Geomorphology
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Lecture 15
Soil Formation

So friends, good morning. Welcome to these lecture series of geomorphology and today we are going to discuss about the soil formation process and how the weathering is responsible for soil formation, what soil means to us, and what is its importance, how geomorphologically, the soil becomes important from geological history. So as you remember your last class, we are talking something about the weathering products.

And among these weathering products, soil is the most important weathering product we get, why? Because without soil, we do not have cultivation. Once cultivation is not there, the existence of life would not be there. So soil is the most important weathering product that we have ever got. So what does it mean? What is soil? Soil science is called pedology.

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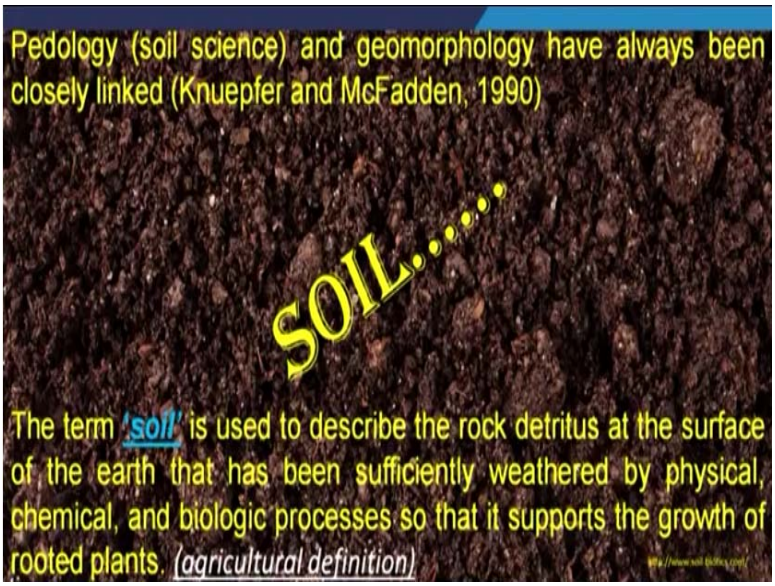

Pedo, pedo means its starts from the word ped. Ped means soil structure. So once we say soil science in geomorphological term or scientific term, we say the study of soil science is called pedology. So pedology and geomorphology, they are closely interlinked. How? If you remember

when we were talking about this geomorphic process, there are different geomorphic process. They are responsible for soil formation.

Because for the soil, we need some material, parent material, which is called parent material. From this parent material, we weather it physically, chemically, biologically in combination of all those weathering, then we disintegrate the parent material and we decompose the parent material. So organisms grown and those organisms they break down from complex mineralogical bonds to simple mineralogical bond. Then the humus is decomposed and the organic matter decomposed.

And the minerals gradually reduce their size by physical weathering. So a mixture of all those things, they create a layer on this parent material and that layer, that promotes the growth of rooted plants and those layers, which promotes the growth of rooted plant that is called soil. It is the definition by agricultural people or the people who are involved in agriculture, but for engineers, the definition of soil is different.

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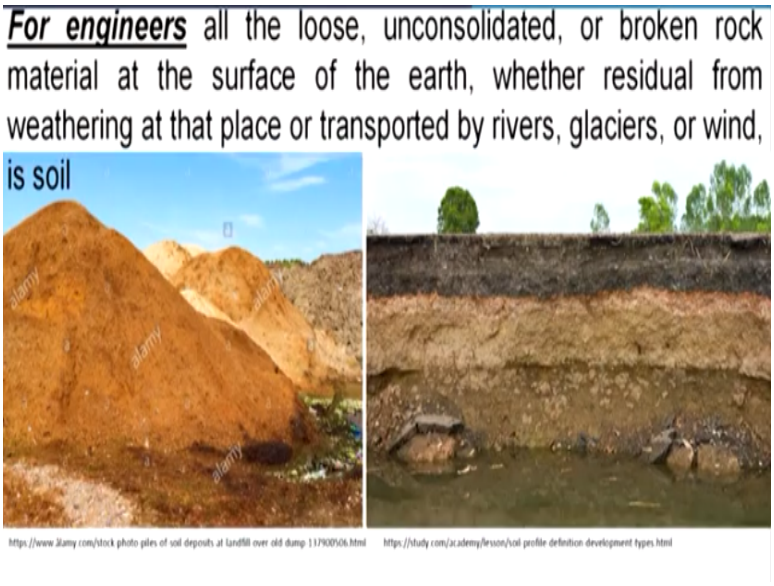

For the engineers, any unconsolidated broken material, any, irrespective of it is decomposed or it is allowing to grow the rooted plant, irrespective of all those things. Any broken material, broken debris, a surface of earth where residual, it may be residual form that is called soil. So there are

two types of definition. One definition by agriculturalist, another is by engineer, but for geologist, the soil means, it has to develop some layer.

