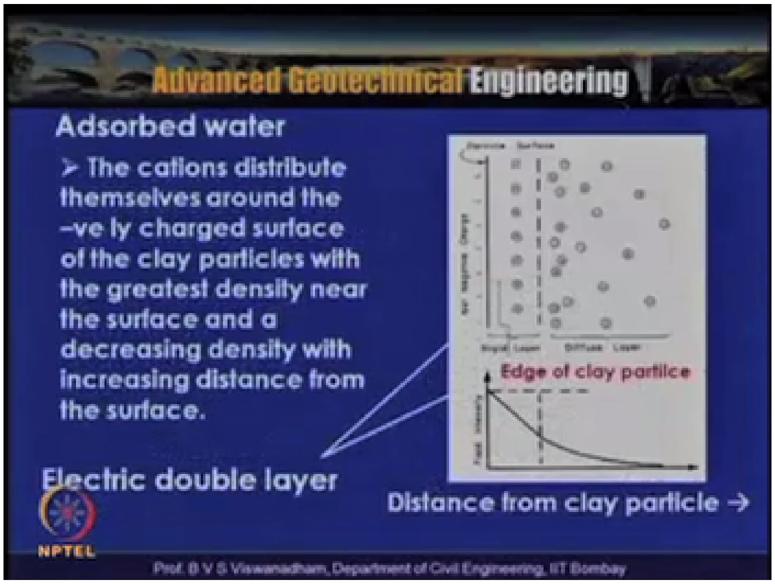

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Adsorbed water

- The cations distribute themselves around the –ve ly charged surface of the clay particles with the greatest density near the surface and a decreasing density with increasing distance from the surface.

Electric double layer

Distance from clay particle →

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So here in this absorber water and here this is the edge of the clay particle and here there is a rigid layer which is actually has got properly oriented cations and water molecules which are actually shown and here this oriented water molecules which are actually there which is actually shown here, so if you see from here the distance from the clay particle and the field intensity which decreases from the edge of the pure particles to go when you go away from the clay particle distance.

So the cations disposed them distribute them around the negative charges surface and of the clay particles with the greatest density near the surface now great the intensity will be very high and as you go away from the array particle it actually decreases. The similar situation through wells on the other side of the clay particle also, so the nature of the electric double layer affects the structure of the aggregates of the clay particles and hence the physical properties of the soil.

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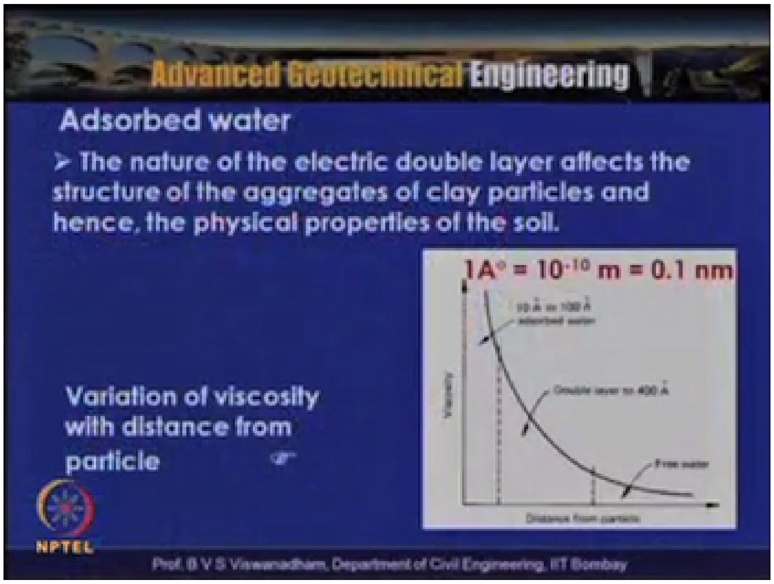

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Adsorbed water

- The nature of the electric double layer affects the structure of the aggregates of clay particles and hence, the physical properties of the soil.

