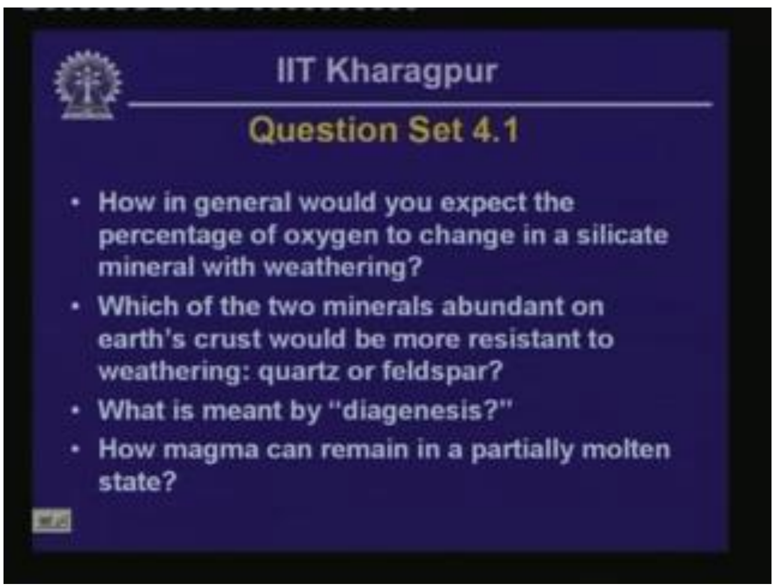
Engineering Geology
Prof Debasis Roy
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

Lecture - 9
Origin and Types of Soil

Hello everyone and welcome to this new lesson on engineering geology. Today we are going to discuss about types and origins of different types of, different soils that are found across the world and before we take up the subject matter of this lesson, we are going to look back at the questions that I gave when we were making the last presentation and the questions that are asked are on the slide here.

(Refer Slide Time: 1:16)

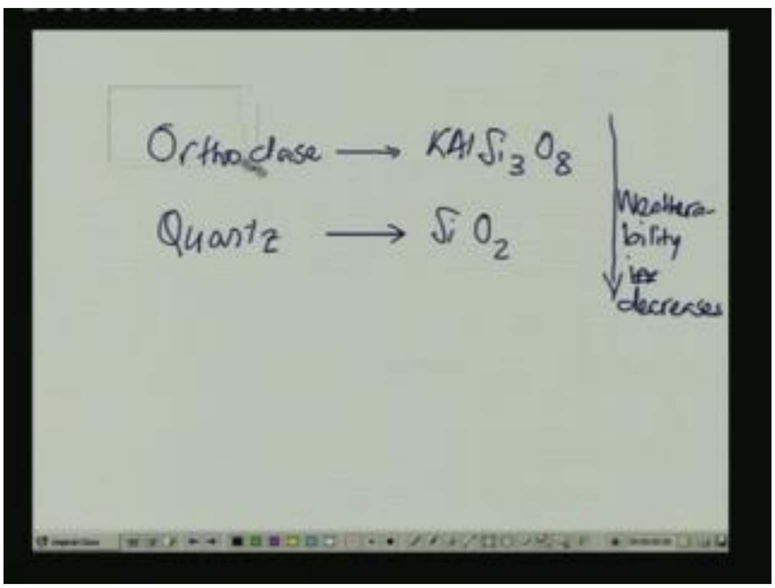


The first question that I gave you was how in general would you expect the percentage of oxygen to change in a silicate mineral with weathering? So, what happens typically is that if you consider, if you consider the Bowen's reaction series, then you will find that the silicate minerals actually will have higher percentage of oxygen in comparison with silica near the top of the reaction series and as you come down, the oxygen percentage becomes smaller in comparison with silica, in comparison with the silica content.

Now, to give you an example actually, the feldspars typically will have a radical of this type; feldspars if you recall, you will have let us consider potassium or orthoclase actually which occur little bit up on the Bowen's reaction series. The formula of potassium feldspar or orthoclase is this; it is essentially potassium alumino silicate whereas as you come down, actually this is becoming a little bit fuzzy, let me open up a fresh page for doing this.

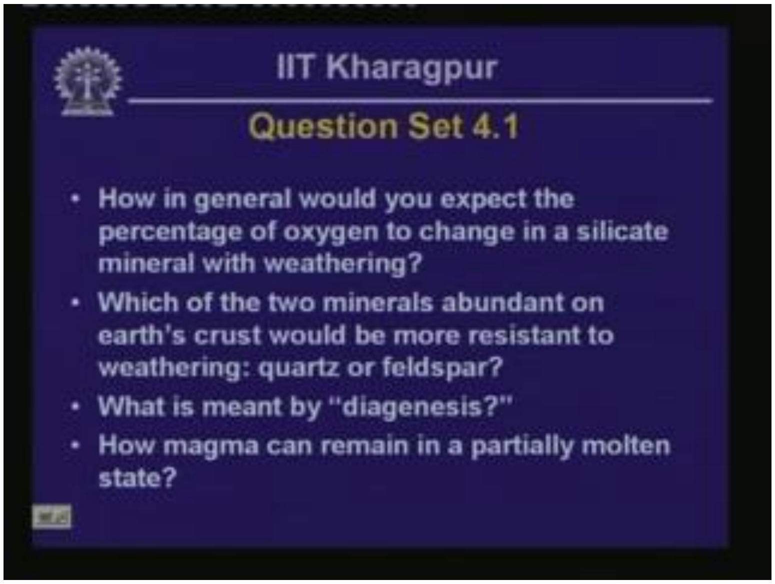
So, what we are saying here is that orthoclase mineral has got a chemical composition as given by this formula here. It is essentially potassium alumino silicate and it occurs high on Bowen's reaction series in comparison with quartz, quartz has got a chemical formula of simply SiO_2. You can see that you can, actually this clearly shows how the oxygen as a percentage of silica changes as you climb down the Bowen's reaction series.

(Refer Slide Time: 3:30)



So, this is the direction, let us say if we can coin the word weatherability, then that increases, that actually decreases sorry not increases, decreases as we climb down Bowen's reaction series. So, you can see how percentage of oxygen changes as you climb down Bowen's reaction series. Getting back to the question set, the second question was which of the two minerals abundant on earth's crust would be more resistant to weathering? I gave you the two minerals - quartz and feldspar and quartz, if you recall the Bowen's reaction series, quartz actually occurs at the bottom of the reaction series and feldspar occur a little bit high above.

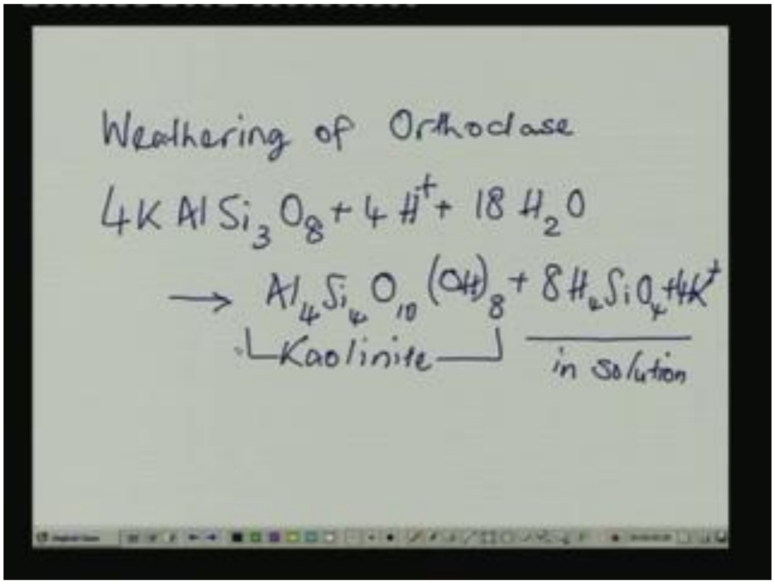
(Refer Slide Time: 1:16)



So, the susceptibility of quartz weathering is going to be much smaller in comparison with feldspar and actually feldspar really is different; it is not a single type of mineral, there are different types of feldspars. It could be containing potassium or it could contain sodium or it could contain aluminum. So, these different types of feldspars are also susceptible to weathering, to a chemical weathering actually to a different two different extents. Now, sodium feldspar is typically more resistant to weathering than the other types of feldspars that I was just now mentioning.

