Soil Mechanics
Prof. B.V.S. Viswanadham
Department of Civil Engineering
Indian Institute of Technology, Bombay
Lecture – 1

Soil is the oldest and complex engineering material. From the early 20th century the rapid growth of cities, industry and commerce required a huge development of infrastructure such as skyscrapers, tunnels, bridges, runways, transmission line towers etc. This course is intended to provide a basic understanding of soil behavior in appreciation of soil mechanics and the basic principles of soil mechanics. Before venturing into the subject let us look into the origin of the soils and the necessity of study of soil mechanics. The earth crust is composed of soil and rock.

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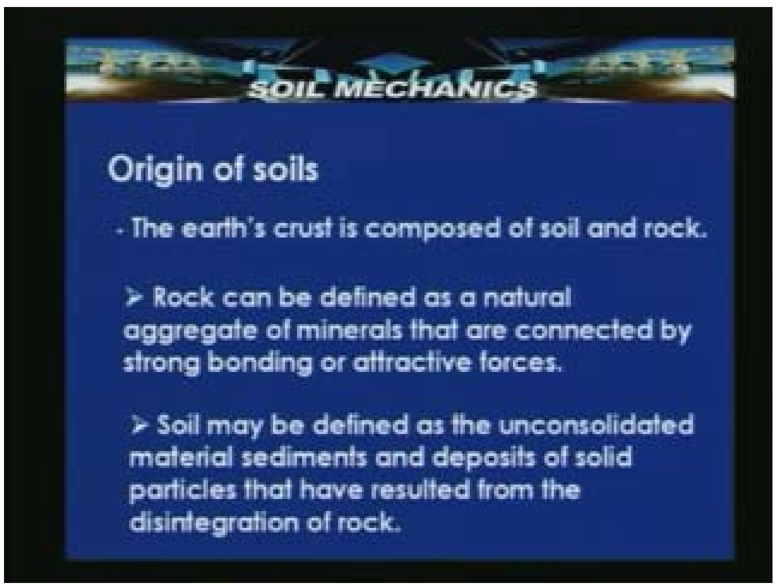

The rock can be defined as a natural aggregate of minerals that are connected by strong bonding or attractive forces. Soil may be defined as the unconsolidated material, sediments and deposits of solid particles that have resulted from the disintegration of the rock. If you look into the rock, rock is a consolidated material with permanent attractive forces. Soil may be defined as an unconsolidated or un-cemented material with attractive forces and may not be permanent as that of rock.

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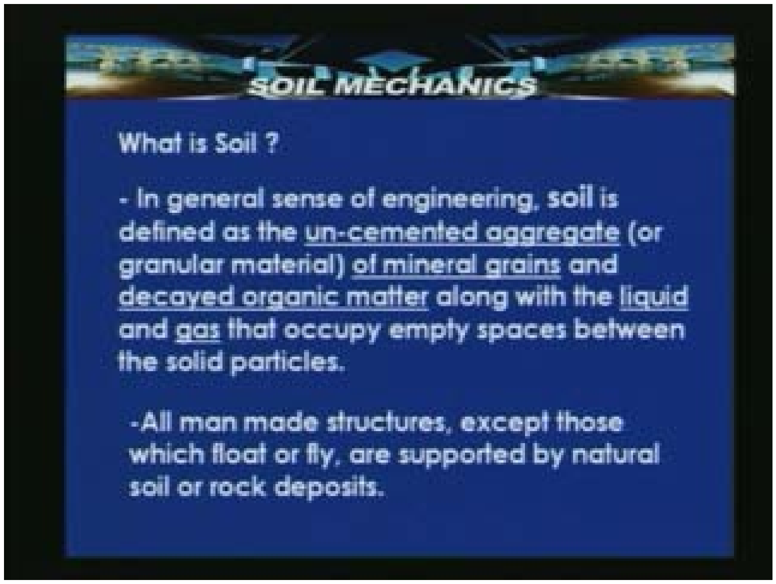

What is soil? In general sense of engineering, soil is defined as the un-cemented aggregate or granular material of mineral grains and decayed organic matter along with the liquid and gas that occupy the empty spaces between the solid particles. Most of the man made structures except those which float or fly are supported by natural soil or rock deposits.

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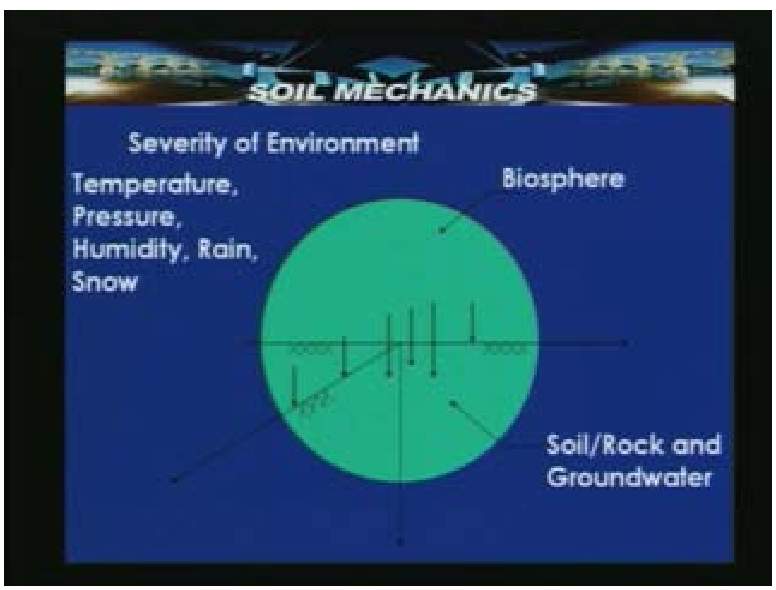

If you look into this sphere, biosphere exists on the top and geosphere exists below it where the soil, rock and ground water exists. They are subjected to a severity of environment such as temperature, pressure, humidity, rain, snow etc.

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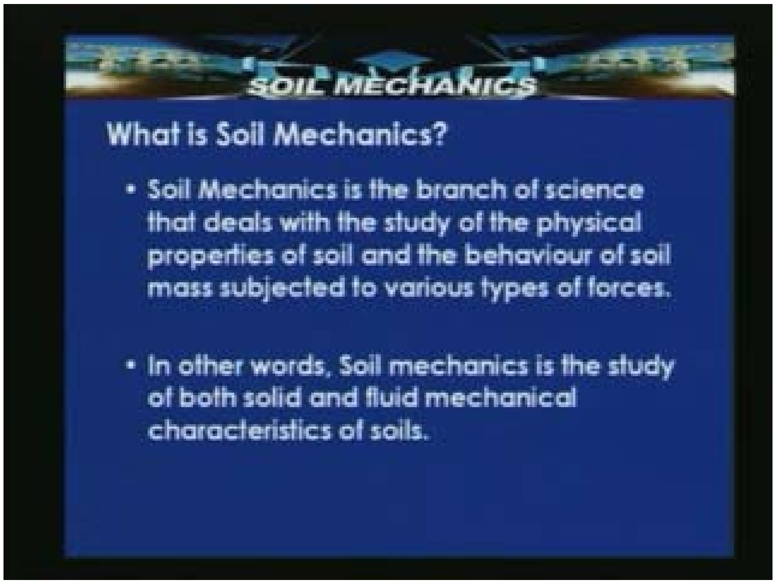

So, before looking into the details of soil mechanics let us define soil mechanics. Soil mechanics is the branch of science that deals with the study of the physical properties of soil and the behavior of soil mass subjected to various types of forces. In other words, soil mechanics is the study of both solid and fluid mechanical characteristics of soils. If you look into the solid mechanics issues, we are interested to see how much soil will deform when it is loaded.

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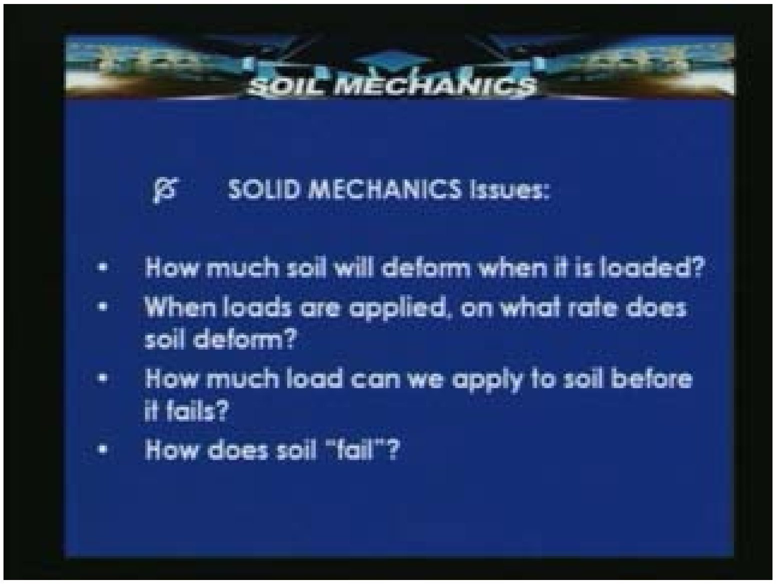

When loads are applied, at what rate does soil deform? That is interesting to analyze. How much load can we apply to the soil before it fails? How does soil fail? These questions are required to be asked from the solid mechanics point of view.

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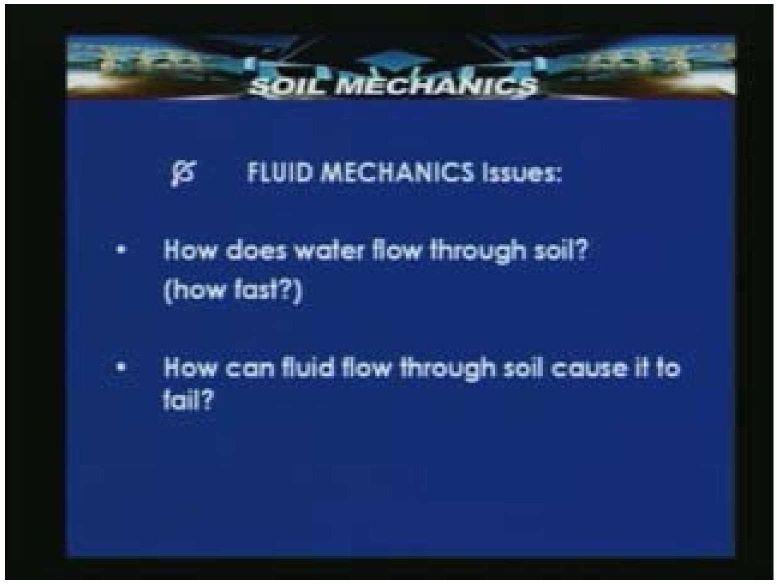

From the fluid mechanics issues: how does water flow through soil or how fast or at what rate? How can fluid flow through soil and cause it to fail? So these issues are required to be answered as far as fluid mechanics is concerned.