It should go up to sufficient weathering, sufficient decomposition, some layers has been developed, then we can create soil and for geologist, we only and only term those reduced material are those weathered material to soil. If there is soil structure developed, soil structure, the unit soil structure that is called ped. If pedological features that means the soil structures until unless it is developed for geologist, that is not soil.

So there are three schools of thought. One is agriculturist, one is engineers, one is geologist, and we will consider those definitions of soil, which is satisfied by the geologist or for the geologist. So for geologist, soils are characterized by horizons.

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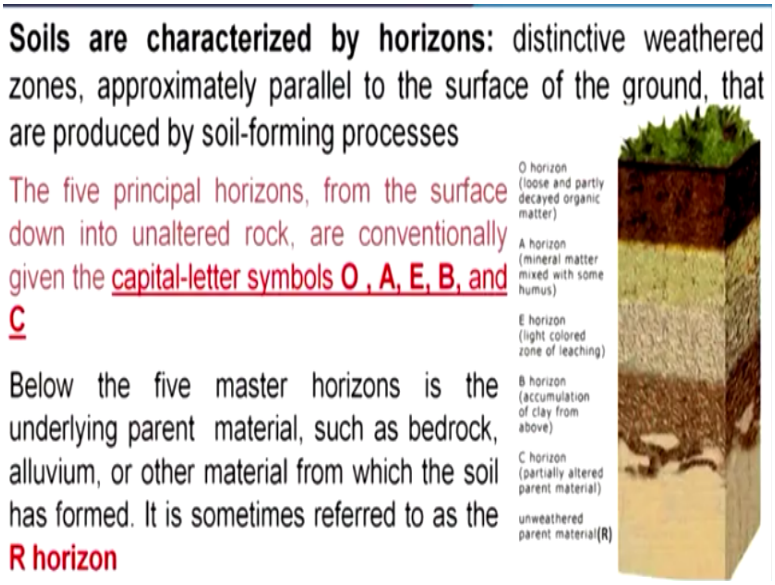

What is horizons? So you see, suppose by any means, a parent material is lying here for millions of years or thousands of years or so, so with disintegration with decomposition and with the illuviation and alluviation. What is illuviation and alluviation? You see, once we have a parent material layer, so raining is there. So due to raining, due to disintegration and decomposition, some materials, they move along this boundaries or move across these boundaries from one place to another.

This is called illuviation. So that means materials removed from the upper layer and gradually moved downwards and that will be accumulated somewhere else. So by this way, there are layers developed. Similarly, if you remember our weathering class, we are talking something about the rhizosphere. Rhizosphere means it is a biologically active layer. So within the soil, we have a biological active layer.

We have a layer, which is characterized by leaching or removal of material and those removal of material, they will be accumulated somewhere. That will define another layer. Similarly at the upper surface, close to the surface or the upper surface, the organic matter will accumulate, that will also create layer and below that once we are moving across this boundary, from top to bottom, then below will get this fresh rock material.

And above this fresh rock material, the rocks will be slightly weathered or these minerals will be slightly weathered and then will be more weathered, and more weathered and more weathered. So in this way, if you see a soil profile, there are different distinct layers are developed and those layers are called soil profiles or soil horizons. So distinctive weathered zones approximately parallel to the surface of the ground that are produced by soil forming process.

That is soil forming process is the key here. What is soil forming process? That we are discussing whatever this weathering is there, erosion is there, transportation is there, accumulation is there, organic decomposition is there, chemical decomposition is there, all those total package, it is under soil forming process. So by this way, 5 principle horizons from the surface to downward into unaltered rocks are conveniently given capital letters, the soil horizon names.