$1 A^{\circ} = 10^{-10}$ m = 0.1 nm

Variation of viscosity with distance from particle

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Here again one angstrom is equal to ten to the minus ten meters or equivalent to 0.1 nanometers, so the thickness of the it is said that the viscosity said to be very high close to the clay particle, so here this is the edge of the clay particle let us say this is the edge of the clay particle as you go away from that you actually have a adsorbed layer and some double layer of water up to 400angstroms thickness and then followed by a free water.

So as if this is one set of the particle then other side of the particle also it actually has got the similar distribution of viscosity, so at close to the clay particle there is a tendency that the water which is said that has got a ice-like tendency with a very viscosity very high viscosity close to the clay particle.

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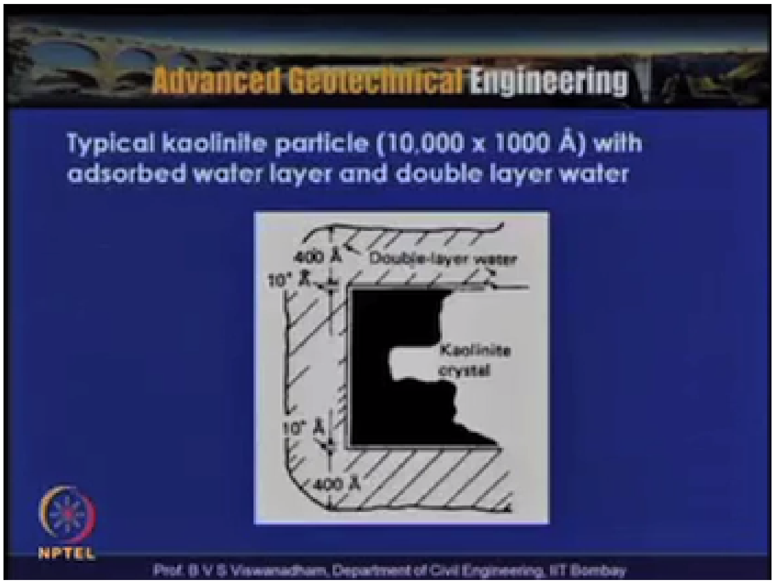

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Typical kaolinite particle (10,000 x 1000 Å) with adsorbed water layer and double layer water

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So in this particular slide a typical ko9 particle with 10,000 x 1000 times angstrom with absorbed layer and double layer water is shown here, so here this is the kaolinite crystal which is relatively large and you here we have 10 angstroms and then the double layer thickness which is actually shown here. So this is that adsorbed water layer surrounding the kaolinite particle.

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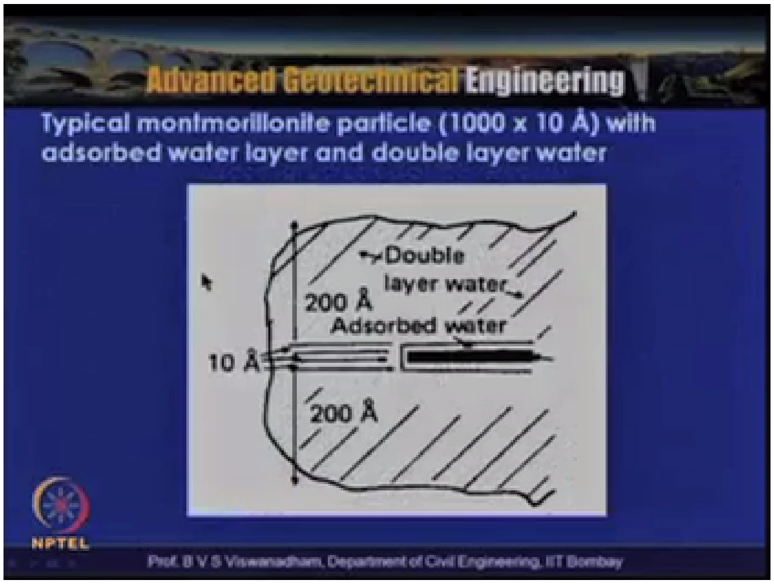

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Typical montmorillonite particle (1000 x 10 Å) with adsorbed water layer and double layer water

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And typical in this slide a typical montmorillionite particle which is 1000 x 10 angstrom, so here the double layer water which is actually amounting to about 200 angstroms and the adsorbed water layer surrounding the clay particle is about10 angstroms thickness where actually it possesses very high viscosity is shown in this slide.