Now, the third question that was asked was what is meant by the term diagenesis. Diagenesis is really chemical change form one type of mineral to another type of mineral. I will give you an example; let us consider again the weathering of feldspar and also weathering of orthoclase mineral. I mentioned that orthoclase is simply potassium alumino silicate and the weathering, a major weathering, chemical weathering goes like this; it occurs in a little bit acidic environment in the presence of ground water and what you get out of this thing is a mineral called kaolinite given by this formula that I am just writing and that releases silicic acid and this is in solution actually, this remains in solution and it also releases potassium ion; so this one, these two things, species - chemical species are in solution and this one is kaolinite, as I mentioned, this one here.

(Refer Slide Time: 06:40)

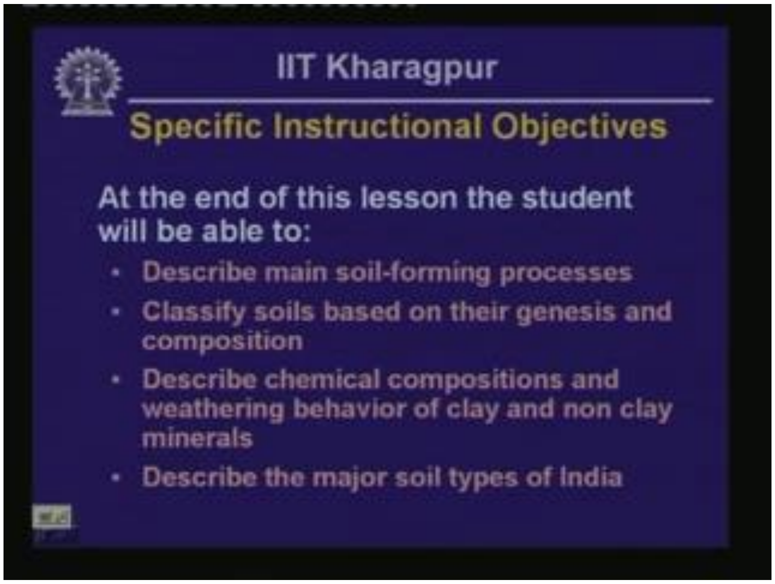


So, that is a reaction which could be classified as diagenesis. So, you can see that the chemical characteristic of the original parent material actually gets altered into a different type of material. So, that sorts out the second problem, second question that I asked - getting back once again - or the third question rather.

The fourth one, the fourth question that I asked that was how magma can remain in a partially molten state? So, magma can be a composition of several different mineral species as I indicated in the last presentation and all these minerals have got different boiling points and as a result the mixture can remain in a partially molten state under different types of environmental values which are pressure, the chemical environment and temperature.

So, basically the magma, the magma essentially could remain in molten state because of the difference in boiling point, difference in melting points rather of different types of mineral species that is contained within the body. So, that is actually wraps up the question set and then we get into the objectives of this particular lesson.

(Refer Slide Time: 9:54)

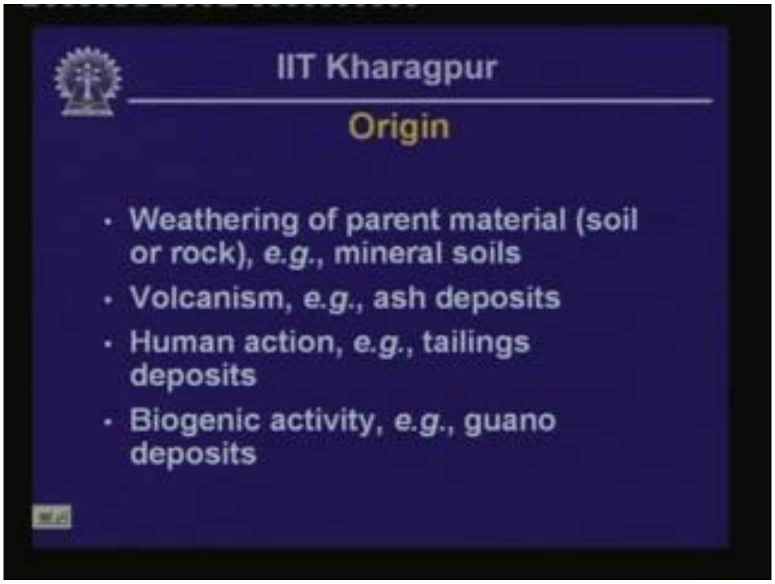


What we are going to discuss in this lesson is essentially different types of soil forming processes, we are also going to discuss about what are the different types of different types of soils that develop because of these processes from parent rock and also we are also going to look at the compositional characteristics of different types of soils and how do we, what are the principles really of classifying these soils and finally, we are going to look at the inventory of different soil types that we come across the nation.

So, these things are listed here on the slide. So, you can have a look at it again; we are going to discuss the soil forming process, we are going to classify as I indicated and different types of soils based on genesis, different formation processes really and composition and then we are going to describe compositional and weathering behavior of different types of minerals that composes these different types of soils and we are going to describe the different soil types that one would encounter, is likely to encounter rather in different parts of the country.

Now, origin of soils; how soils originate basically? The major processes involved there include weathering of parent material which is essentially soil, preexisting soil or rock mass and these things actually give rise to a class of soils called mineral soils, then another process that can give rise to soil deposits is volcanism. As a result of volcanism, directly soil deposits can form and example of this thing is volcanic ash and mummy sands, then soils would also develop because of human action like tailings dams, tailing deposits where mining activities, because of mining activities waste materials get dumped.

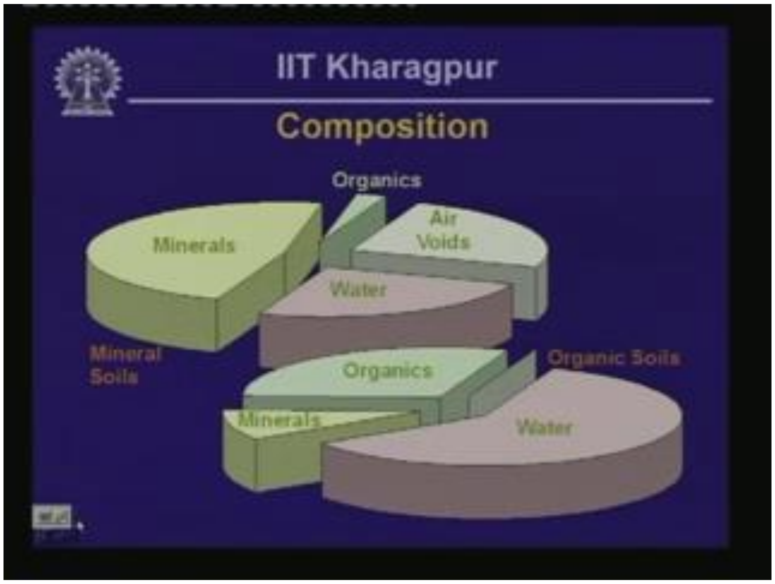
(Refer Slide Time: 12:02)



So, tailings are essentially mine wastes or soils can form also because of biogenic activity, activity of other types of biological organisms. For instance, there could be excreta from birds or bats or there could be deposits really because of biogenic activity and example of this thing is phosphate deposits that are found at different places like some islands of the coast of Peru and other places and actually these are economic minerals really, they are called guano deposits and they are essentially a very large source of phosphate minerals and they are commercially exploited as well. So, the biogenic activity also can give rise to very large volume of soil like deposits.