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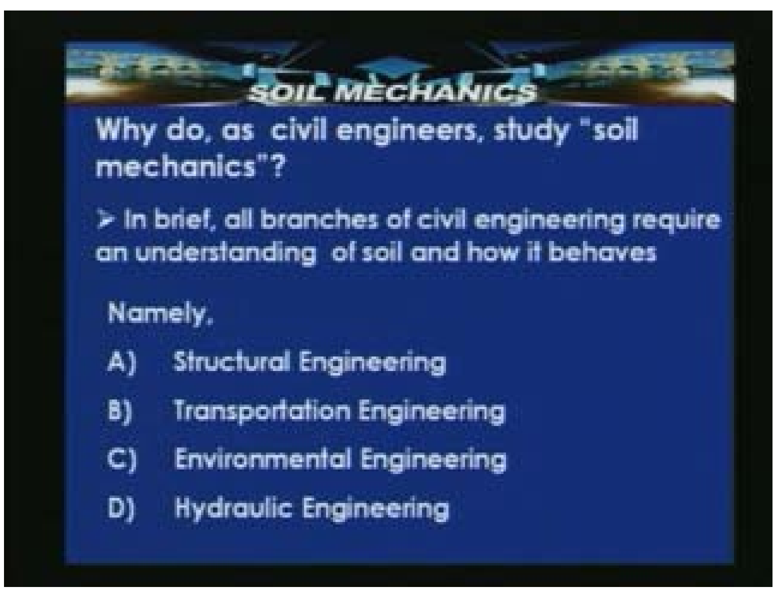

Why do, as civil engineers, study soil mechanics? That is the question we should ask to ourselves before venturing into the subject. In brief all branches of civil engineering require an understanding of soil and how it behaves namely structural engineering, transportation engineering, environmental engineering and hydraulic engineering. They require these particular concepts of soil mechanics to analyze the problems of civil engineering.

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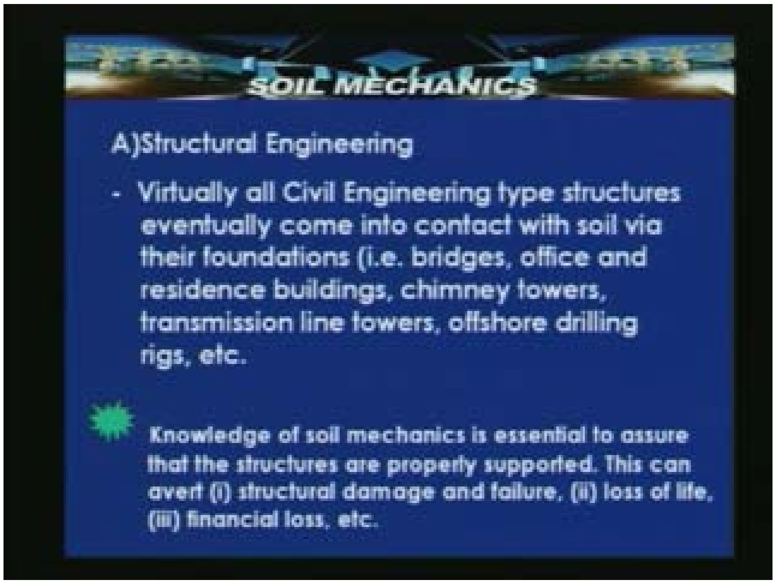

As far as the structural engineering is concerned, virtually all civil engineering type structures eventually come into contact with soil or via their foundations. That is, for bridges, office and residence buildings or large public buildings, chimney towers, transmission line towers, offshore drilling rigs etc. So knowledge of soil mechanics is essential to assure that structures are properly supported. This can avert the structural damage and failure, loss of life and financial loss.

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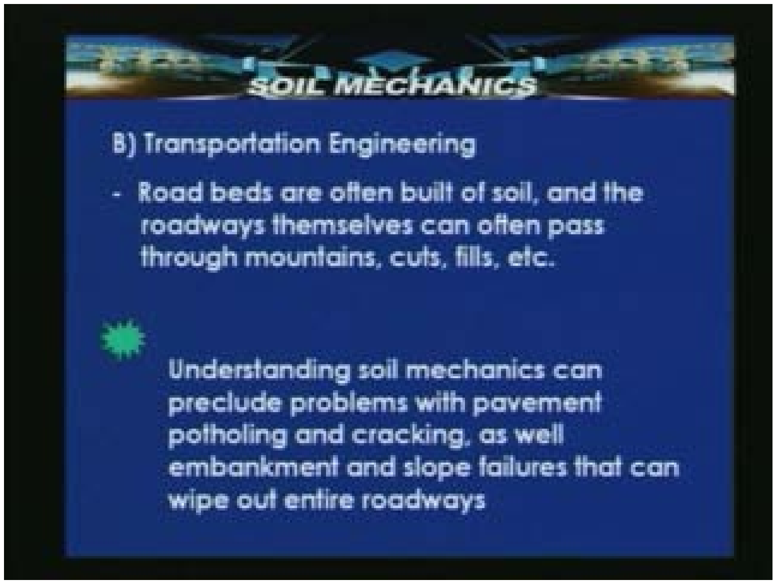

As far as transportation engineering is concerned we see road beds are often built of soil and the roadways themselves can often pass through mountains, cuts, fills etc. So understanding soil mechanics can prevent problems with pavement potholing, cracking, embankment and slope failures that can wipe out entire roadways.

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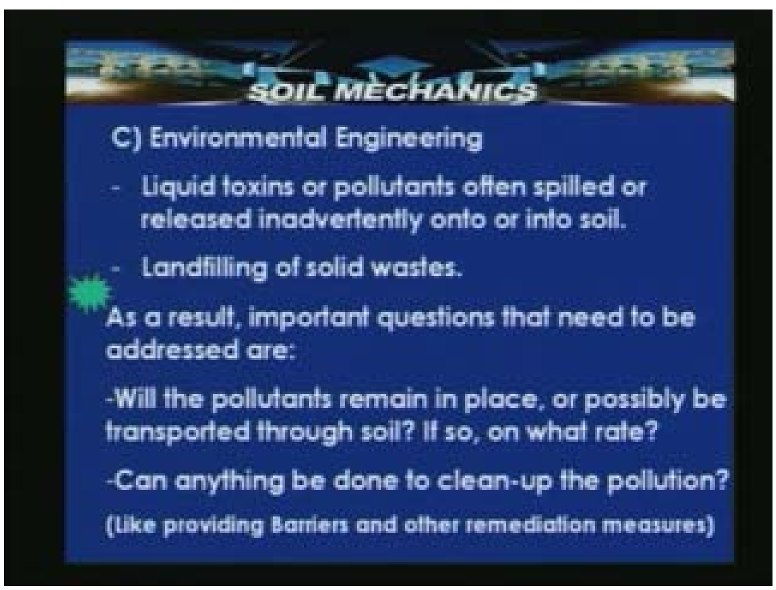

From environmental engineering point of view: liquid toxins or pollutants often spilled or released inadvertently into or onto the soil or land filling of municipal solid wastes or hazardous solid wastes. As a result, the important questions that need to be addressed are: Will the pollutants remain in place or possibly be transported through soil, if so at what rate? Can anything be done to clean-up the pollution such as working out of remedial measures like provision of the barriers or remediation measures for cleaning the pollution?

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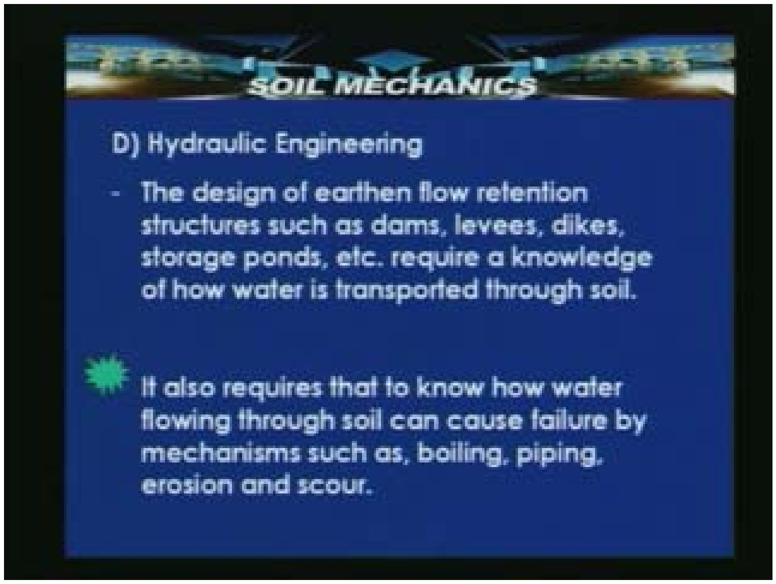

From the hydraulic engineering point of view: The design of earthen flow retention structures such as dams, levees, dikes, storage ponds etc. Require knowledge of how water is transported through soil. It also requires that to know how water flowing through soil can cause failure by mechanisms such as boiling, piping, erosion and scour. So, before we look into the details of the origin of soils let us look into some field case histories.

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This particular case history shows a severe rutting of roads on weak formations. So this can create a rutting which as shown which affects the ride ability of roads.

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This particular building as you have seen in the figure shown above is hanging on the top of the landslide debris. And these sort of things really causes alarming signals for the soil mechanics engineers.