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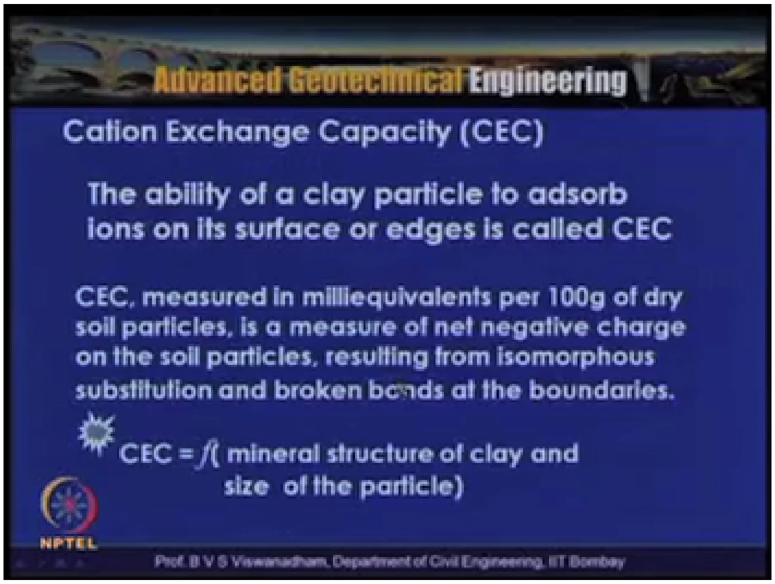

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Cation Exchange Capacity (CEC)

The ability of a clay particle to adsorb ions on its surface or edges is called CEC

CEC, measured in milliequivalents per 100g of dry soil particles, is a measure of net negative charge on the soil particles, resulting from isomorphous substitution and broken bonds at the boundaries.

- CEC = f(mineral structure of clay and size of the particle)

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So having discussed about clay minerals clay water particle interaction clay particle and water interaction and we also have defined that the specific surface area and there is another parameter which we called cation exchange capacity which is called CEC which is in which is referred here as CEC the ability of a clay particle to adsorb ions on its surface or ingest is called cation exchange capacity.

The CEC is basically measured in milliequivalents per 100 grams of dry soil particle in is a measure of the net negative charge on the soil particles resulting from the isomorphous substitution and broken bonds at the boundaries, so CEC's function of the mineral structure of the clay and size of the particles. So the CEC is nothing but which actually measures the net negative charge on the soil particles resulting from the isomorphous substitution or broken bonds at the boundaries so CEC is a function of the mineral structure of the clay and the size of the particle.

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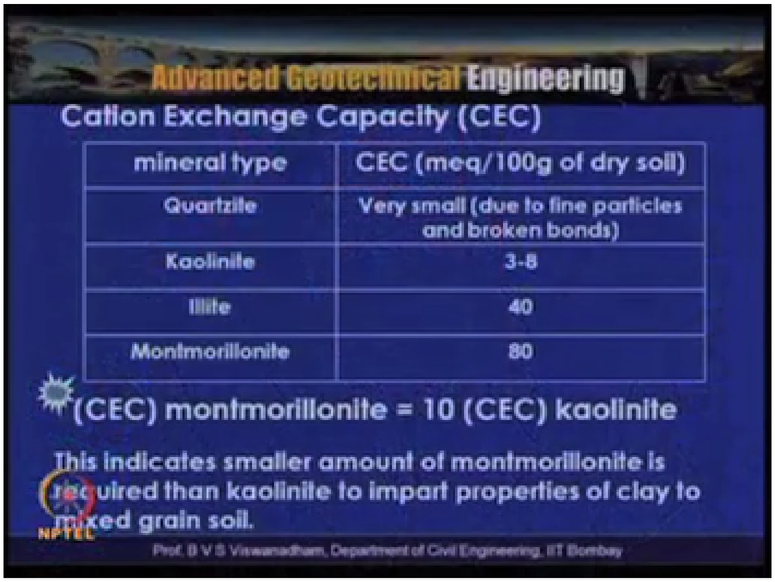

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Cation Exchange Capacity (CEC)

mineral type	CEC (meq/100g of dry soil)
Quartzite	Very small (due to fine particles and broken bonds)
Kaolinite	3-8
Illite	40
Montmorillonite	80

(CEC) montmorillonite = 10 (CEC) kaolinite

This indicates smaller amount of montmorillonite is required than kaolinite to impart properties of clay to mixed grain soil.

