**Geomorphology**
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**Lecture - 16**
**Soil Formation Processes**

So friends, welcome to lecture series of geomorphology and in this class, we are going to discuss about the soil formation process, some factors, and how they influence the formation of soil at different geological conditions. Different geological conditions once I say, I say about these parent material, the climate, the organisms, the time, the topography, how those factors influence the degree of soil development and how those factors they change the characteristics of soil at different places.

So if you remember, we were talking something about this residual soil. Residual soils, they are of different characteristics as compared to their parent material.

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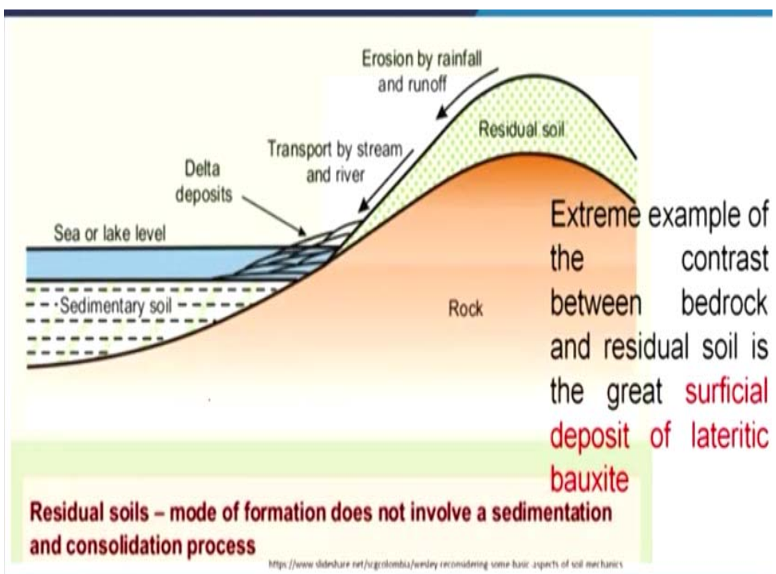


For example, if we see here, we have some certain rocks and if you see this residual soil, the residual soil mostly it is a leached soil. It is an extremely leached soil. So that means those unstable minerals, which are here. Unstable means, they are chemically unstable, they are removed from this part and they are getting transported and deposited or accumulated somewhere here.

Similarly, if it is in alluvium, which is the porous medium and permeable medium, they also leach down and will be accumulated somewhere in this zone. So that is why, this residual soil, which is of totally different characteristics as compared to this parent material. So residual soil mode of formation does not involve sedimentation and consolidation process. So here, only leaching is there, okay.

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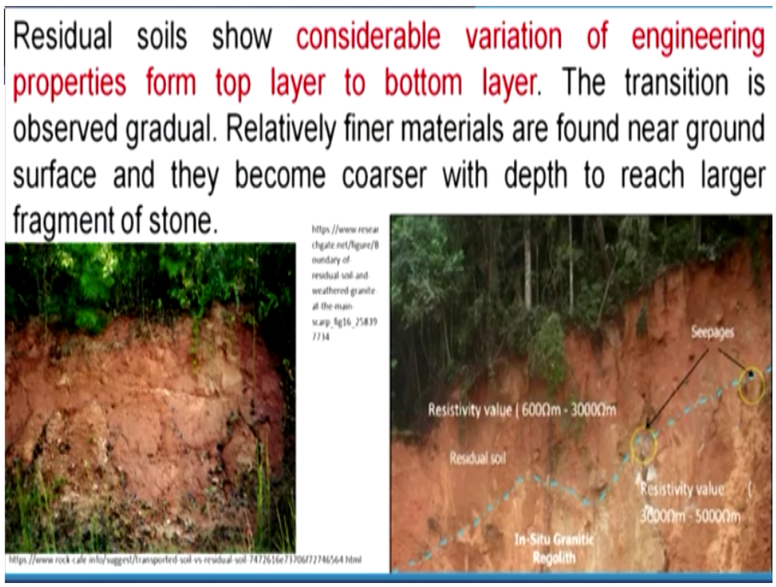


Residual soil properties, shows considerable variation in terms of their engineering property from top to bottom. In these 2 photographs if you see, here this is in situ granitic regolith. That means, this parent material is granite and this is the thickness of this residual soil developed. Granitic mostly quartzofeldspathic rocks. Now if you analyze this chemically, this part, it will be more rich in aluminum.