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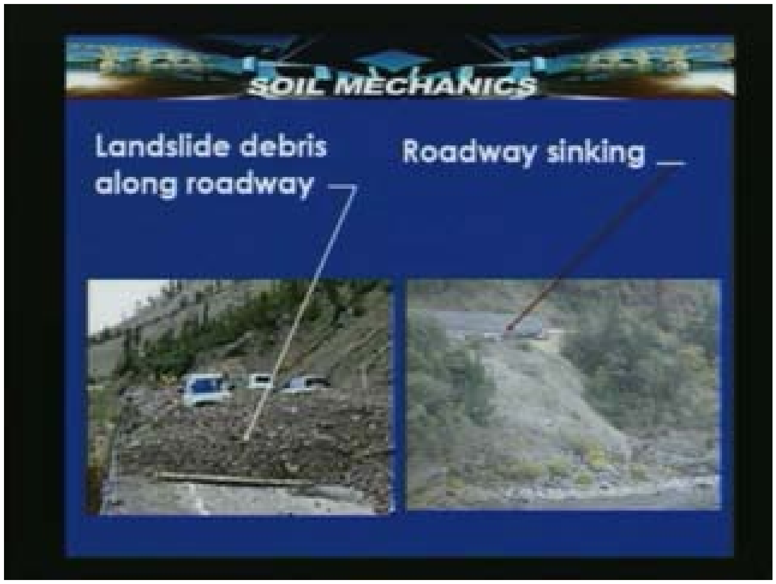

What you are seeing in the figure on the left hand side is the land slide debris along roadway which stops that roadway for number of days and also affects the normal life of the people. On your right hand side you are seeing a photograph of the roadway sinking problem. These sort of problems are very challenging to the soil mechanics engineers or geotechnical engineers.

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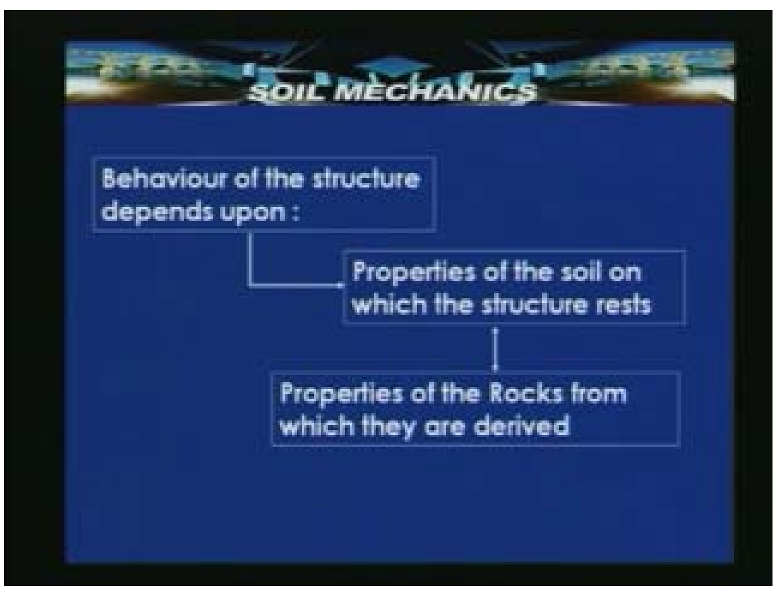

As we have seen, the behavior of the structure depends upon the properties of the soil on which the structure rests. Again the properties of the soil depend on the properties of the rocks from which they are derived. As far as civil engineers are concerned, we are required to study the properties of soil such as its properties of origin, grain size distribution, ability to drain water, strength of the soil, mechanical behavior of the soil when they are sheared or compressed or when water flows through it.

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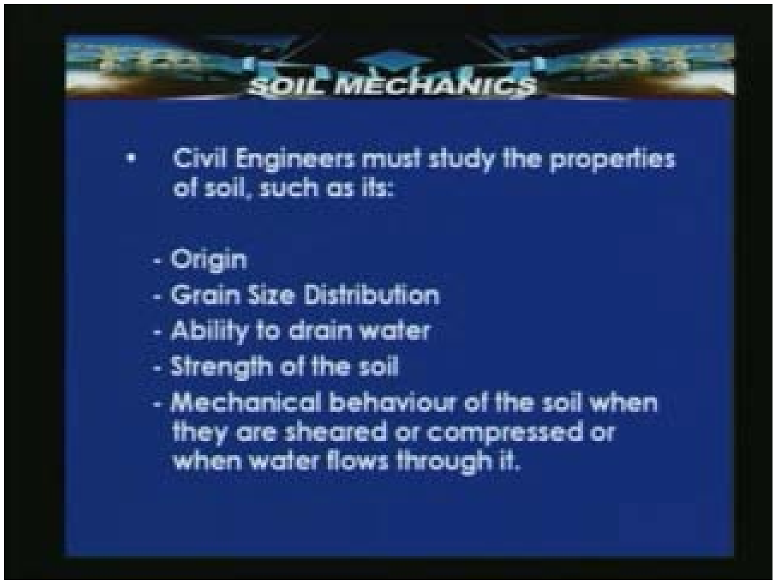

These aspects will be covered in the due course of lectures in this course. So, before giving the origin of the soils let us look into the classification of the rocks based on their deposition.

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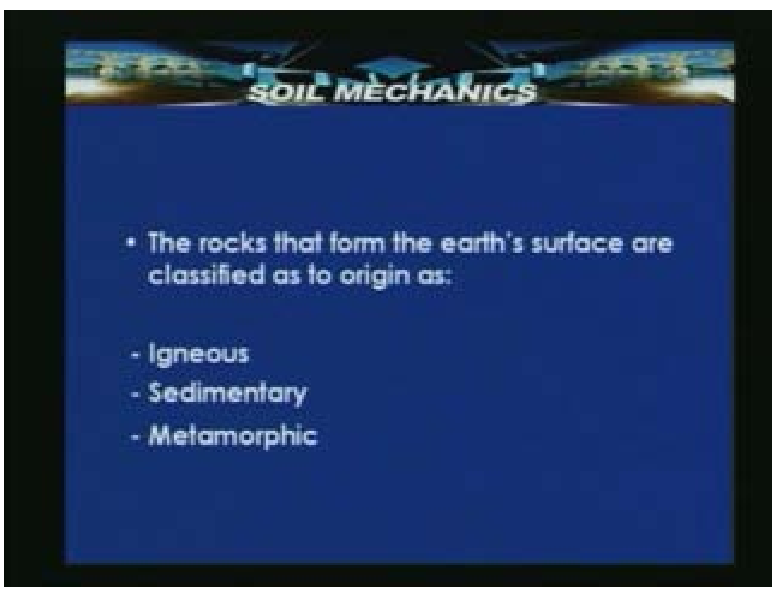

The rocks that form the earth's surface are mainly classified into three types: they are igneous, sedimentary and metamorphic. Igneous rocks are those formed directly from the molten state of magma.

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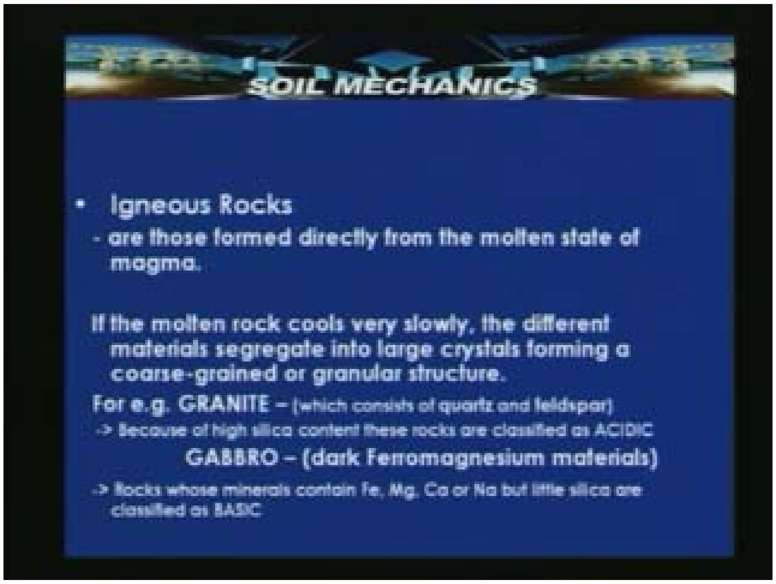

If the molten rock cools very slowly, the different materials segregate into large crystals forming a coarse grained or granular structure. In this case of igneous rocks, the magma cools very slowly. So the different materials segregate into large crystals forming a coarse grained of granular structure. For this type of igneous rocks, we can give the example like GRANITE which consists of quartz or feldspar minerals. These rocks are called ACIDIC rocks because of the high silica content and basically they are light colored rocks. GABBRO is another example of igneous rock which is due to the presence of the dark Ferro magnesium materials. Rocks whose minerals contain iron, magnesium, calcium or sodium but little silica are classified as BASIC rocks. So more silica rocks are called ACIDIC rocks and less silica rocks are called BASIC rocks.

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When you look into the igneous rocks again: when the solution of the minerals is cooled more rapidly, tiny crystals of the minerals are formed in a glossy matrix or vitreous matrix. Examples for this case are FELCITE which are extremely fine grained rocks or BASALT which is formed with ferromagnesian materials.

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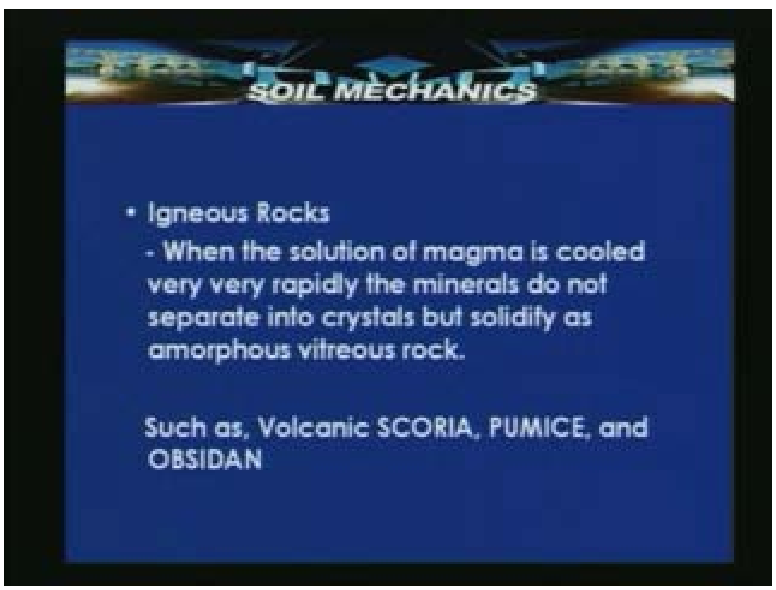

Igneous rocks like SCORIA, PUMICE and OBSIDAN are formed when the solution of magma is cooled very rapidly and the minerals do not separate into crystals but solidify as amorphous vitreous rock.