Those soil horizon names are termed as O, A, E, B, and C. So O is the top, which represents for the organic matter and C is the bottom, which represents the parent material, but below this 5 master horizons, there is underlying parent materials. Such as bed rock, alluvium, or other material, from which the soil has formed, it is sometimes reported as R horizon. So that means, we have 5 principle horizons and below that 5 principle horizon that is one horizon that is called R horizon. R for regolith and it is unweathered and represents the parent material.

In each sub-horizons O, A, E, B, C, all horizons that again subdivided into sub-horizons. So in this class we will not discuss about the sub-horizons, but we should keep in mind those 5 principle horizons and each horizon has distinct characteristics and it represents distinct class of weathering, distinct degree of weathering and each horizon it signifies something during the soil formation process, but it has to be kept in mind here that not necessarily all these 5 principle horizon, we will get in each geological soil profile.

So it may be possible that after O and A horizon, there will be C horizon. Then after A, E, B horizon, there will be C horizon. So that means I want to say these 5 principle horizons, they represent the ideal condition. If the condition satisfies, then in each and every soil profile, we will get this O, A, E, B, and C horizon. Otherwise, there may be some horizon missing at some places. That depends upon the soil forming processes involved.

So depending on the process, depending on the time, time and process, both are related here, so depending upon the process and time, we may get all 5 principle horizon at a point or we may not get those all 5 ideal principle horizon at a process. So in between, there may be some transition horizons. For example, suppose E and B, some horizon, it is not approaching to B and some horizon it is not totally or fully approaching to E. So in that case, we can say EB horizon.

So similarly, once we go downward, there may be or may not be distinct horizons present. Some horizons may represent the transition from one horizon to another horizon. So accordingly, we name the soil horizons at the point of study. So these are some field photographs of soil horizons taken from Ganga plain.

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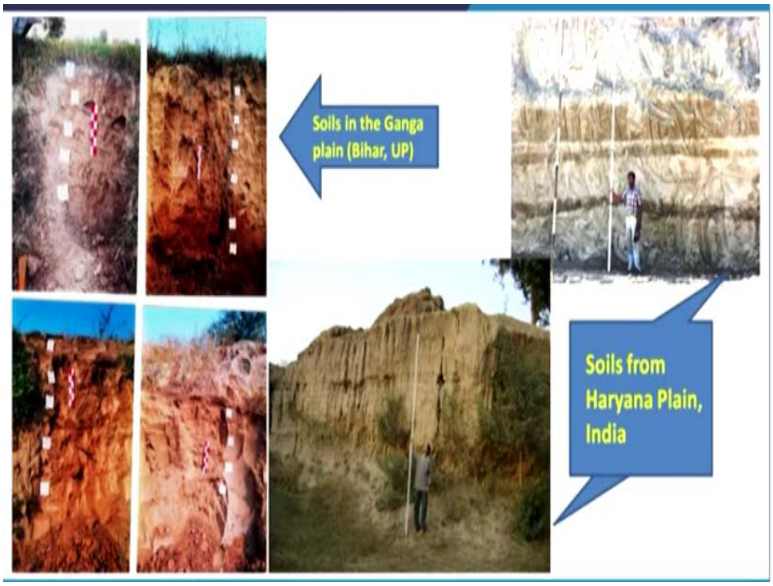

In the western side are the 4 photographs, if you see here the scale is given. It is of one feet scale and these 5 horizons have been marked, here 5 horizons are marked, here 6 horizons are marked and if you see here the scale, it is one feet, so around 3 feet, the total thickness here is around 3 feet. Similarly, the total thickness here will be around 5-6 feet, but if you see here in soils from Haryana plains, these are 2 photographs from Haryana.

And you see, the soil thickness is this much. The soil thickness is this much or beyond that. So that means I want to say, though we have 5 principle horizons, so thickness of those 5 principle horizon is not same throughout. That depends upon the parent material. It depends upon the climate that depends upon the degree of weathering. That depends upon the time, under which the weathering condition is prevailing.

So depending upon all those factors, the thickness of soil horizon varies. In particular, if we confine ourselves in the Indo-Gangetic alluvium, in the western part, like these Western UP, Haryana, Punjab, we will get thick soil development. Similarly, if we go to eastern part like Bihar, eastern UP, so we will get very thin horizon of soil. So that depends upon the degree of weathering, the time, the parent material, all those things.