Now, this actually tells you the varied nature of soil because of the fact that soils can form from processes as varied as those listed on the slide, the characteristics of different types of soils can also be expected to vary by a wide margin.

(Refer Slide Time: 14:24)

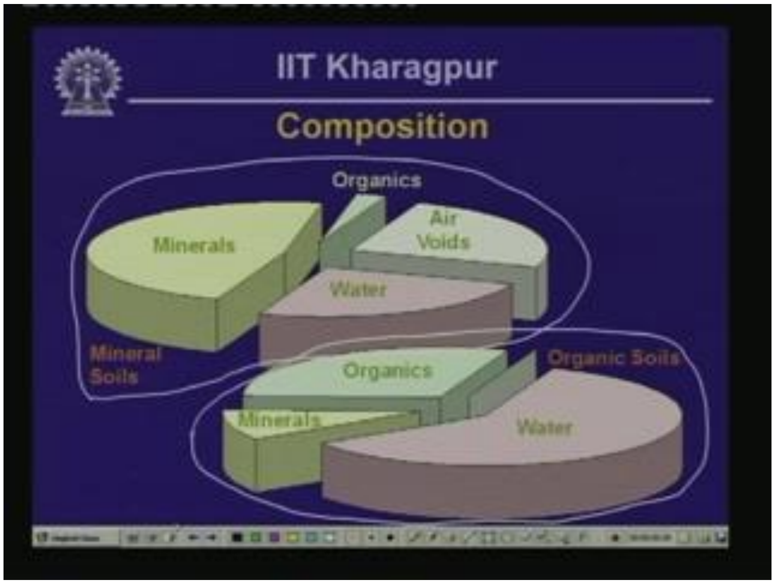


Now, we look at on this slide; we look at typical composition of soil mass. Soils in a sense are composed of solid grains, then they would, the soil mass will also include void spaces and some of this void spaces can be filled with pore fluid or and some of it is going to be filled with air.

Now, pore fluid can be of any, can be of very wide, a large number of different types of chemical characteristics really and mineral, rather the solid grains can also be of a very different or a great variety of solid grains can also be included in the soil mass. Now, the soil grains are typically formed of minerals which are weathering products of preexisting rocks or they could be from the deposits, they could be essentially deposits formed because of biological activities or they could be even partially decomposed organic material like wood fibers and other things. Now, as a result, the composition of soils can also range over a wide; can range over a wide variety.

Now, a typical composition of soil is shown on this particular slide here and we have considered two examples here; one is a mineral soil. Mineral soil would be roughly 25% water, 25% air voids and 25% solids and as I indicated, the solids could include minerals - inorganic minerals or organics like wood debris and other different types of organic inclusions and then on the bottom part what I have shown is a typical composition of organic soil and here, these types of soils would contain a very large proportion of the total volume as water and this could be more than 50% of the total volume really and rest of it would be composed of organics and minerals.

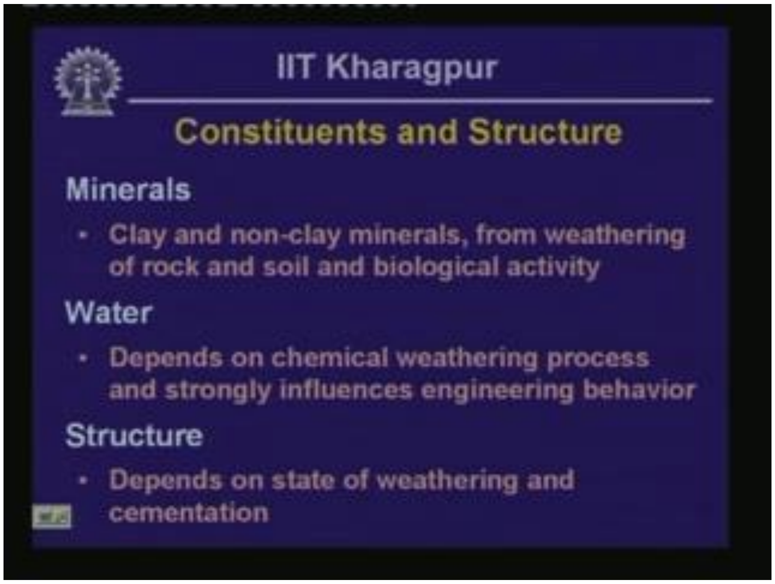
(Refer Slide Time: 14:24)



We consider saturated soil in this case and if the soil is saturated, then of course the air voids, the volume of air voids is going to be 0 as indicated on the bottom pie chart. So, the one on the top there, this one here, this pie chart represents mineral soils and the pie chart on the bottom here, bottom right represents a typical composition of organic soils.

Now, these are typical compositions you should realize and the composition of a particular soil that you might actually encountered during an assignment of engineering geology can in fact vary over a very wide margin and the details that is presented on this slide should be considered only an approximate indicator of different types of constituents of a volume of a certain volume of soil.

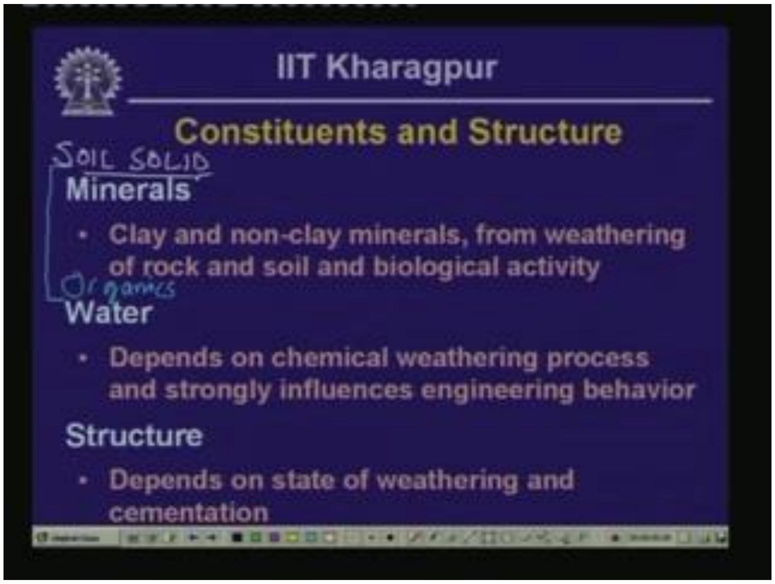
(Refer Slide Time: 18:29)



To summarize, we look at the constituents and structure of soils and as I indicated when I was showing the previous slide was the soils have got solids in it and the solids are, the solids could be minerals or they could be in fact organics, they could also be organics and the minerals; so this part here is solid, soil solid and the minerals could be clay or non-clay minerals. What we mean by clay or non-clay minerals will become a little bit more apparent when we proceed through this particular presentation and they originate from, typically they originate from weathering of rock or soil or they originate from biological activity or they are really, they are really waste material from decomposition of biological inclusions within the mass of soil.

Now, the liquid phase of a soil mass is typically composed of water but there could be other types of liquid also within the soil mass like there could be other polar fluids like in polluted areas, polluted environments there could be pore fluid composed largely of petroleum waste. Now this thing, the liquid phase depends on the chemical weathering process, the chemical characteristics of the liquid phase that depends on chemical weathering process and that actually strongly influences the engineering behavior of a type of soil.