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So the cation exchange capacity is in units of milliequivalents or 100g of dry soil of quartzite kaolinite illite and montmorillonite are given here and where we have got two very small due to fine particles and broken bonds this is very small and kaolinite actually has got three to eight illite actually has got 40 and montmorillonite is 18 the CEC of montmorillonite is 10 times the CEC of kaolinite similarly the specific surface area of the montmorillonite is 100 times the specific surface of the key on light.

But when you look into this basement surface of montmorillonite it is about the 10 times of the CEC of the kaolinite. So this indicates that the smaller amount of multiple light is required than QM light to impart the properties of clay to mix in grain soil, so if they a smaller amount of multiple light is actually mix and that can actually impart its properties then a you know larger fraction of you is of clay kaolinite.

So this indicate that smaller amount of montmorillonite is required than kaolinite to impart properties of clay to the mixed grain soil.

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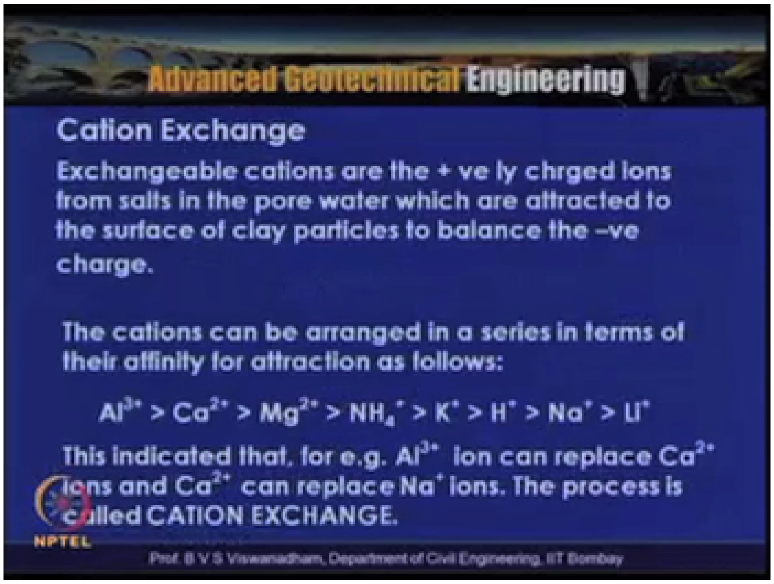

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Cation Exchange

Exchangeable cations are the + ve ly chrged ions from salts in the pore water which are attracted to the surface of clay particles to balance the –ve charge.

The cations can be arranged in a series in terms of their affinity for attraction as follows:

$$Al^{3+} > Ca^{2+} > Mg^{2+} > NH_4^{+} > K^{+} > H^{+} > Na^{+} > Li^{+}$$

This indicated that, for e.g. Al^{3+} ion can replace Ca^{2+} ions and Ca^{2+} can replace Na^{+} ions. The process is called CATION EXCHANGE.

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See the cation exchange capacity the exchangeable cations or the positively charged ions from salts in the pour water which are attracted to the surface of the clay particles to balance this negative charge the cations can be arranged in a series in terms of their affinity for attraction as follows aluminum 3 + c 8 2 + + mg 2 + NH 4 + k + h + n a + and lithium + this indicate that for example aluminum 3 + ion can replace calcium 2 + and the calcium 2 + can replace sodium ion so this process is called cation exchange.