And second thing, the very important thing here I want to mention here that it is the tectonic process, which is responsible for soil formation. Soil is a tool, nowadays being used successfully

to define the tectonic stability of an area. The thicker the soil, the more tectonic stable the area is. So accordingly, if we compare these 2 photographs or these 2 parts of this photograph, these 4 photographs, they are representing thin soil, however these 2 photographs represent thick soil.

So that means, we can say these area or Haryana, Punjab, those area, they are tectonically, relatively more stable as compared to the Eastern Gangetic counterpart and soil formation or soil development, it represents an unconformity in geological timescale. How? Unconformity, we know, different types of unconformities. Here soil formation means, the surface is exposed to the surface. So exposed surface means, it is above the depositional level.

So as per the definition of unconformity says, it is the surface of erosion or non-deposition in a geological timescale. So here, once we allow the sediments to expose to the surface, interact with the atmosphere, interact with the organism, so in that case, that means it is getting decomposed disintegrated. So soil formation starts. So till that, the area is not covered with the younger sediments. That is why, soil of an area it represents the unconformity.

Similarly, in geological past, if you analyse the geological records from precambrian to recent, we have different soil profiles, they are covered with younger sediments. So those are called paleosols. Paleosols means old soil. So either soil or paleosols that are indicator of surfacial exposure. That means weathering, erosion, so that other words we can say that is representing the unconformity in a geological timescale and soils play important role to define the paleoclimates.

Because if you are getting a soil profile or if it is a paleosols profile, it is a geological treasure, in terms of defining the geological history, in terms of defining the paleoclimatic process, paleo-tectonic process, okay. So that means, paleosols study is also important in terms of geology to unravel the past geological climate. Now let us discuss about the 5 principle horizons of the soil.

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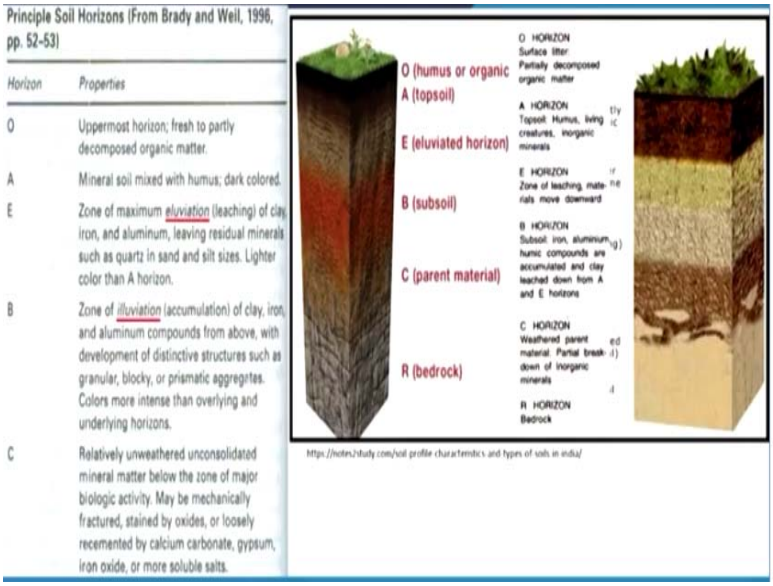

Principle Soil Horizons (From Brady and Weil, 1996, pp. 52-53)

Horizon	Properties
O	Uppermost horizon; fresh to partly decomposed organic matter.
A	Mineral soil mixed with humus; dark colored.
E	Zone of maximum eluviation (leaching) of clay, iron, and aluminum, leaving residual minerals such as quartz in sand and silt sizes. Lighter color than A horizon.
B	Zone of illuviation (accumulation) of clay, iron, and aluminum compounds from above, with development of distinctive structures such as granular, blocky, or prismatic aggregates. Colors more intense than overlying and underlying horizons.
C	Relatively unweathered unconsolidated mineral matter below the zone of major biologic activity. May be mechanically fractured, stained by oxides, or loosely recemented by calcium carbonate, gypsum, iron oxide, or more soluble salts.