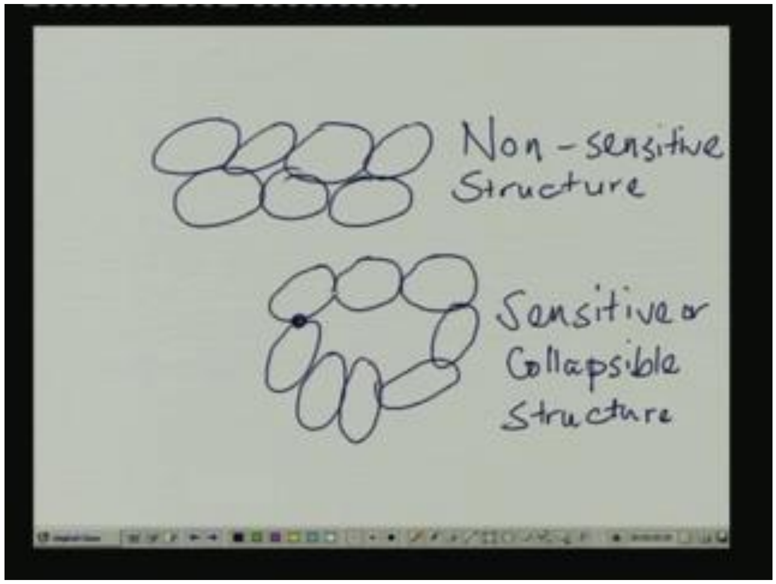
(Refer Slide Time: 18:29)



Now, in addition to it which I did not mention here, you have got air voids as well, air void and the way these different constituents mineral or soil solids, pore fluid and air void, they are distributed within the volume of soil that is given the name of soil structure and the structure that develops also strongly depends on the state of weathering, cementation and the characteristic of pore fluid in addition to the mineral grains or organics or soil solids that the soil mass is composed of.

To give you an example, what is meant by a structure; now you think about soil grains, soil solids; the soil solids could be oriented in this manner and the soil solids could also be oriented in a card house like structure open worked, card house like structure because of several different things and this thing is called a non-sensitive structure and this is called a sensitive or collapsible structure.

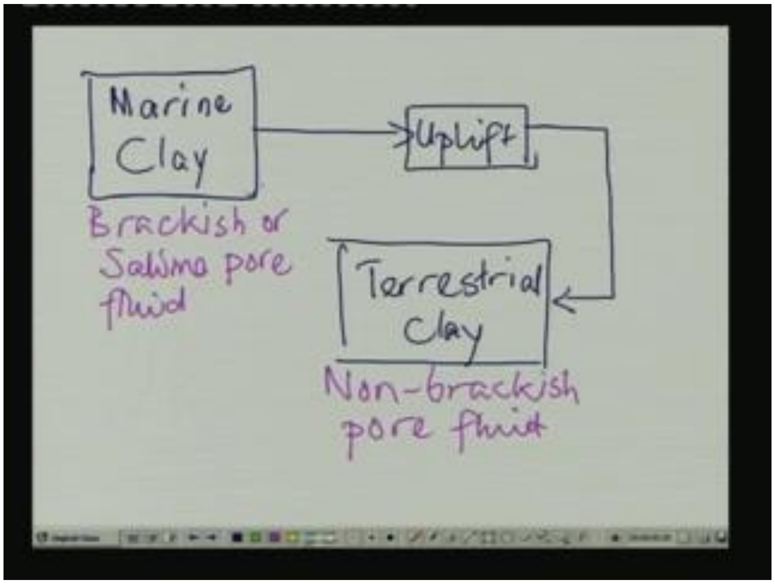
(Refer Slide Time: 21:54)



Now, the question arises; how a collapsible structure could actually develop? A collapsible structure could develop because of weak cementation at the inter-granular context, at the inter-granular context or because of other chemical influences. For instance, the clay masses that originate in marine environment, they sometimes are uplifted and they form a part of the sub-aerial environment and in that case what happens, ground water infiltration leaches out the brackish water that was occupying the interstitial void space when the clay was in marine environment and eventually, the water that occupies the inter-granular void space that becomes fresh water, that becomes non-brackish and as a result what happens actually, that process also gives rise to a sensitive structure.

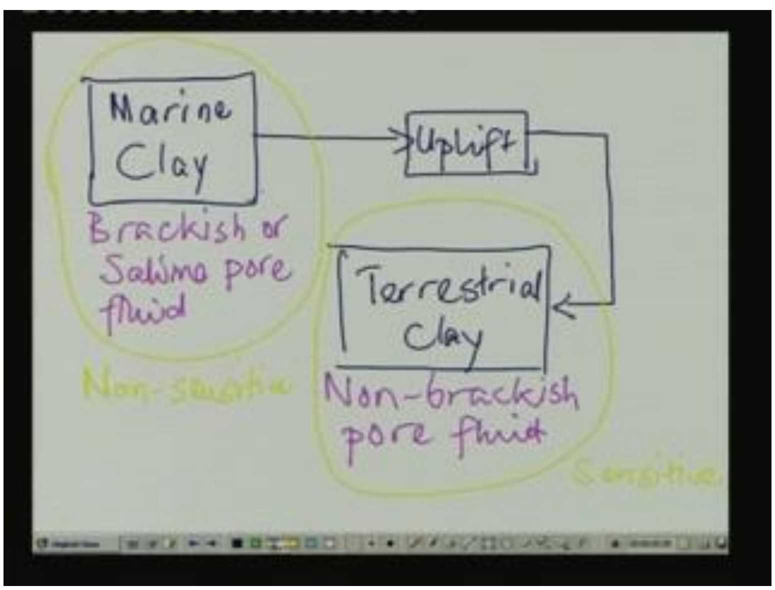
So, what I mean by that? Let us say, you have got a clay that was originally deposited in marine environment that is called a marine clay and then that gets subjected to an uplift and becomes a terrestrial deposit, terrestrial clay and if you consider this type of transition, then this has got fresh pore fluid or non-brackish actually, non- brackish pore fluid, let us call it non-brackish pore fluid, non-brackish pore fluid and this one here has got a brackish for saline pore fluid.

(Refer Slide Time: 24:20)



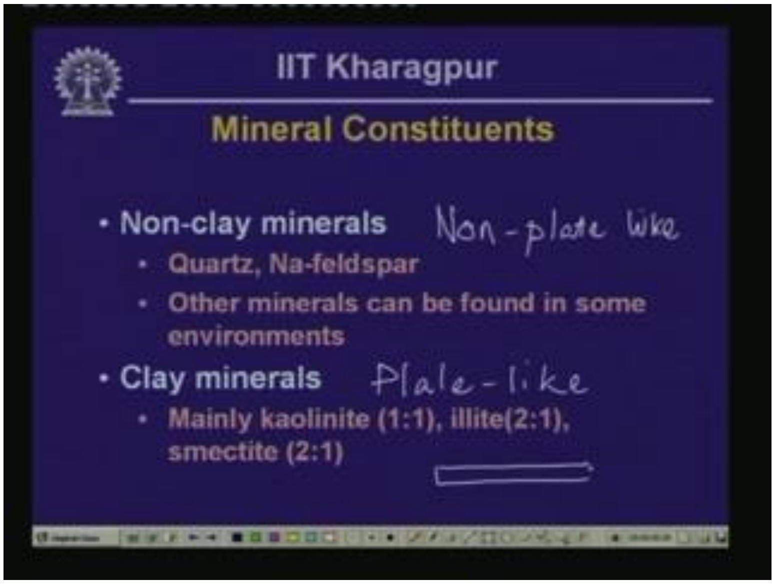
This particular clay, this particular clay could be non-sensitive to begin with but because of the leaching of the saline pore water by fresh ground water that infiltrates the clay mass, a sensitive structure could develop within the soil.