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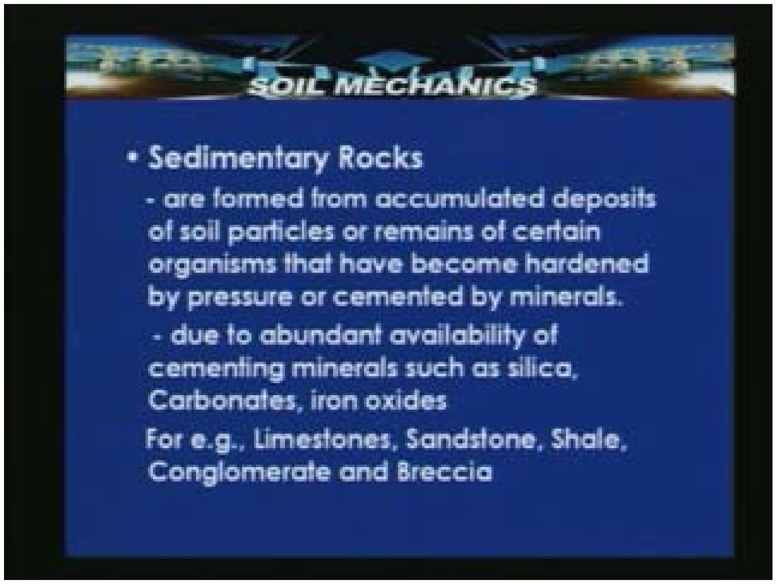

The next classification of the rock is sedimentary rocks. These rocks are formed from the accumulated deposits of soil particles or remains of certain organisms that have become hardened by pressure or cemented by minerals. This is due to the abundant availability of cementing materials in the flowing water such as silica, carbonates and iron oxides. Examples for these sedimentary rocks are lime stones, sandstone, shale, conglomerate and breccia. So the sedimentary rocks are formed from the accumulated deposits of soil particles or remains of certain organisms that have become hardened by pressure or cemented by minerals like carbonates and iron oxides.

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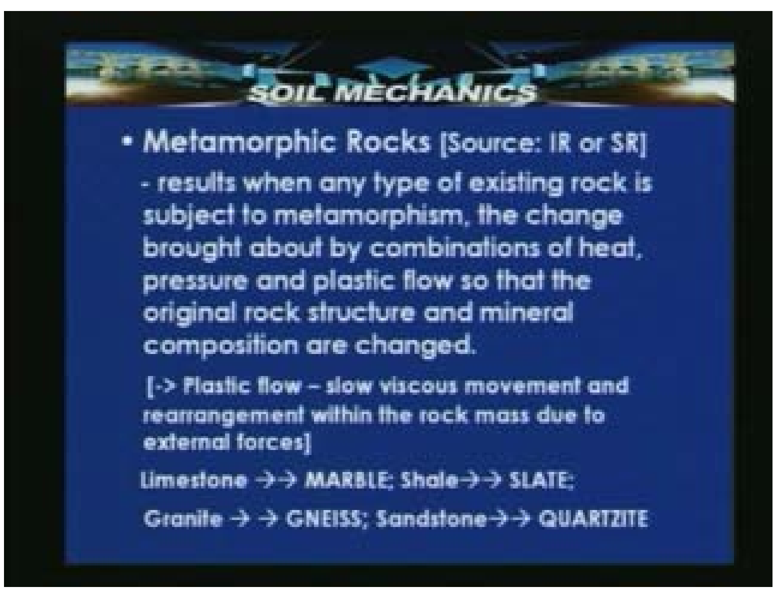

The third one is metamorphic rocks. The origin of this rocks or source of this rocks is either due to igneous rocks or due to sedimentary rocks. This results when any type of existing rock is subjected to a process called metamorphism. The metamorphism is nothing but the change brought about by the combinations of heat, pressure and plastic flow so that the original rock structure and mineral compositions are changed. Here the plastic flow refers to a slow viscous movement and rearrangement within the rock mass due to external forces.

For example, if you look here, metamorphism of limestone gives MARBLE, metamorphism of shale gives SLATE foliated rock, metamorphism of granite gives GNEISS and metamorphism of sandstone gives QUARTZITE. So, we have three basic rock classifications namely igneous, sedimentary and metamorphic rocks. These rocks are subjected to different types of weathering like physical or chemical weathering. In this process rocks get transported by different agencies and they get disintegrated into boulders, gravel, sand, silt and clay.

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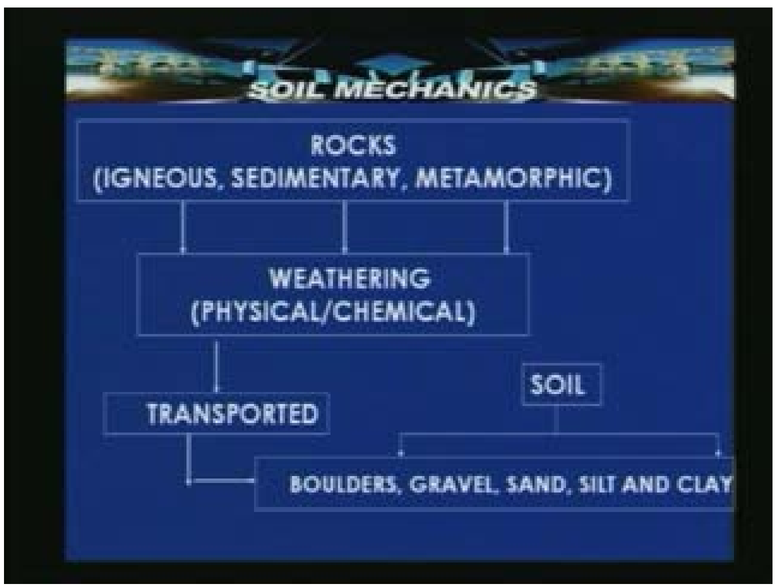

In the figure which is shown here in this slide, the portion containing the gravel, sand, silt and clay is relevant to soil mechanics. If we go from boulders to gravel to sand to silt and clay, the size of the particle reduces which indicates that the soil has got wide range of particles.

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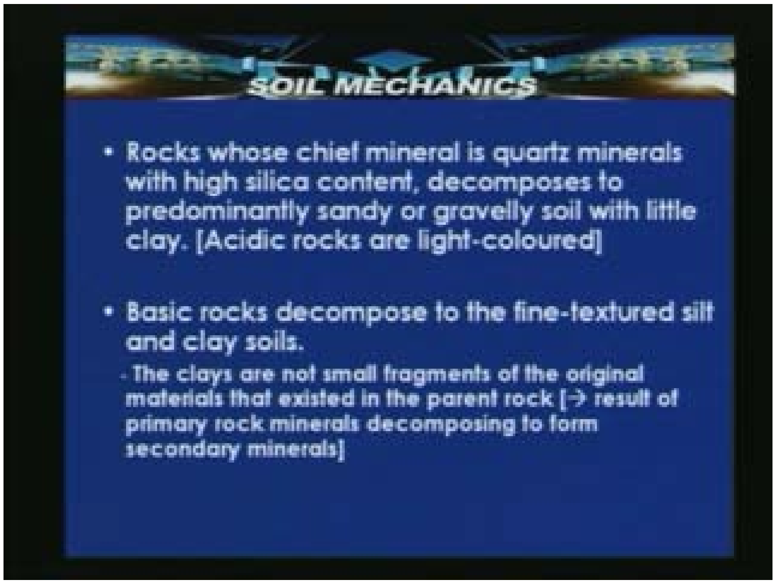

Now, rocks whose chief mineral is quartz with high silica content when they decompose and disintegrate predominantly they deduce sandy or gravelly soil with little clay. So as we said the Acidic rocks are light colored. So the sand and gravelly soil are reduced from or deduced from quartz minerals with high silica contents. Similarly, the Basic rocks decompose to the fine textured silt and clay soils. The clays are not small fragments of the original materials that existed in the parent rock but they are result of the primary rock forming minerals decomposing to form secondary minerals. So the basic rocks decompose to fine textured silted and clay soils whereas acidic rocks decompose to give sandy and gravely soils. Soil can be grouped into two broad categories depending upon the method of deposition like residual and transported.

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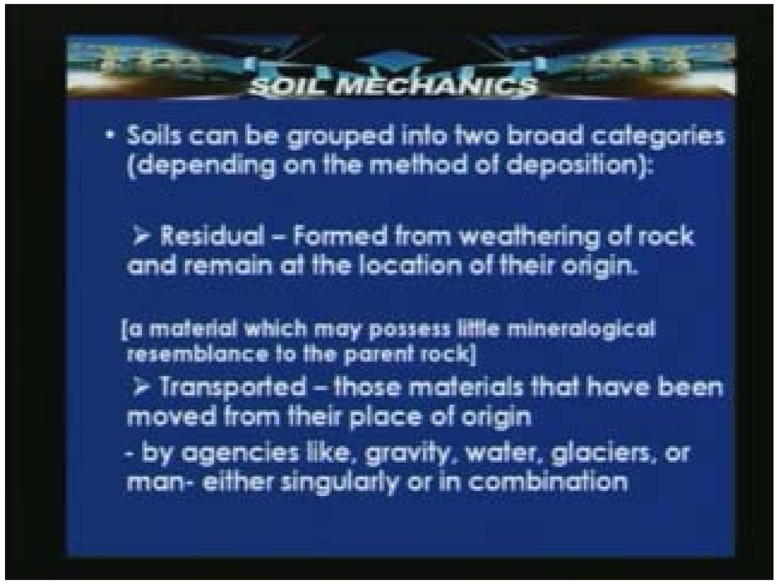

Residual soil is formed from the weathering of the rock and they remain at the location of their origin; this is the material which may possess mineralogical resemblance to the parent rock. Transported soil is the soil where the materials are being moved from the place of their origin to agencies like gravity, water, glaciers or man either singularly or in combination but residual soils remain in the same place.