The first is O horizon. O is upper most horizon fresh to partly decomposed organic matter. Here, if you see, this O or humus organic O horizon, here this is black in colour and it is organic matter. That means all the organic matters they are embedded here and forming near about black colour and this is called O horizon. Below that is A horizon. Mineral soil mixed with humus and dark coloured.

Now humus is here that O horizon and here these minerals and parent material, they are mixed with humus and forming a mixture horizon of mineral and humus or organic matter, this is called O horizon. That is called top soil. Then, below is E horizon and gradually you see how the colour is changing. E horizon means zone of maximum alluviation. Alluviation means leaching, maximum alluviation or leaching of clay, iron, and aluminium leaving residual minerals, such as quartz, sand, silt size, lighter colour and A horizon.

Now you see, whenever we talk about parent material or alluvium is there, on which the soil is getting formed. We have mixture of minerals either ferromagnesium mineral are there, quartzofeldspathic mineral is there. So if you remember our weathering class, the ferromagnesium minerals, they are more prone to weathering. So their weathering rate is fast. Now suppose, we have a mixture of all those minerals and we allow it to weather physically, chemically and biologically.

So the ferromagnesium mineral, they will leach from this place. So the resultant will be or the resulting mineral will be enriched in the quartzofeldspathic mineral, which are mostly of light colour. So now here is, this is the maximum alluviation zone or leaching zone. Once these dark colour minerals, they are weathered and leached out, so the resultant horizon will be white in colour and rich in quartzofeldspathic minerals or the light-coloured minerals.

So now the question arises, if it is leaching, then where it will move, at which place it will accumulate, the leached material where it will accumulate. Now come to B horizon. It is the zone of illuviation or accumulation here. So that means those minerals, which are leached from E horizon and they are accumulating at the lower horizon, just lower horizon, it is called B horizon. So it is the accumulation of clay, iron, aluminium compound from the above with development of distinct structure.

This is important here. It is the development of distinct structure that is the bed structure, such as granular, blocky, prismatic aggregates, colours more intense than overlying and underlying horizon, because leached material are placed here, accumulated here. So that means, it will change the colour of this parent material. So that is why there will be development of peds, ped structure like blocky, prismatic, whatever the structures are there, whatever the size is there.

So that means B horizon is the actual soil horizon. It is the prominent soil horizon. Then, come to C horizon, relatively unweathered, unconsolidated mineral matter below the zone of major biological activities, may be mechanically fractured, stained by oxide, or loosely cemented by calcium carbonate, gypsum, iron oxide and more soluble salts and if you see here, this figure, there are distinction of different colours of different horizons.

Similarly, C is the parent material horizon, then R is the bedrock. That means, it is the intact rock, on which this weathered material it is weathered and this is the weathering zone. It is here clearly and this is the zone of accumulation and it is the zone of leaching, it is the zone of mixture of organic matter and parent material and it is the zone of organic matter. So these are the 5 principle horizons in a soil profile, ideal soil profile.

But not necessarily, all those 5 principle horizon will present everywhere in a soil profile we want to examine. So that depends upon the degree of weathering in terms, degree of exposure or the intense of the climatic condition. If suppose, a rock is exposed in warm and humid climate, that means, it will undergo rapid chemical weathering. So rapid chemical weathering may able to develop all these 5 horizons and sub-horizons.

However, if it is in cold climate, only maybe under R horizon there will be C horizon, there will hardly be any B horizon or E horizon or A horizon. So that means, where we are going to see it. Where we are going to examine a soil profile that will define whether we will get these all 5 principle horizon at a place or not.