(Refer Slide Time: 24:20)



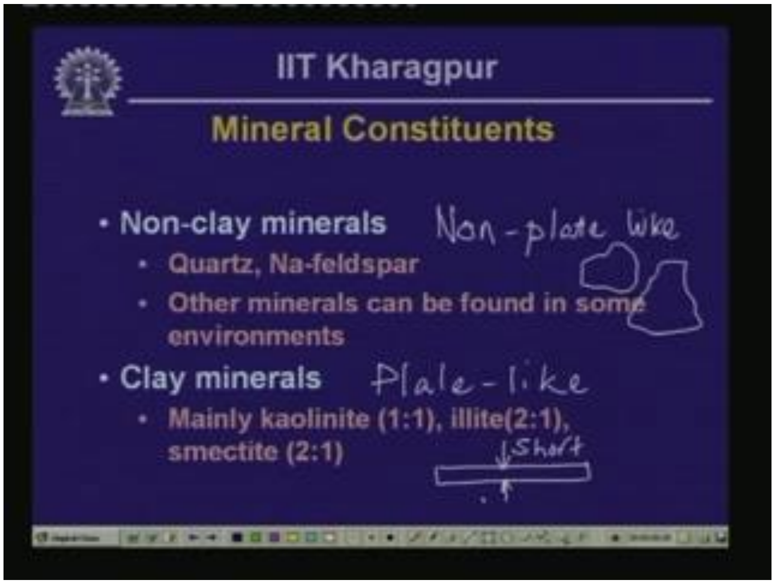
So, this one here is non-sensitive clay, this is a non-sensitive clay, sensitive structure whereas the one at the bottom may have a sensitive structure. So, that is another example of development of sensitive structure because of chemical changes. Now, what are the mineral constituents of the soil?

(Refer Slide Time: 27:10)



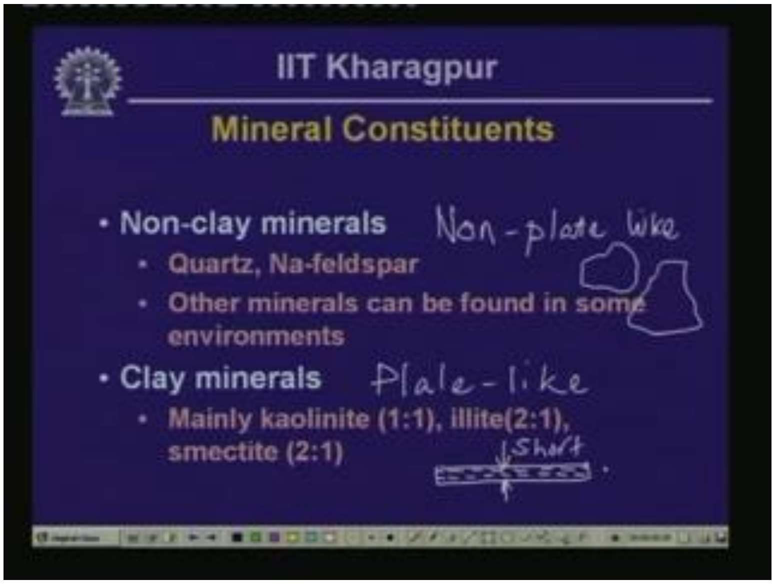
As I indicated earlier, the mineral constituents could be non-clay minerals and mineral constituents could also be clay minerals. Now, non-clay minerals actually will have a non-plate like, non-plate like structure or non-plate like particle, non-plate like; what I mean by that?

(Refer Slide Time: 27:50)



So, these are essentially roundish grains whereas the clay minerals that developed, they are typically plate like. So, clay minerals will have grains which are likely to be much longer in one direction in comparison with the dimension that is there in perpendicular to those long directions. So, this is going to be a very short dimension in comparison with other direction whereas non-clay minerals have got other types of shapes and the shapes could be of very different geometry but they are not going to be plate like, they are typically not going to be plate like.

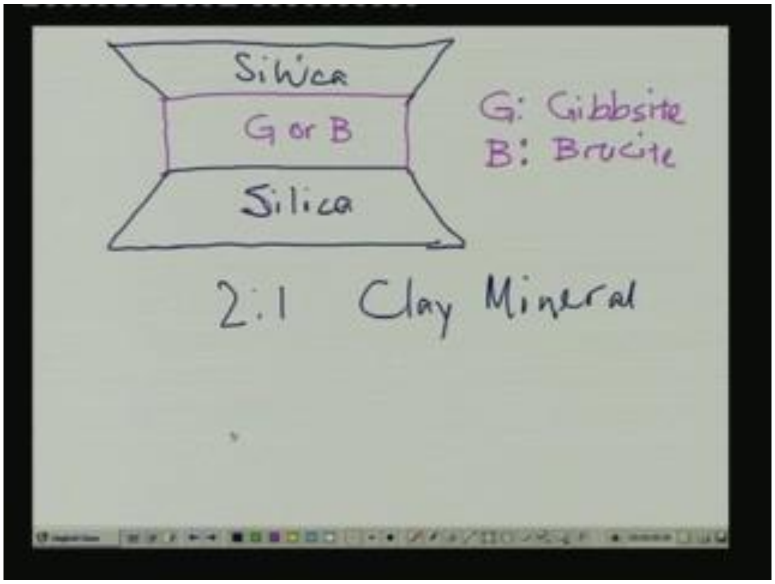
(Refer Slide Time: 28:30)



And these things, the clay minerals typically develop negative surface charges because of isomorphic, because of chemical substitution, substitution of cations and that is why they develop negative charges; whereas, the charge density on non-clay minerals are much smaller. Examples of non-clay minerals are quartz and feldspar - the other types - these are most abundant actually, quartz and feldspar, sodium feldspar, they are most abundant because of their resistant to weathering. There could be other minerals found in special environments which are not especially exposed to chemical weathering.

Now clay minerals, they would typically include kaolinite. They are the major, these minerals are the major types of clay-minerals. They include kaolinite, Illite and Smectite and here you can see, I indicate that kaolinite is a 1:1 clay mineral, whereas Illite and Smectite are 2:1 clay mineral. What do I mean by that is these clay minerals typically are combinations of tetrahedral silica sheets, tetrahedral sheets of silica and octahedral sheets of Gibbsite or Brucite. So, this is actually Gibbsite or Brucite; G is Gibbsite and the symbol B I used here is for Brucite whereas this one here is silica.

(Refer Slide Time: 30:20)



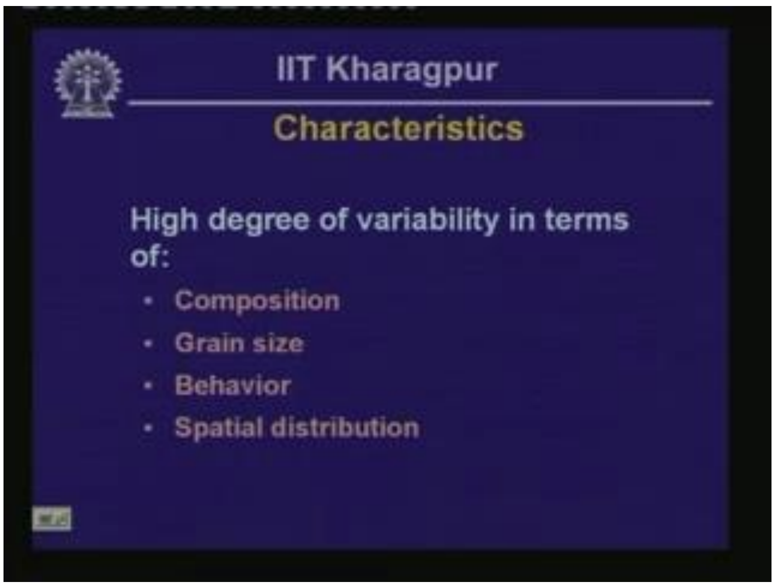
So these things, the top one, the top layer is actually octahedral, it could be bi octahedral or other types of octahedral species whereas the silica sheet, they are tetrahedral in composition in geometry and this is an example really of 1:1 clay mineral where you have got basically one tetrahedral sheet and one octahedral sheet. Now, if we have got two tetrahedral sheets, two tetrahedral sheets and one octahedral sheet, then what we are going to end up with is basically 2:1 clay mineral.