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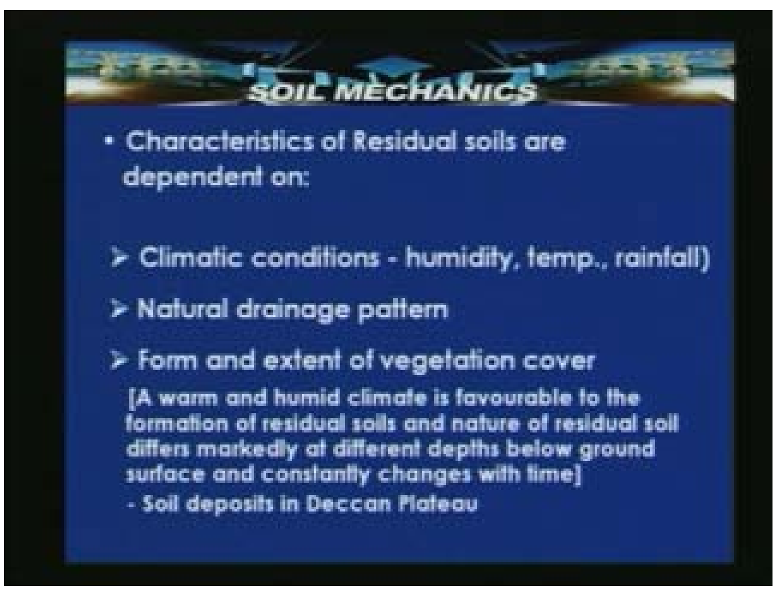

The characteristics of residual soils mainly depend upon the climatic conditions like humidity, temperature, rainfall in that particular area or the natural drainage pattern and form and extent of vegetation cover. For the formation of residual soil to take place a warm and humid climate is favorable. The nature of residual soil differs markedly at different depths below ground surface and constantly changes with time. Soil deposits in the Deccan plateau are mainly of residual in nature.

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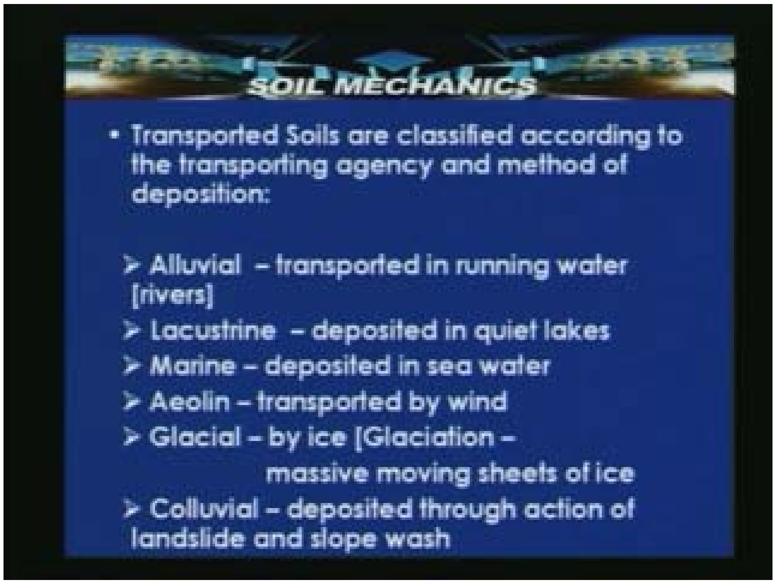

Further, this transported soils which are transported by different agencies are classified based on the transporting agency and the method of deposition like Alluvial soils transported in running water like rivers, Lacustrine soils deposited in quiet lakes, Marine soil are deposited in sea water, Aeolin soils are transported by agency called wind, Glacial is transported by ice whereas Glaciation is a process of massive movement of the ice sheets. Colluvial soils are deposited through the action of landslide and slope wash. Here in this slide, we have discussed about the types of the transported soils like alluvial soil, Lacustrine soil, marine soil, Aeolian soil, glacial soils and Colluvial soils.

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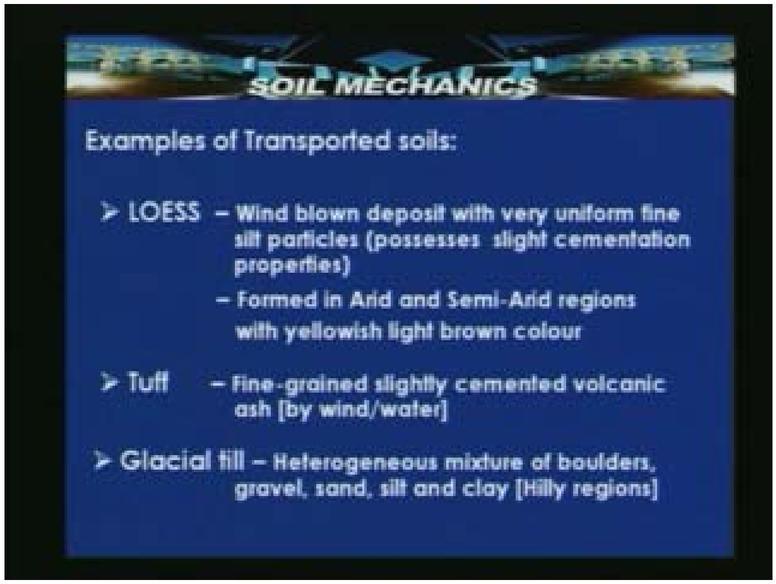

Before we look into the transported soils let us have some examples about different types of transported soils. Some typical examples are as follows: LOESS is the wind blown deposit with very uniform fine silt particles and possesses slight cementation properties because of the presence of carbonates within it. They are formed basically in arid and semi-arid regions with yellowish light brown color. Tuff is the fine grained slightly cemented volcanic ash which is formed by wind or water. The Glacial till which is mainly formed in hilly region is heterogeneous mixtures of boulders, gravel, sand, silt and clay. Here we have seen one example of transported soil like loess, tuff and glacial till.

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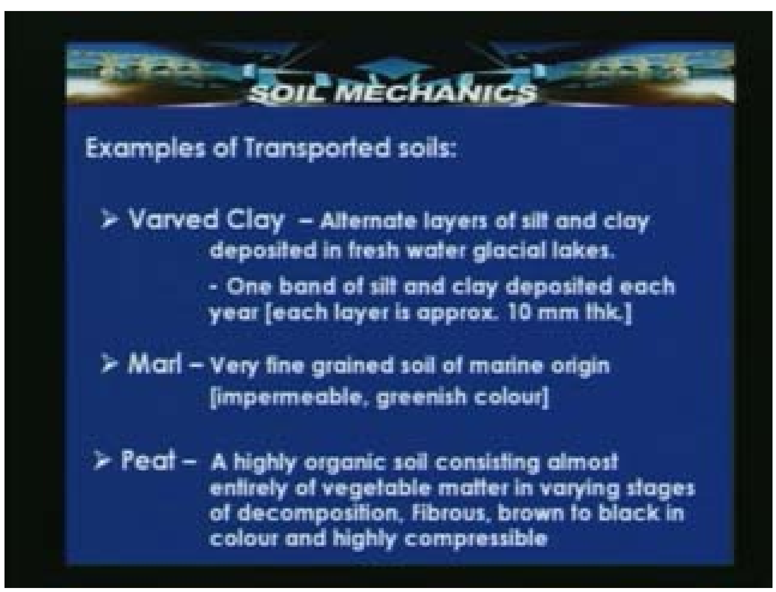

Another example of transported soil is varved clay where alternate layers of silt and clay deposited in fresh water glacial lakes. Generally one band of silt and clay deposited each year and each layer is approximately around 1 cm or 10 mm thick. Clay gets deposited whenever there is slow run off and silt gets deposits whenever there is high run off. Marl is a very fine grained soil of soft marine origin which is impermeable in nature and greenish in colour. Basically Marl origin is in the marine environment. Peat is a highly organic soil consisting almost entirely of vegetable matter in varying stages of decomposition. Basically it is fibrous in nature, brown to black in colour and highly compressible. So, peat is a material which is required to be avoided in the construction of foundations.

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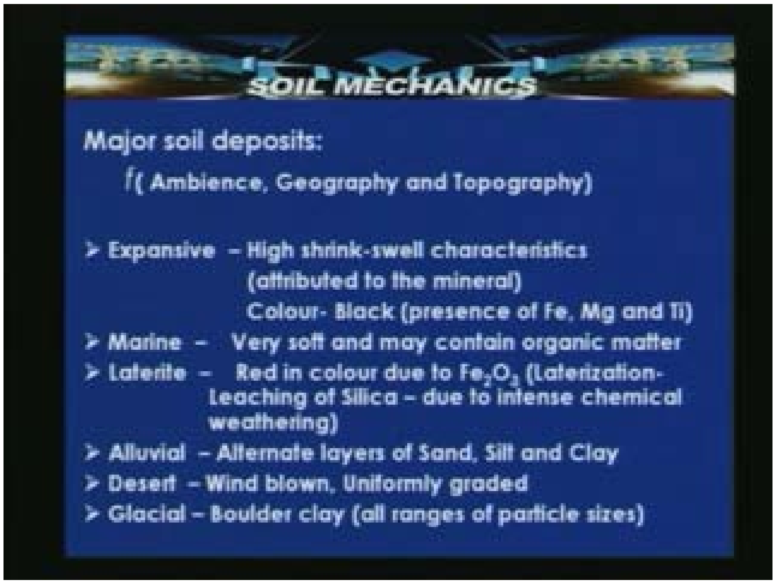

Basically the major soil deposits are divided by keeping following factors into consideration like ambience, surrounding environment, Geography and Topography. Soils are interpreted like expansive, high shrink and swell characteristics attributed to the mineral. These soils are basically black in colour due to the presence of iron, magnesium and titanium. So these types of soils are called black cotton soils in India. They extend around 3 lakh square kilometers.