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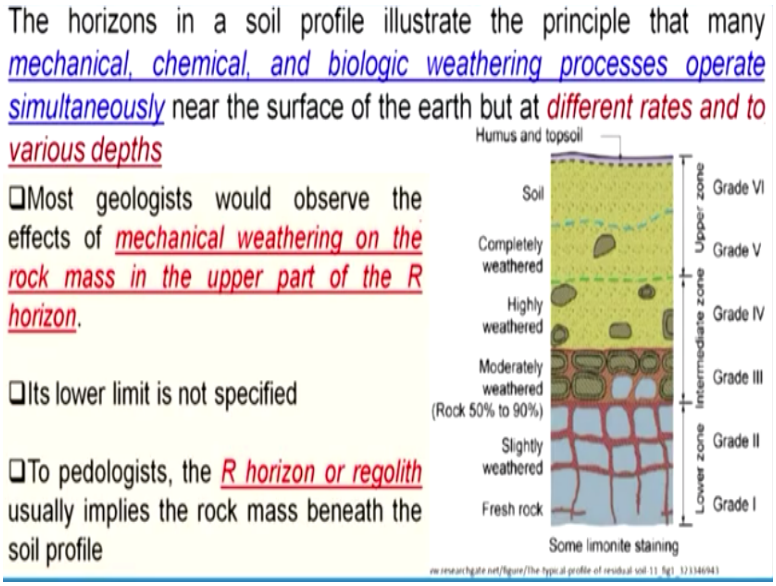

The horizons in a soil profile illustrate the principle that many mechanical, chemical and biological weathering process operate simultaneously near the surface, but in different rate and various depth. This is important. The different rates and various depth, as we are discussing the difference upon the climate, so most geologist would observe the effect of mechanical weathering on the rock mass in the upper part of this R horizon.

So we are talking something R horizon, the parent material. This is unweathered bedrock on which the soil horizon is developed. So this R horizon, it is totally unweathered. So this R horizon it may be regolith. Regolith means soil and regolith. There are 2 different things.

Regolith means this weathered material from the parent rocks and soil means the weathered material in which the soil horizons has been developed or soil structures have been developed.

But regolith, no soil structure, only the weathered material on the parent material are in the bedrock that is regolith. Its lower limit is not defined and to pedologist, the R horizon or the regolith unusually implies the rock mass beneath the soil profile. So here, this R horizon, if you see here, this is R horizon, that means it is totally the bedrock and this is the regolith and this is C horizon and this B, E, A, something, something whatever is there.

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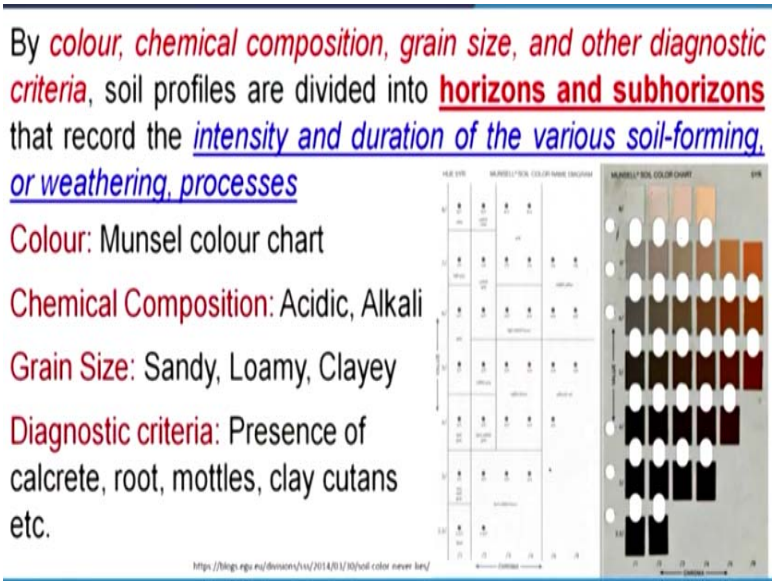

These horizons are distinct from one another and this distinction is based on the color, based on the chemical composition, based on the grain size and other diagnostic criteria is there. Soil profiles are divided into horizon and sub-horizons that record the intensity and duration of the various soil forming or weathering processes. If you see here, it is the photograph of a soil colour chart in soil colour is defined by Munsel colour. It is defined by Munsel colour chart.

It is one page of this Munsel colour chart. If you see here, this direction is increasing and in this case, suppose this or this soil colour. Generally, these are the holes within the page. So if you want to examine a soil colour, what we generally do, we put the soil below this hole and we compare this colour with the given colour chart. So accordingly, we define which colour, what is the number or what is the name of that soil colour.

So suppose, for example, here this hole is indicating or this colour is indicating the soil. So it will be 5yr 8 by 4. It is 5yr is the number and 8 is the subdivision, and this is the fourth place, so it will 5yr 8 by 4. So in this way, soil colours are named and soil colours, generally they define the climate, define the parent materials. So climate, parent materials, degree of weathering, mixture of organic matter, degree of leaching, all those indicates the soil colour.