So, that tells you actually what is the structure or what is the structure of a grain of clay mineral and now these basic units, they are going to actually, they are going to be interlinked to other grains by covalent or other types of bonding which we will examine in details when we talk of clay minerals later on in one of the future presentations of this particular course.

So, then the mineral constituents of soil could be clay minerals or non-clay minerals and most abundant non-clay minerals include quartz and sodium feldspar whereas most abundant clay minerals include Kaolinite, Illite and Smectite. Now, what are the characteristics, what are the characteristics that one needs to consider while looking at clay or a soil deposits?

Soil deposits typically show a very high degree of variability in terms of composition, grain size, behavior and spacial distribution though the composition of different types of soils as I mentioned in the previous slides there, would vary by a very wide margin. For example, one could have an organic deposit which is composed of organic, partially decomposed organic material and a large volume of it is comprised of water voids whereas you could have a relatively compact mineral soil which has got a relatively smaller proportion of void space and a non-collapsible structure. Whereas, an organic soil could have an open work, open worked or card house like structure in many situations.

(Refer Slide Time: 34:30)



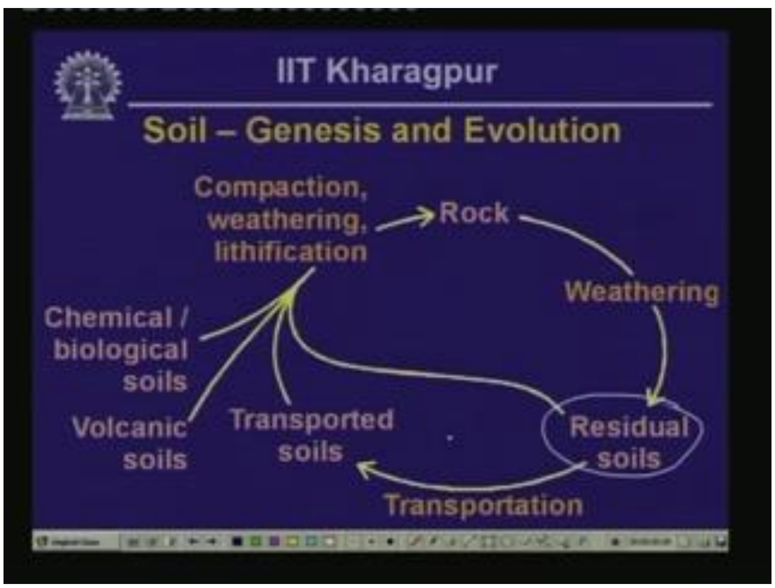
Then you could have grain size distribution; the grain sizes that is composed that the soil is composed of can also vary over a very wide margin. You could have soils which are composed largely of very fine clay sized particles which are typically I mean, their dimensions could be on the order of a few microns; whereas, you could have soils that could include boulders and these boulders could a meter across in size.

Now, the behaviour of the soil could also vary because of the reasons that, because of the reasons some of which I mentioned earlier and the thing that we consider here was the open worked

structure and non-open worked structure or collapsible or non-collapsible structure that develops because of different types of orientation of soil solids and wide space within the soil mass.
And, facial distribution of soils can also vary by a wide range and what you could get is a soil of very different characteristics right next to a side occupied, right next to a side where the soil type is totally different. So, that actually gives you a very challenging environment, it poses a great problem in designing different types of structures or different types of projects because of the soil variability, particularly in certain environment as we will see later on in the course of this and other presentations.

Now, soil genesis; how soil actually forms out of rock or chemical or biological processes or volcanism is indicated on this slide here.

(Refer Slide Time: 36:33)



As I mentioned, from weathering of rock, a class of soil develops which is called essentially residual soil. In – situ, from in – situ weathering, from weathering without any transportation and then residual soils can be transported from the place where they originally formed by different agents of transportation like water, wind, glacier ice or even submarine current and they give rise to another class of soils that is called transported soils.

You also could have volcanic soils and chemical or biological deposits; all of these things can be subjected to different types of processes, physical and chemical processes that could be compaction, weathering and lithification and that may end up in formation of sedimentary rocks.

So, this is basically, this basically tells you how different types of soil deposits are formed and how they evolve with time. Now, we consider soil types based on the formation process. As I indicated, residual soils formed out of weathering of bedrock and example of that is decomposed granite; they are also called in some places, they are also given the name in some places Gruss or Saprolite.

(Refer Slide Time: 38:17)

Then you could have transported soils and transportation could be by gravity and if you find a soil deposit that is basically because of gravitational transport and that is called Colluvium. For example, slope failure debris Talus slopes, transportation could be by air and these things are called Aeolian deposits. Loess is an example of Aeolian deposit, example of Colluvium is Talus.

Then you could have water deposited soils and they include fluvial if they are worked by flowing river water or there could Lacustrine which are lake bed deposits or glacio-fluvial, basically they are melt waters that form in different parts of glacier, glaciers or transported soils could be directly deposited from ice. They are called glacial deposits.

Then wave action can also lead to development of transported soils or submarine currents can also transport, can also lead to the development of transported soils. Examples of all these soils include alluvium, alluvium are essentially fluvial deposits or till they are deposited by ice or actually till or moraine is used for essentially the same kind of deposits, similar type of deposits.

(Refer Slide Time: 40:53)

You could also have chemical or biological soils as I mentioned earlier. Chemical soils, chemical soils and biological soils include evaporites; evaporites are solid precipitates because of evaporation of different types of water that have dissolved colloids in it and we could have one of the examples of evaporite is basically the salt deposits that develop in dessert environment.

We could have phosphorites, they could be droppings of different organisms, they are phosphate rocks. You could have carbonates, they also get deposited from solutions of carbonate minerals or it could be hydrogenous deposits that develop in submarine environment, environments where near hydrothermal vents which we will consider later on in one of the future presentations.

Examples of these deposits include calcareous sand, they are basically composed of grains broken grains of calcite and these calcite grains could have biological or inorganic origin. Many of the continental shelves are underlain by calcareous deposits of this type and finally you could have volcanic soils and volcanic soils as I mentioned directly originates, volcanic soils directly originates from volcanic activity. Examples of it include volcanic ash and sands composed of pumice grains.

So, these are the different types of classification of soils that you might get depending on the process of origination, how the soils actually originate. Engineering classification of soils is slightly different and here what we actually are interested about are the engineering behavior of soil when we classify soils in this manner and as we have seen from one of the previous slides is that soils, the soil behavior is going to be very different depending on whether the soil, I mean the soil solid is composed of clay minerals or non-clay minerals.

Why is that it is because in case of clay minerals, the individual grains are comparatively less heavy in comparison with the inter-granular forces that develop because of the charge density as I indicated on the surface of the clay particles

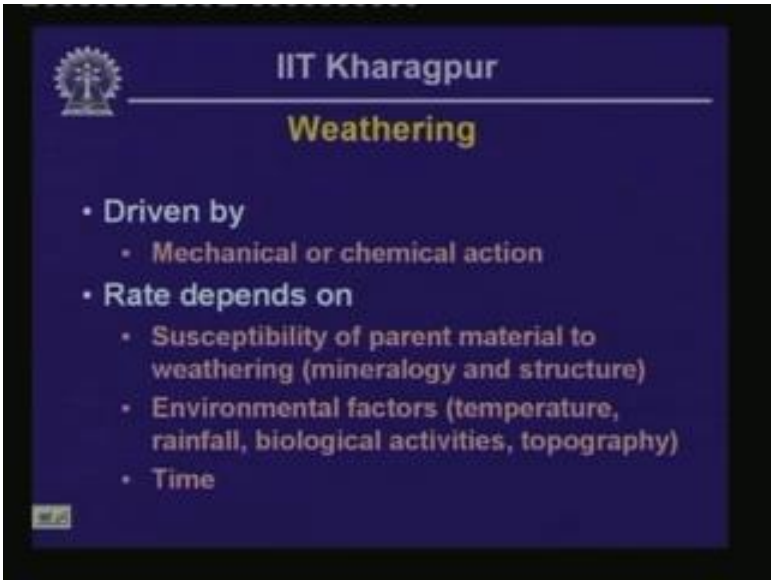
(Refer Slide Time: 43:39)

Whereas in case of non-clay minerals, the charge density as a percentage of the weight of the particle is comparatively much less and as a result, the behavior of soils composed of clay minerals is going to be greatly different from soils composed of non-clay minerals. While clay minerals are going to be driven by the stickiness or plasticity that develops because of the interaction of electrical nature between individual soil grains while non-clay minerals, they will derive the strengths based on the packing or interlocking of individual soil particles.