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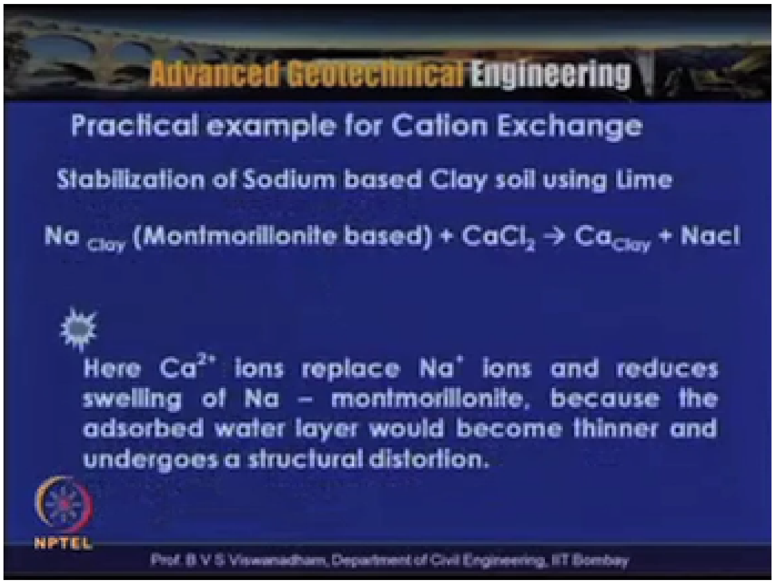

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Practical example for Cation Exchange

Stabilization of Sodium based Clay soil using Lime

Na_{Clay} (Montmorillonite based) + $CaCl_2 \rightarrow Ca_{Clay}$ + Nacl

- Here Ca^{2+} ions replace Na^{+} ions and reduces swelling of Na – montmorillonite, because the adsorbed water layer would become thinner and undergoes a structural distortion.

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So the practical example of for the cation exchange is that which is used is that the stabilization of sodium based clay soil using line if you look into the sodium clay montmorillonite base and if it is a if it is added with calcium chloride then there is a calcium clay and sodium chloride is formed, so here what happens is that the calcium 2 plus ions replace any a plus ions and reduce the swelling of sodium montmorillonite because of this the adsorbed water layer would become thinner and undergoes a structural distortion.

So that affinity for keeping water decreases because of this, so this is actually used or this is how the concept of the lime stabilization which is actually used for strengthening as a stabilization measure used in practice for soils which actually contain multiple light basal soils in the field. So here the structure of the clay soils which actually shown the fine-grained soils.

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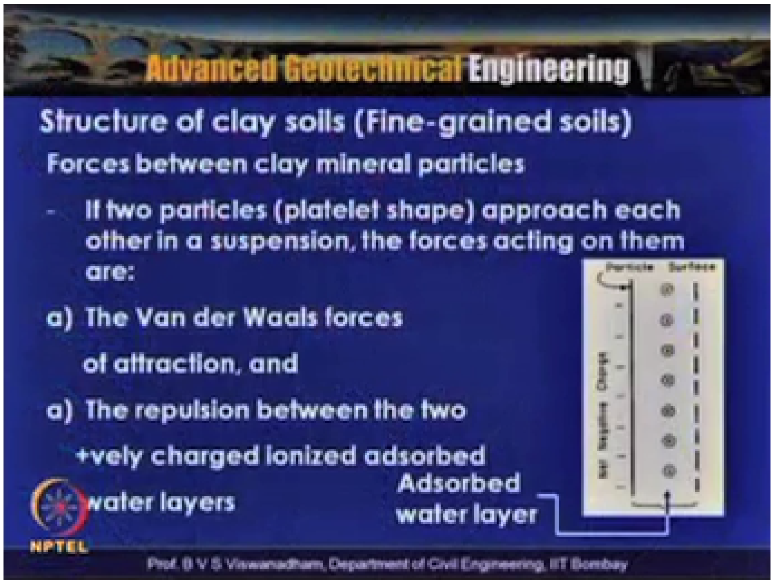

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Structure of clay soils (Fine-grained soils)

Forces between clay mineral particles

- If two particles (platelet shape) approach each other in a suspension, the forces acting on them are:

a) The Van der Waals forces of attraction, and

a) The repulsion between the two +vely charged ionized adsorbed water layers

Adsorbed water layer

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The forces between clay mineral particles if the two particles basically we have discussed it that the clay particles are platelet particles and they have a net negative charges, so there is always a possibility that is too full of particles of petrol particles have a tendency to get repulsive tendency they can actually have a repulsive tendency or if they are actually have got the positive charges then there is a possibility of the attraction.