Marine clays are very soft and may contain organic matter that exists along the coastal environment that is coastal belt of the countries. Laterite soil is basically red in colour due to Fe_2O_3 which undergoes a process called laterization. Laterization is nothing but the leaching of the silica due to advanced chemical weathering. Another soil is Alluvial soil consists of alternate layers of sand, silt and clay. Basically they are formed along the river beds and they are prone for liquefaction if they are very fine grained in nature. Desert soils are basically wind blown are uniformly graded and it is very difficult to compact them and it is also very difficult to construct the roadways on the desert soils. Glacial soils are basically boulder clays that occur along the hilly region where they consist about all ranges of particle sizes. Major soil deposits are divided into Expansive, Marine, Laterite, Alluvial deposits, desert soils and glacial soils.

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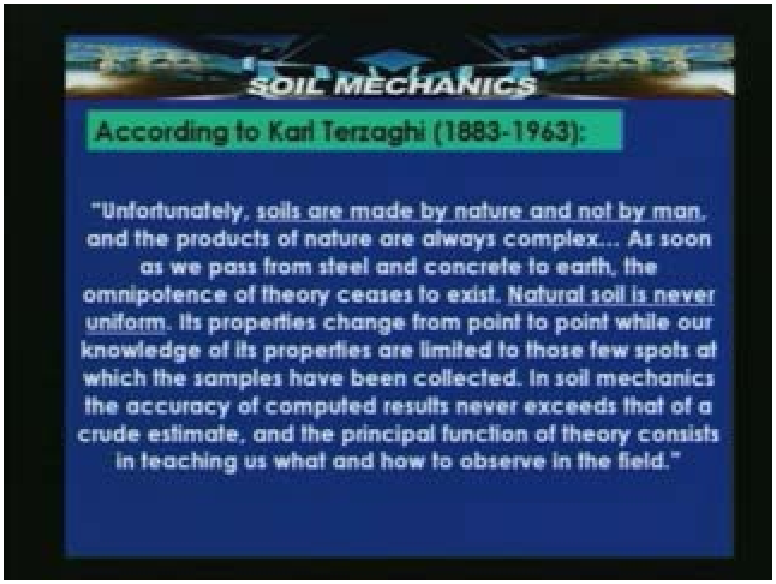

Before looking into this I would like to make the quote of the Karl Terzaghi the father of soil mechanics.

On quote: “Unfortunately soils are made by nature not by man and the products of nature are always complex. As soon as we pass from steel and concrete to the earth the omnipotence of the theory ceases to exist. Natural soil is never uniform. That is a very important consideration he has made at that time. Its properties change from point to point while other knowledge of its properties are limited to those few spots at which samples have been collected. In soil mechanics the accuracy of computed results never exceeds that of a crude estimate and the principle function of theory consists of in teaching us what and how to observe in the field”.

So, one important thing which is required to be noted is soils are made by nature not by man. The natural soil is never uniform and its properties change from point to point. This complicates and indicates the complex behavior to the soil. Before looking into the details let us look into the constituents of the soil mass. So basically its origin is from the disintegration of the parent rock with the different levels of weathering either due to physical weathering or due to chemical weathering. Wide ranges of soil solids can also be possible.

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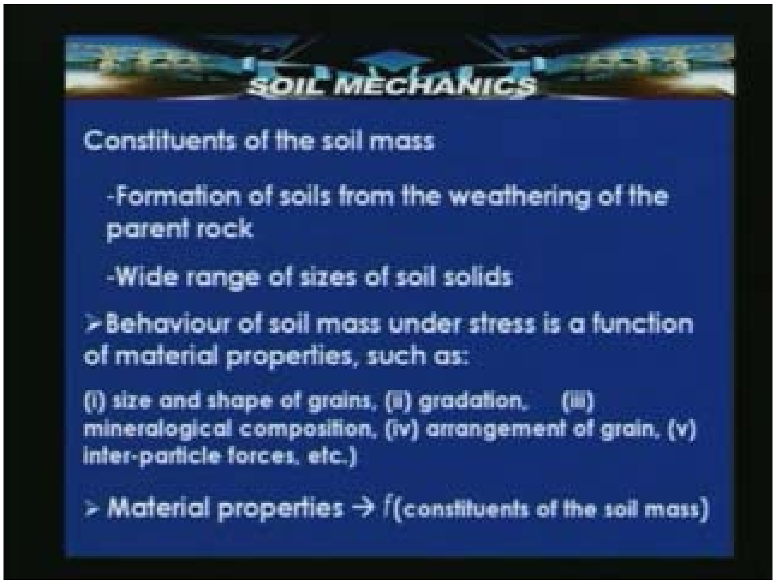

So the behavior of the soil mass and stress is a function of the material properties such as size and shape of the grains. Sometimes if you have got a rounded or sub-rounded aggregate it may not be good for generating resistance against its external forces or angular, sub-angular grains may provide good resistance against its external forces. Gradation is the proportioning of the soil sizes.

Mineralogical composition is the minerals prevalent in the soils. Arrangement of the grains whether it is loose or dense arrangement shows the soil structure arrangement. Inter particle forces: Basically the resistance to external forces is governed by inter particle forces, it all depends upon how the inter particle forces mobilized during the pore process of the soil phenomena. The material properties are functions of constitutions of the soil mass. Material properties here you have seen they are functions of constituents of the soil mass like size and shape of the grains, gradation, mineralogical composition, arrangement of the grains and inter particle forces.

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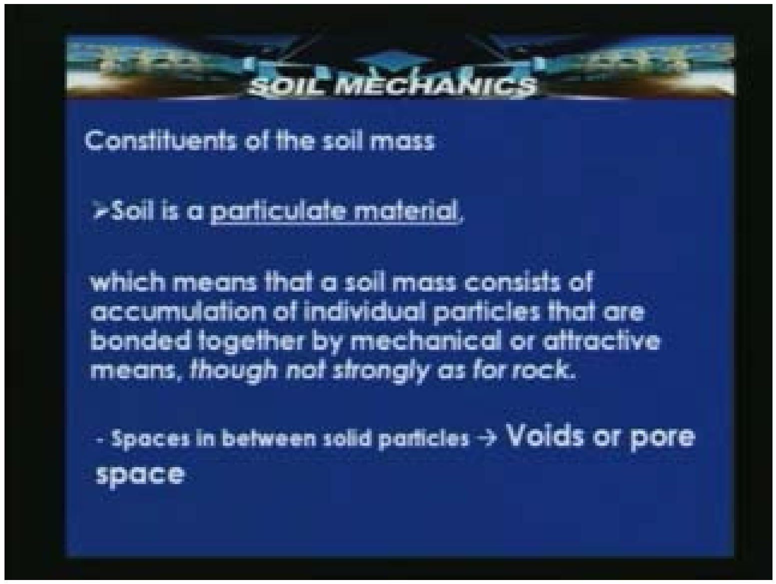

As you have seen here now, soil is a particulate material which means that a soil mass consists of accumulation of individual particles that are bonded together by mechanical or attractive means though not strongly as for rock.

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For example, if you look here, the soil mass has got solids which are covered within the soil mass, spaces between these solid particles are called voids or pore spaces in soil mechanics. These are the solid particles and these are the pore spaces. These pore spaces either can be filled with water or air they are usually it is referred like either liquid or gaseous materials.

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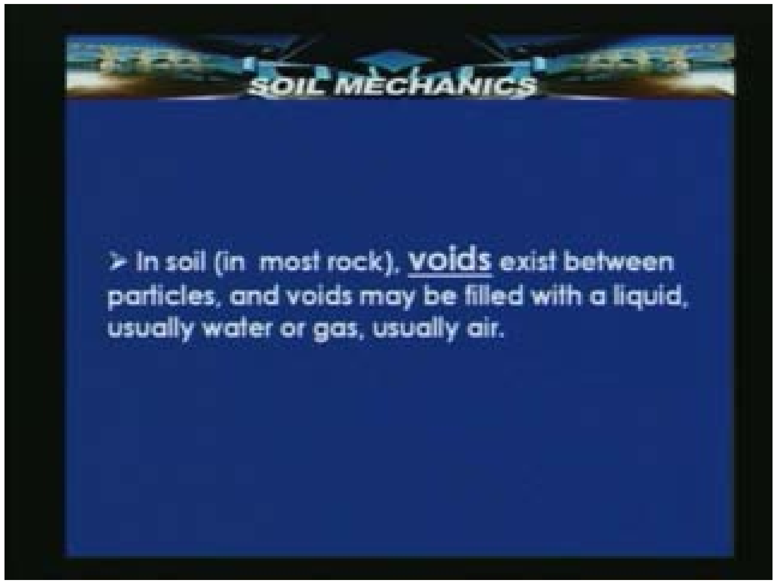

In soil (in most rock), voids exist between the particles and voids may be filled with a liquid usually water or gas, usually air. So in rocks also the voids do exist but the soils have pore voids which are filled with liquids or gas.