So, the behavior of soils composed of clay particles or clay minerals will be different from the soils composed of non-clay minerals. So here, what we have got is basically the classification looks at the grain size distribution mainly and to some extent it looks at the compressibility of the structure and also the organic content of the soil. How the individual classifications, individual classifications of soil will be considered later on in one of the future presentations of this course.

Then we get into weathering; weathering as I indicated is mainly driven by mechanical and chemical action. Rate of weathering depends on susceptibility of parent material; actually this is quite intuitive, it depends on the susceptibility of parent material to weathering that includes mineralogy and structure, it also depends on environmental factors that include temperature, rainfall, biological activities and topography and the rate will depend on time; the more is the time of exposure, greater will be the chance of weathering.

(Refer Slide Time: 46:16)



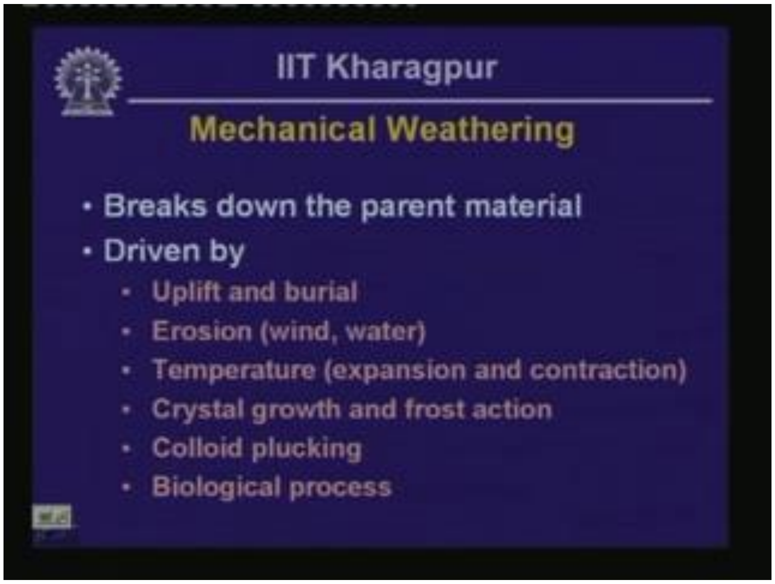
Now, you can imagine, let us consider the susceptibility of weathering of soils depending on the mineralogy of the parent material. As I indicated, quartz is very resistant to weathering, quartz and sodium feldspar in comparison with other, in comparison to other basic mafic minerals. Temperature actually is another factor that increases the weathering rate. You can imagine that if there is a 10 degree Celsius rising average temperature, then the rate of chemical reactions that occur that drives the weathering processes; the rate of those equations, the rate of those chemical reactions can increase two fourth.

Rainfall also increases the weathering rate, biological activity, root penetration, burrowing animals; they actually gives access of oxygen to different layers underground, underneath the surface of the soil, gives oxygen, actually gives access to oxygen to different layers and this actually gives rise to different weathering processes.

Topography, actually also triggers weathering because the weathering products, they quickly get carried away because of cope failure or because of flowing water in steep terrain and as a result that may accentuate actually the rate of weathering.

Mechanical weathering breaks down the parent material, it actually reduces the size of the original mass of parent material and because of reduction of size, the surface area that is exposed to the environment increases and that actually increases the rate of weathering.

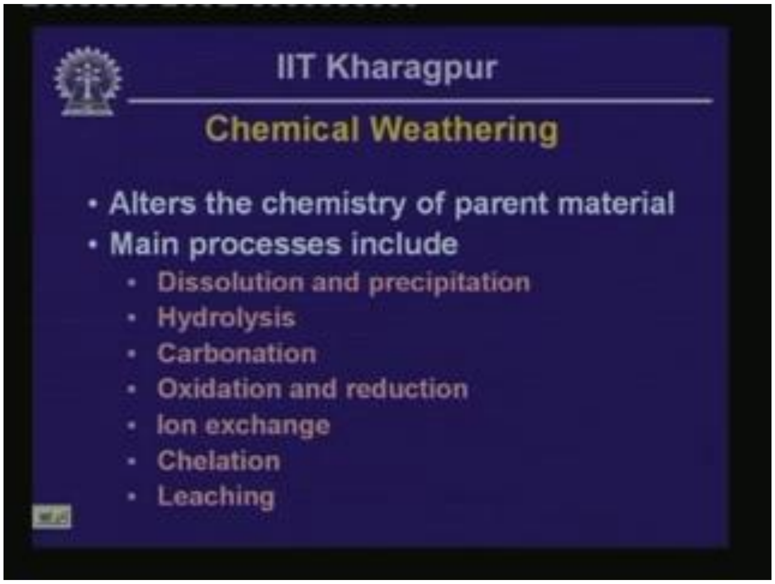
(Refer Slide Time: 48:53)



The main processes involved in mechanical weathering are listed there, listed on the slide. They include uplift and burial because of uplift and burial, rock masses can crack and that gives access to the environmental agents, weathering agents to the different parts of the rock mass and that drives the weathering process, erosion would also expose different parts of rock mass to weathering, temperature driven expansion and contraction can lead to development of cracks and that may in turn lead to mechanical weathering.

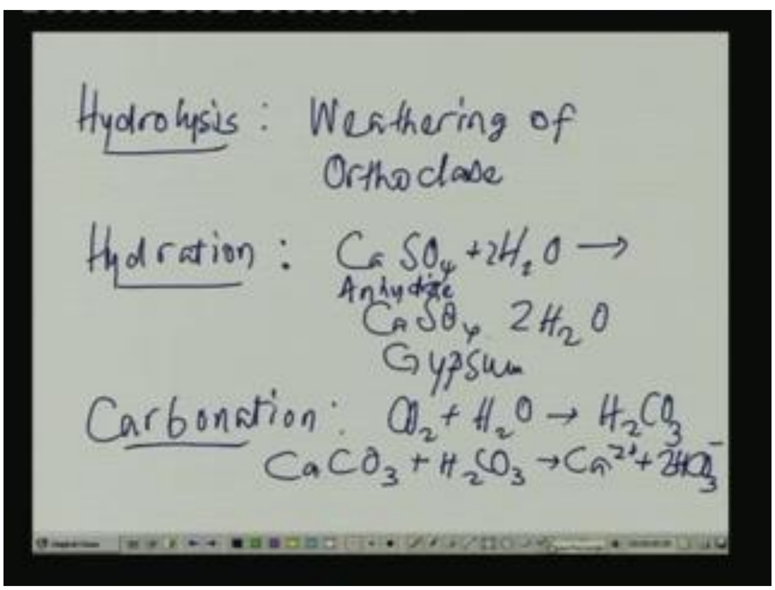
Crystal growth and frost action actually can split a rock mass because of the volume of the secondary crystal that develops in that process is different from the original solid and that splitting of rock mass actually can also give rise to mechanical weathering. Colloid plucking or shrinkage of colloids as they harden can also crack rock mass and give rise to mechanical weathering. Biological processes can also cause mechanical weathering. So, these actually are the major agents that drive mechanical weathering.