So if the two particles platelets ship would approach each other in a suspension the forces acting on them are or the Vander Waals forces of attraction the repulsion between the two positive charges ionized absorbed water layers. So the Van der Waals forces of attraction or the repulsion between the two positively charged I you know easily above water layers. So here it is atypical lately charged clay surface which is actually shown here.

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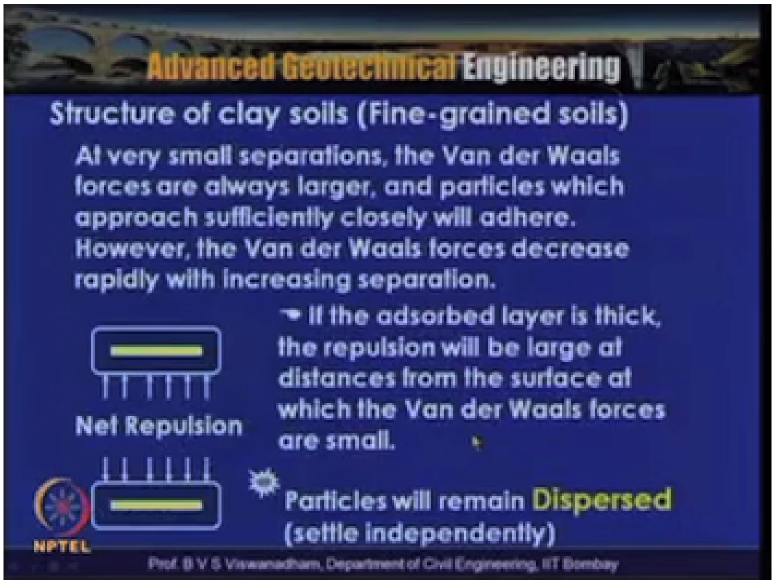

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Structure of clay soils (Fine-grained soils)

At very small separations, the Van der Waals forces are always larger, and particles which approach sufficiently closely will adhere. However, the Van der Waals forces decrease rapidly with increasing separation.

- If the adsorbed layer is thick, the repulsion will be large at distances from the surface at which the Van der Waals forces are small.

- Particles will remain Dispersed (settle independently)

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So because of this particular phenomenon one of the clay structure the soil structure which we are not discussed so previously we have discussed that if you have what a large particles there is a possibility of the bulk structure or the what we said is that bulk structure then we also discussed for some certain silt particles there is a possibility that you have what honeycomb structure but we actually have not discussed about the type of the structure which is actually prevalent in fine-grained soils.

So as we have actually discussed that the fine-grained soils actually has negatively charged the clay particles and which are basically have a plate shaped part which basically they are plate shaped particles, so if you look into this here you have got a two plate shaped particles which are actually surrounded by these absorbent and double layers and there is always a tendency of the net repulsion. So at very small separations the Vander Waal forces are always larger and the particles which approach sufficiently closely will had air however the Van der Waals forces decrease rapidly with increasing separation.

So if the absorber layer is thick the repulsion will be large at the distances from the surface which from the surface at which the Van der Waal forces are small so the particles will remain dispersed and settle independently.

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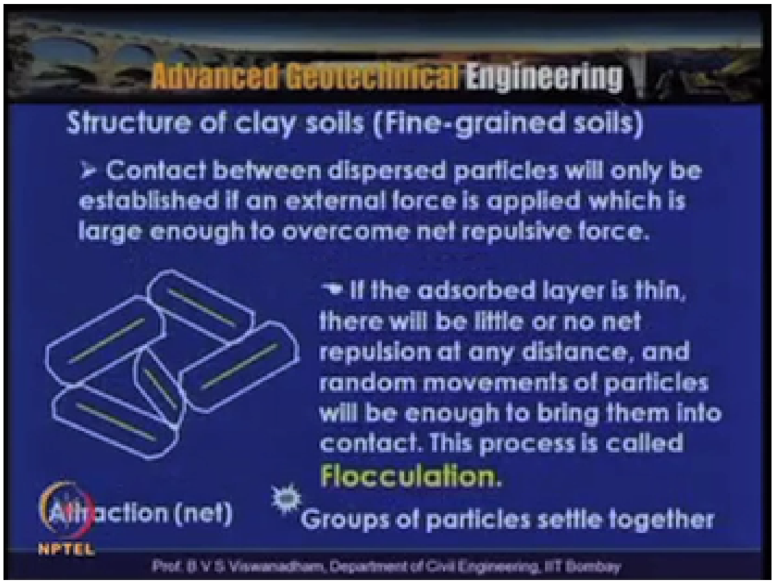

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Structure of clay soils (Fine-grained soils)

- Contact between dispersed particles will only be established if an external force is applied which is large enough to overcome net repulsive force.