Then, chemical composition of soil, it may be acidic soil. It may be alkali soil. Then grain size may be loamy soil, may be sandy soil, may be sandy loamy soil, so like that. Diagnostic criteria, presence of calcrete, it is important. Last class, we were talking something about calcrete and calcrete development and its importance. Then, presence of calcrete, root, mottles, clay cutans, these are the diagnostic horizons.

So those soil profiles are distinguished on the basis of this colour, basis of chemical composition, basis of grain size, basis of diagnostic criteria. So by defining a soil horizon, all those parameters, all those characteristics have to be noted by a geologist.

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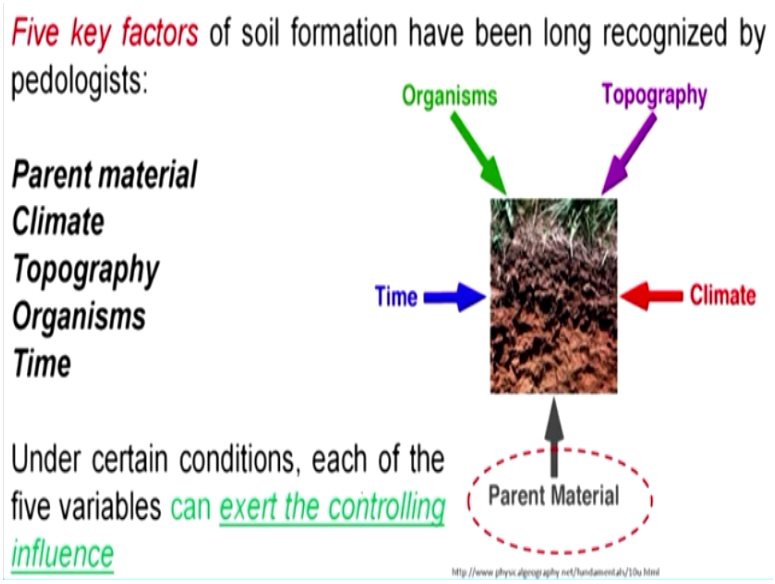

Now the question arises, how the soil forms? What are the factors responsible for formation of the soil. There are 5 key factors. They are responsible for soil formation and those key factors either which factor will dominate over other that depends upon the geological condition, the

geographical condition. For example, these 5 factors are parent material, climate, topography, organism and time. So now you see, parent material, you cannot change.

Time you cannot change. So suppose, we take a window of 1 million years, for say, 1 million years. Within that 1 million years, we cannot change the parent material of a place. We cannot change the time, however, we can change these 3. One is topography, we can change, because we know there is inversion of topography within geological timescale, whereas positive topography nowadays due to weathering and erosion, there may be negative topography comes.

Similarly, climate there are many times the climate changes occur in geological past. Organisms, depending upon the change of climate, the organisms also change. So that means, though there are 5 principle factors or the soil forming processes, out of this 5, this time and parent material, these 2 remain constant, but those 3 factors, that is climate, topography and organisms, they change with time. So accordingly, the characteristics of the soil horizon that will vary.

So under certain conditions, each of these 5 variables can exert the controlling influence. How these different parameters they control the soil forming process, let us discuss.

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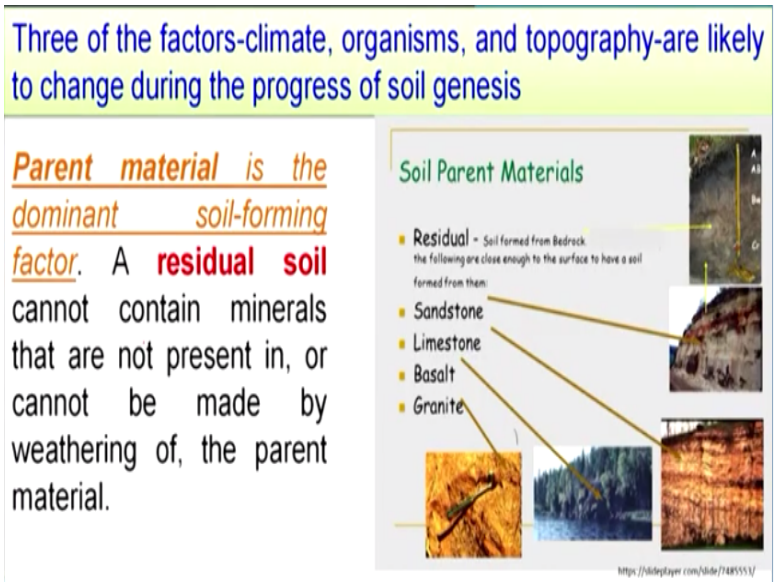