(Refer Slide Time: 50:49)



Chemical weathering; chemical weathering as the name suggests it alters the chemistry of parent material and here the main processes that we look at include dissolution and precipitation, hydrolysis, carbonation, oxidation and reduction, ion exchange, chelation and leaching.

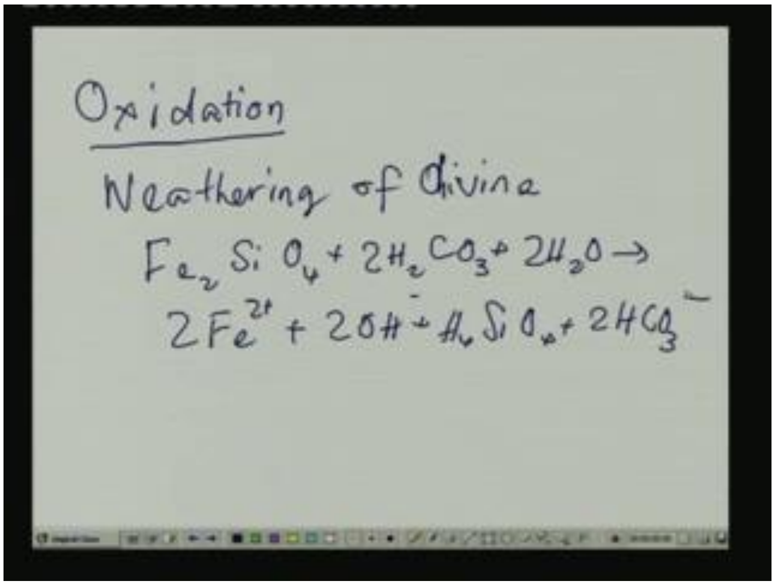
(Refer Slide Time: 51:32)



Now, we have to actually consider the different types of, different classes of reactions that give rise to chemical weathering. Let us consider hydrolysis. We are going to consider whether this one is already shown to you when we were considering the weathering of feldspar, weathering of potassium feldspar or orthoclase. Then let us say hydration; anhydrite, a mineral called anhydrite upon absorbing moisture, this actually hydrates the crystal and that gives rise to gypsum. Then we have got carbonation, combination of carbon dioxide in atmosphere with water forms a mild acid which is called carbonic acid and that reacts with limestone or marbles giving rise, releasing calcium iron in the atmosphere and dissolved by bicarbonates.

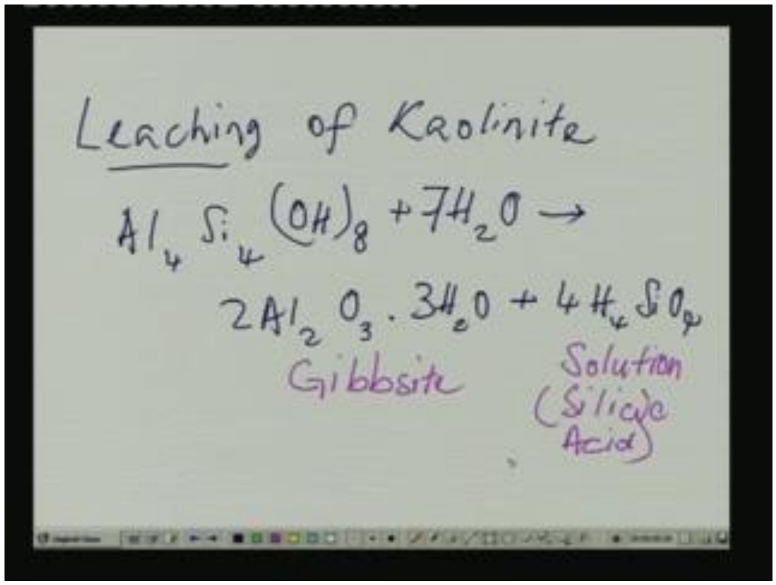
So, that gives you or that take care of the first three classes of chemical weathering processes. Then we have got oxidation; let us consider an oxidation process.

(Refer Slide Time: 54:00)



Let us consider weathering of olivine mineral. What you have got here is basically ferrous silicate and that reacts with carbonic acid and in presence of water giving rise to ferrous ion in solution, hydroxyl ion in solution, silicic acid and dissolved bicarbonates. Ion exchange; the Illite mineral actually converts to ((55:05)) because of this transformation and what it leads or what it originates from is loss of potassium and update of magnesium and then chelation, chelation is essentially taking on mineral ions in hydrocarbon chains that is what is meant by chelation and let us take an example of leaching because leaching is a very important weathering process in tropical and sub-tropical environment like those encountered in many parts of India and we are going to consider the leaching of kaolinite soil.

(Refer Slide Time: 55:48)



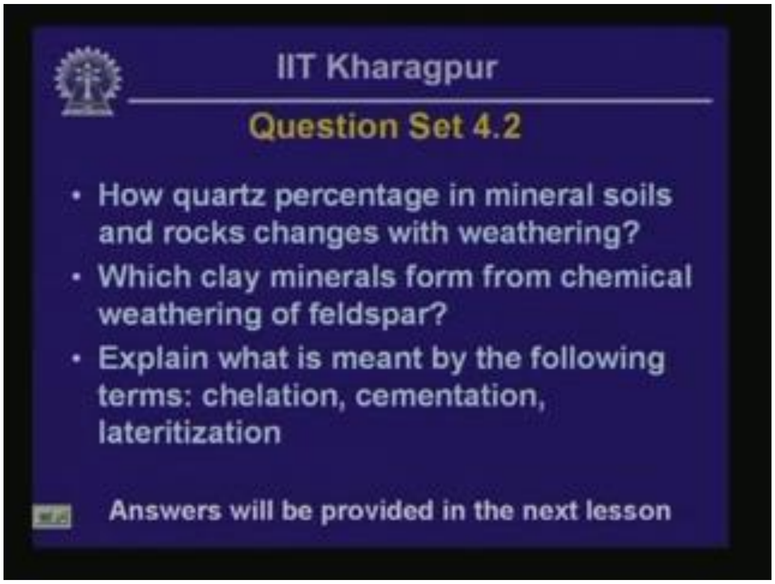
So here, what you get, as I indicated kaolinite soil has got this kind of chemical composition and leaching takes place mainly in presence of water and what you will end up with is hydrated alumina or Gibbsite and silicic acid in solution. So, this one is gibbsite and this is in solution, this silicic acid is in solution. So, that is an example of the leaching process.

We look at the weathering products of different felsic minerals and what we consider here are the felsic minerals of which are the main rock forming minerals. You may recall that we considered 9 rock forming minerals that composes most of the igneous rocks and we considered the felsic minerals of those 9 main rock forming minerals and this table here shows the rock forming, the weathering process that actually weathers 3 of these minerals.

(Refer Slide Time: 57:11)

Muscovite actually re-crystallizes to form Illite or in the presence of acidic ground water, it gives rise to kaolinite and releases potassium ion in the solution. Orthoclase, in case of shallow burial carbonation and hydrolysis, it actually gives rise to kaolinite and that eventually leaches to form bauxite. It also gives rise to the formation of quartz and potassium ((Video Problem. Refer Slide Time: 58:31)) And, finally we end this presentation with the question set.

(Refer Slide Time: 58:33)



What I asked here in the first question was that how quartz percentage in mineral soils and rocks changes with weathering? Which clay mineral forms from chemical weathering of feldspar? Then I asked you to explain the terms; chelation, cementation and lateralization. You try to answer these questions and I will try to give my take on these questions when I meet you the next time with the next presentation.