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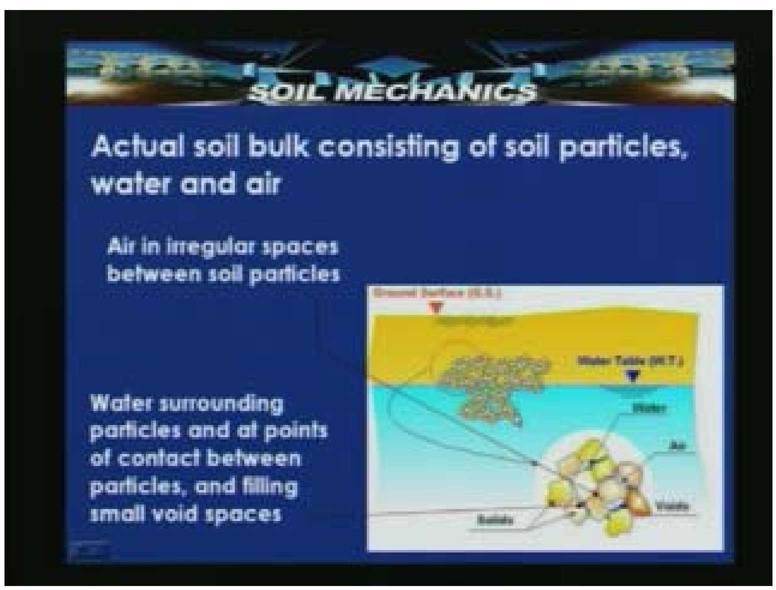

Here, in this slide, the actual soil bulk consisting of the soil particles, water and air is shown. As you can see here, this is the ground surface which is the top surface of the existing ground level in this particular figure. This is the ground water table also called the prioritic surface where the atmospheric pressure is 0, this is the arrangement of the solid grains. The grains which are submerged below the water table are all filled with water which means all void spaces are filled with water. So, water surrounding the particles at points of contact between the particles and filling the small voids can be seen here in some of the locations. In some of the locations that we have seen there are some void spots which are nothing but a portion within the pore space filled with air. So, above the water table the soil can be partially saturated and below the water table the soil can be completely saturated depending upon the type of the soil. There are also some cases that may arise where soil can be completely dry also.

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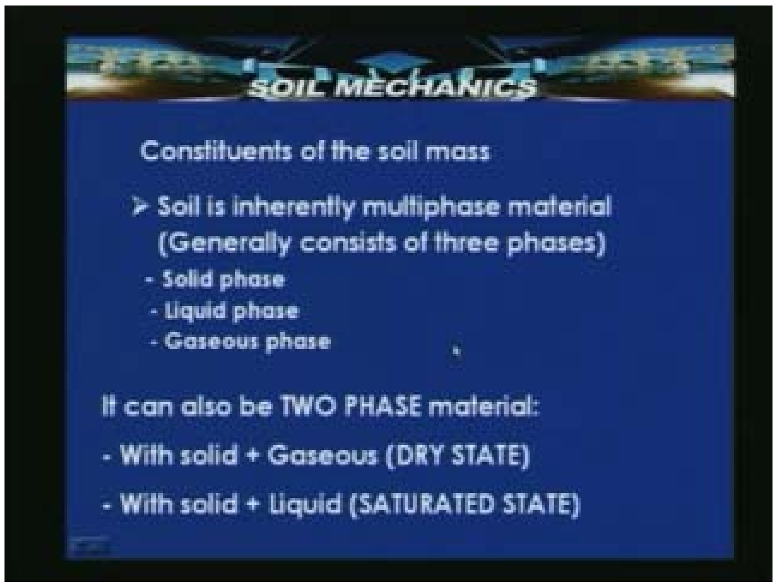

When you look into soil, soil is inherently multiphase material. Generally it is called a three phase material because it has got solid phase, liquid phase and gaseous phase.

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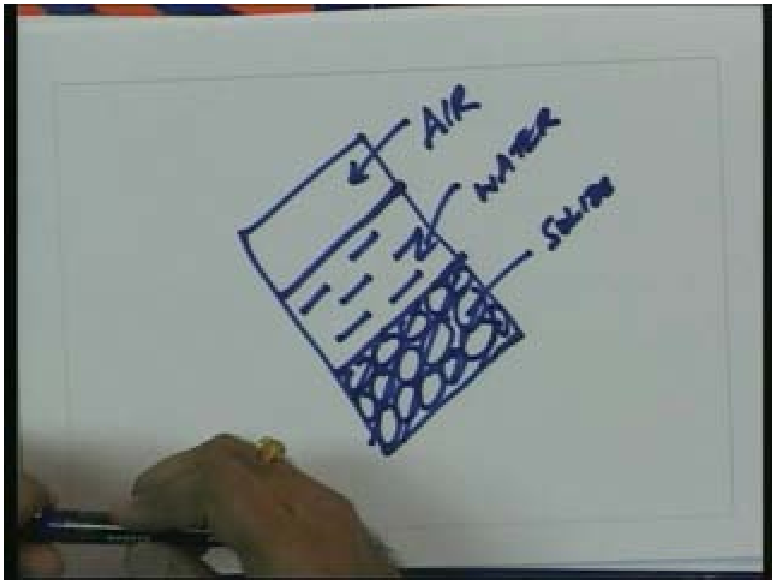

As you have seen here, if you look into this particular block having the unit cross sectional area if you idealize solids then solids form in this particular location. This particular portion is filled with water and this is air. So what you are seeing is air, water and solids. As you look into this, the solid phase is with solids, liquid phase is with water and gaseous phase can be usually with air.

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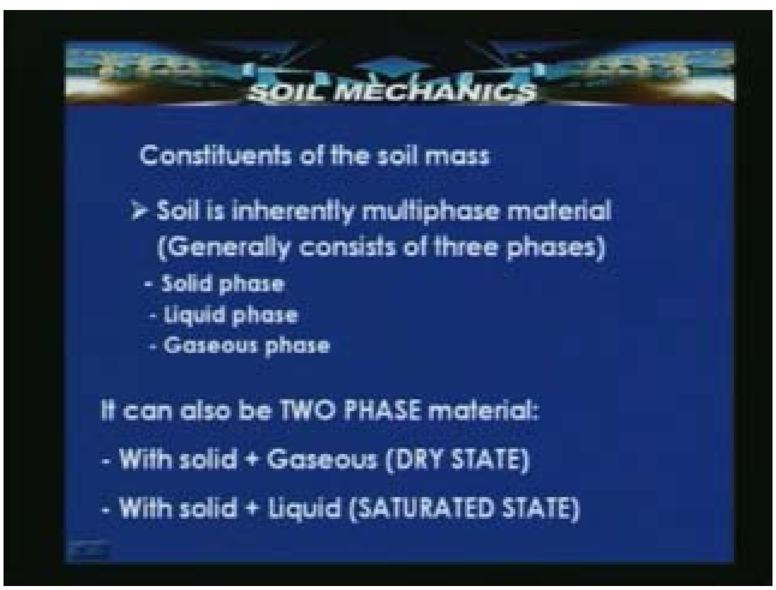

It can also be two phase material. For example, soil is set to be dry when it has got solid and gaseous phase like solids and pore voids are filled with air only. It is also said it is saturated if the voids are filled with water completely. So soil can be a two phase material also in dry state as well as in the saturated state. Generally it is a three phase material with solid phase, liquid phase and gaseous phase as shown here.

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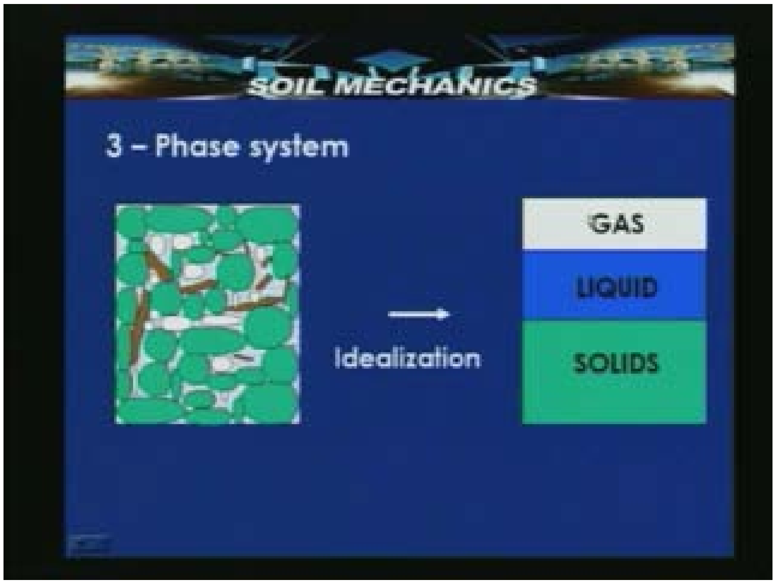

The unit cross section of the block is shown where the three phase system consisting of the green ones which are solids, the brown colored solid particles which are due to the present organic matter or due to the decade vegetable matter and these white spots are portion of the voids which are filled with air and the rest of the portion of the voids are filled with water. So this type of soil is a three phase system soil in which solids, liquid and gaseous phase exist. As I have shown before these are idealized as solids, liquid and gas.

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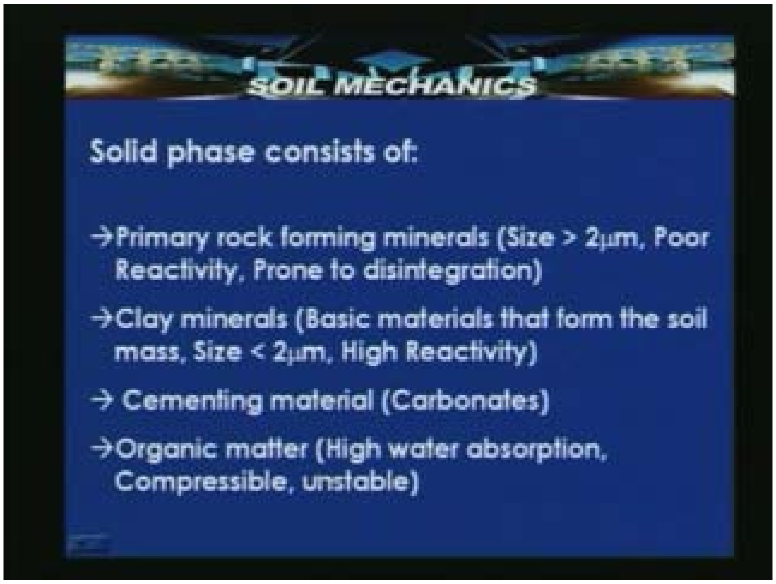

If you look into the solid phase they are primarily consisting of rock forming minerals where the size can be greater than 2 micro meters. Their reactivity is poor and prone to disintegration into smaller size because they are basically rock forming minerals with large in size. Basically clay minerals are formed due to the decomposition of the parent rock, minerals and accumulation of the secondary minerals in the process of transportation. So basic materials that forms the soil mass are clay minerals, their size can be less than 2 micro meters and they have high reactivity. Solids also do posses cementing materials with the presence of carbonates. They are actually having the carbonates or oxides in the organic matter. They try to induce the binding property to the soil mass. The main characteristics for Organic matter is high water absorption, they are compressible and unstable. Therefore, solid phase of the soil consists of primary rock forming minerals, clay minerals or cementing minerals which induce binding properties. Basically the presence of high organic matter causes problem in which the compressibility increases, it is an unstable material with high water absorption.