- If the adsorbed layer is thin, there will be little or no net repulsion at any distance, and random movements of particles will be enough to bring them into contact. This process is called **Flocculation.**

Attraction (net)

Groups of particles settle together

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So if you have the structure of the clay soils particularly in the fine grained soils you have got say you have got particles which are actually how AG to face orientation then they have a tendency of the for flocculation so if the adsorbed water layer is thin and there will be little or no net repulsion at any distance and the random movements of particles will be enough to bring them into contact and this process is called fluctuation.

So what we said is that because of the repulsive forces there is a possibility of some structure which is actually can occur it is because of the dispersal structure is called is called dispersed structure and because of the thinner adsorbed layer and absence of any repulsion then there is a possibility of the flocculation. So net force if it is attraction then you have a flocculation the groups of particles they actually settle together.

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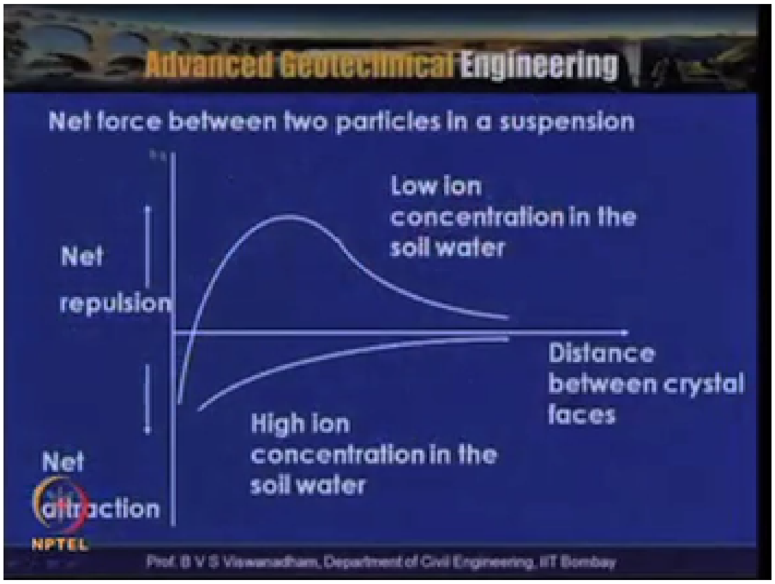

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Net force between two particles in a suspension

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So this is actually explained that net force between the two particles in suspension if you look into this net repulsion where you have what a low ion concentration in salt water in soil water in this in the soil then there is a possibility of you know repulsion which actually takes place and when you have what high ion concentration in the soil world in the in the soil water there is a net attraction takes place.

So this particular type of environment makes actually two different types of structures particularly called flocculent and dispersed structures, so in this particular lecture what we try to understand is that we define a specific surface area then we also discussed about the how the specific surface area or cation exchange capacity are varied with reference to the three fundamental three clay minerals and we also discussed about different types of clay minerals and the basic structures which are actually like the gibbsite sheet and the silicate sheet.

So kaolinite is not but you have got a two sheet mineral and multiple light is nothing but 2 : 1 and mineral it is called at two sheets of silicate and one gibbsite sheet and similarly yogurt and two and you like you like mineral which is actually formed by also nothing but 2:1 mineral but is actually has got two edges and silicate sheets are bonded with potassium cations strongly, so in the next lecture we are going to discuss about the introduce ourselves we ourselves to this particular flocculent dispersed structures and then we will discuss further on the different types of clay minerals particularly other than this kaolinite montmorillonite light like some structures of illite muscovite etcetera.

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