Three of the factors, that is climate, organisms, and topography are likely to change during the process of soil genesis, but parent material it never changes in the soil forming process. Parent

material is a dominant soil forming factor. A parent material, suppose what is the characteristics of the soil. Suppose, the soil is developing on granite, a soil is developing on limestone, the characteristics of this soil and that soil will be different.

So that is why the parent material on which the soil is getting developed, that also define, which type of colour the soil will be, what type of mineral content will be there in the soil horizon? What type of organic matter will be in the soil horizon? What is the colour of the soil horizon? So that depends upon the parent materials. A residual soil cannot contain minerals that are not present in or cannot be made by weathering of this parent material.

So if you see here, this photograph, sandstone is getting some soil. Limestone and soil, basalt soil, granite soil, you see all these 5 photographs of the soil, they are showing different colour. Similarly, if we analyze their soil horizon characteristics that will also vary from one place to another place. So that is why, parent material plays an important role to define the soil characteristics.

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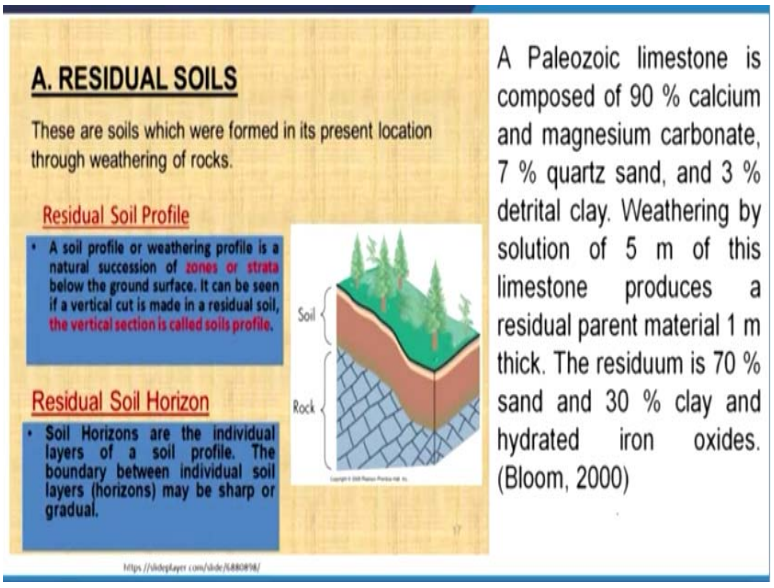

A residual soil, suppose a residual soil is there. Residual soil means after the development or after this removal of this unnecessary material, a soil horizon will be there. This is called residual soil. That is in situ soil. Now, there are two types of soil, one is called in situ soil, another is

called transported soil. So residual soils, they are in situ soil that is indicating the parent material, on which the soil is developed.

For example, here if you see this photograph, this is limestone. On the limestone, we are getting thick soil development and within that soil there are horizons, there are subhorizons, like that. So this soil is called residual soil, because it is developed in situ by removal of this unstable minerals and enriching the stable minerals and that is developed on this limestone. So those soil that will hold the characteristics of this limestone. So this is residual soil.

So residual soil, suppose for example, in a Paleozoic limestone is composed of 90% calcium carbonate, 7% quartz, 3% detrital clay. When weathering of this solution of 5 meter limestone produce a soil profile having 70% sand, 30% clay and hydrated iron oxide. So that means I want to say, a residual soil will hold this characteristics of the parent material, but may not be of same composition, because here leaching is involved, removal is involved.

So some unstable minerals will be totally removed, some stable minerals will be enriched. So the residual soil may not get the exact composition of this parent material. I think we should stop here. I will meet in the next class. Thank you very much. Thank you.