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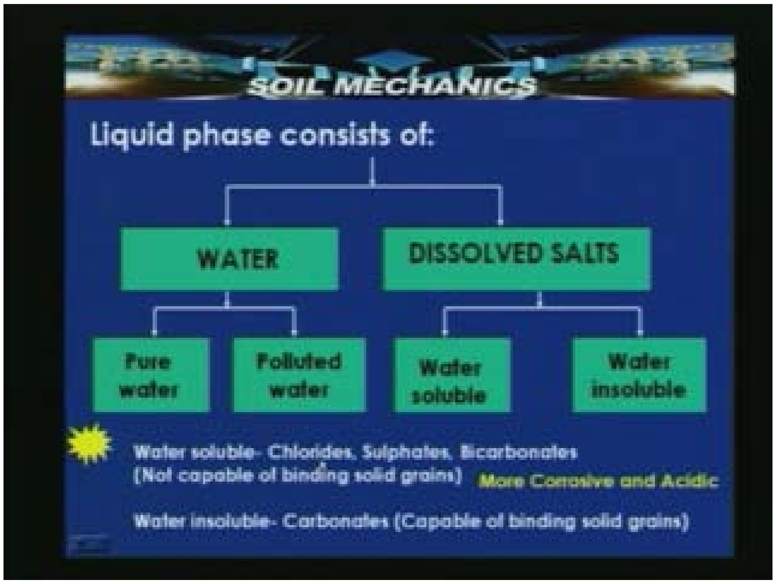

If you look into the other component like liquid phase, liquid phase can be further divided into either water or dissolved salts. If you look into the water, it can be either pure water or polluted or contaminated water. So, the pure water soils or polluted water soils also do exist. Dissolved salts can be either water soluble salts or water insoluble salts. Water soluble salts basically can have chlorides, sulphates and bicarbonates. These minerals are basically water soluble in nature, they are not capable of binding solid grinds and they are more corrosive and acidic in nature. Water soluble salts have less binding property to the soil. And water insoluble salts basically carbonates or oxides which are present in the organic matter is capable of binding the solid grains. They induce a binding property to the soil mass in the form of liquid phase with the water insoluble resolved dissolve salts.

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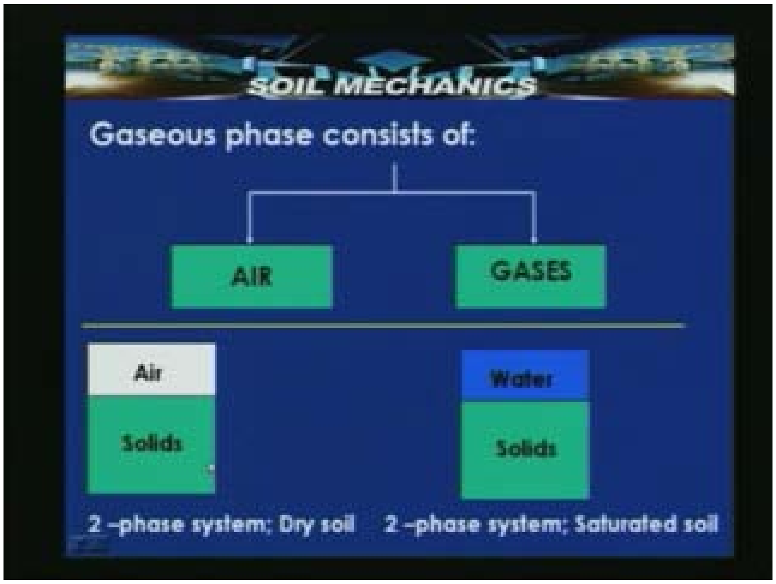

Again, when you look into the Gaseous phase they are basically divided into air and gas. If the solids have air and solids it is called two phase system with dry soil state and if the voids are filled with water completely as you have discussed in the previous figure then it is called a saturated soil. So the Gaseous phase can be filled with air and solids with a two phase system.

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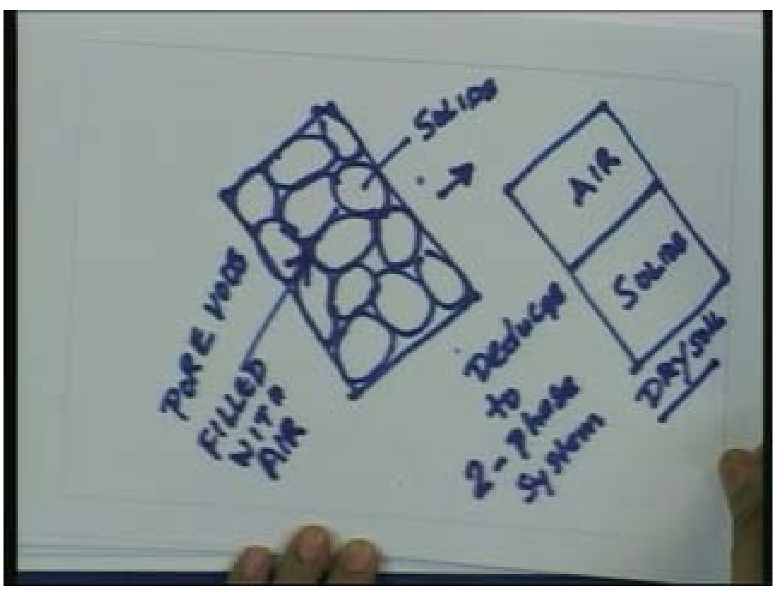

Here, we will see a system with solids and pore voids as idealized. The idealized figure changes like shown which consist of solids and air. These are the soil solids and organic matter. These are pore voids filled with air. So the idealization deduces to a 2-phase system. This is called a dry soil. In this case, this are the voids which are filled with air only and this are the solids which are separated by air, which is prevalent in the voids and idealized like this. If you separate solid and air then it will deduce to be 2-phase system having two phases like solid phase and gaseous phase which is filled with air here. So this is a two phase system called a Dry soil. These things we will be using in the future lectures.

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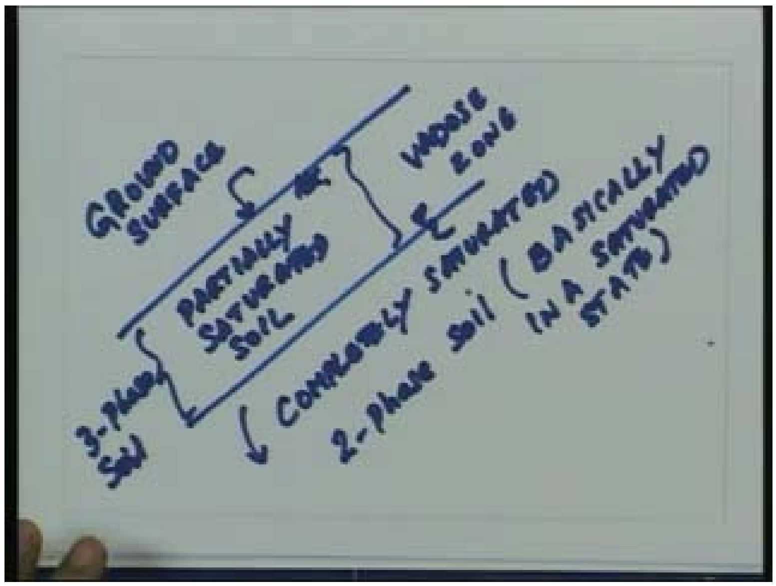

Below the ground water table, for example if there is a ground water table here where soil can be completely saturated or partially saturated in this zone. So this zone is called Vadose zone. This is the ground surface. In this case, below the ground surface it can be partially saturated soil. Here, below the ground water table to maximum extent the soil can be completely saturated. The soil above the ground water table can be three phase soil and below the ground water table, it can be two phase soil basically in a saturated state.

Here what have been shown are a ground surface and a partially saturated zone; it can be saturated completely depending upon the type of the soil that will be discussing in the future lectures. For this case, where the soil above the ground water table is referred as partially saturated soil or three phase soil; it can be dried because of the evaporation of the water in the soil void. It can transform into a two phase system soil and the zone above the ground water table is called Vadose zone. This terminology we will be referring in the future lectures of our soil mechanics. In this case, below the ground water table the soil is completely saturated means that all the voids are filled with water. In this lecture we have seen the necessity of the soil mechanics that is basically why we are required to study soil mechanics from the different disciplines in engineering like structural engineering, transportation engineering, environmental engineering and hydraulic engineering point of view.

Definitely we appreciate the interest of this subject and complexity of this behavior of the soil. It necessitates us to understand its properties in a better way so that safe structures can be constructed for the better performance of the structures. In this lecture we have seen the origin of the soils and we have discussed that the basic origin is from the parent rock, they get disintegrated due to the physical and chemical weathering.

The parent rocks are basically igneous rocks, sedimentary rocks and metamorphic rocks. With the disintegration of these rocks, they form two basic types of soils namely residual soils and transported soils.

Residual soils basically remain in the place and they have their resemblance to the parent material's mineralogical characteristics whereas transported soils get transported from their origin to some other place either by agencies like wind or air or water or ice. Then we have further classified transported soils and discussed about some of the examples of the transported soils like Loess, tuff and marl and also these are the examples of the varved clay or the examples of the transported soils. Then we tried to understand the constituents of the soil mass and we said that soil basically has got three phases namely solid phase, liquid phase and gaseous phase. Basically the solids which are disintegrated from the parent rock are some clay minerals which are very fine in size and having secondary mineral characteristics.

Also, the soils can have organic matter due to the decade vegetable matter which is prevailed in that particular area. Water or liquid in the form of pure water or polluted water or with the dissolved salts basically insoluble or soluble salts or gaseous phase, we also discussed that soil can have air or gases. In this particular lecture we also introduced 2-phase system like dry state and saturated salt state.