So there are examples also, a sandstone body, which is by chemical leaching, by formation of the residual soil, it becomes an economically viable aluminum deposits. I will discuss in the later stage. So now you see the transition is observed gradually, relatively fine material found near the ground surface and they become coarser with the depth to reach the larger fragment of stone. So here once we are going downward, here finer, finer materials will be there and relatively coarser material.

And this regolith, again these are the coarser material will be here and finally the bedrock, but within the system, suppose for example, here one property like this electrical resistivity is given there and this is the resistivity value and this resistivity value, the change of resistivity value, that depends upon the change of the characteristics of soil. Somewhere their fractures are there, water will be percolated there. This part will be more moisture conditions.

So their resistivity value will be there. So there are different soil properties, once we measure, it will completely different from their parent material. So residual soil is totally different characteristics, it shows from their parent material.

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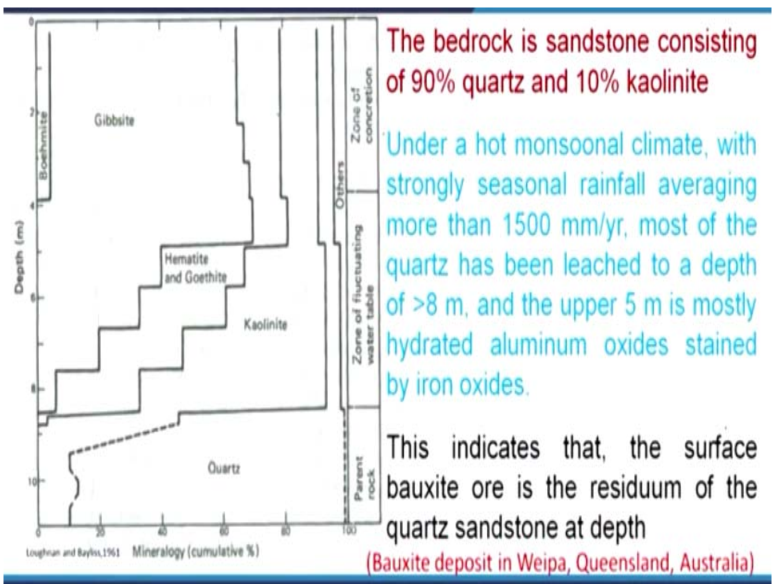


Here is the example we were talking about. It is the bauxite deposit of Weipa, Queensland, Australia. So this is a classical example of residual soil. How? Now, you see, in this figure, this is the parent material. This part is the parent rock, parent material. It is composed of near about 90% of quartz and 10% it is kaolinite or clay. Now this is the depth. It is from 0 to 10 meter depth or more than 10 meter depth.

Now you see, this bedrock is the sandstone consisting of 90% quartz and 10% kaolinite. Under hot monsoonal climate with a strongly seasonal rainfall averaging more than 1500 mm per year, most of the quartz has been leached to a depth of greater than 8 meter and the upper 5 meter is mostly hydrated aluminum oxide that is called gibbsite. So now, that means I want to say, if you confine yourself up to this depth, that means you are getting an economically viable bauxite deposit.

However, if you compare this bauxite deposit with its parent material, this bauxite deposit is evolved from a sandstone body simply. So that means the residual soil or the residue of weathering, it is also totally different quality, different characteristics as compared to this parent material. So this indicates that surface bauxite ore is a residuum of quartz sandstone at depth.

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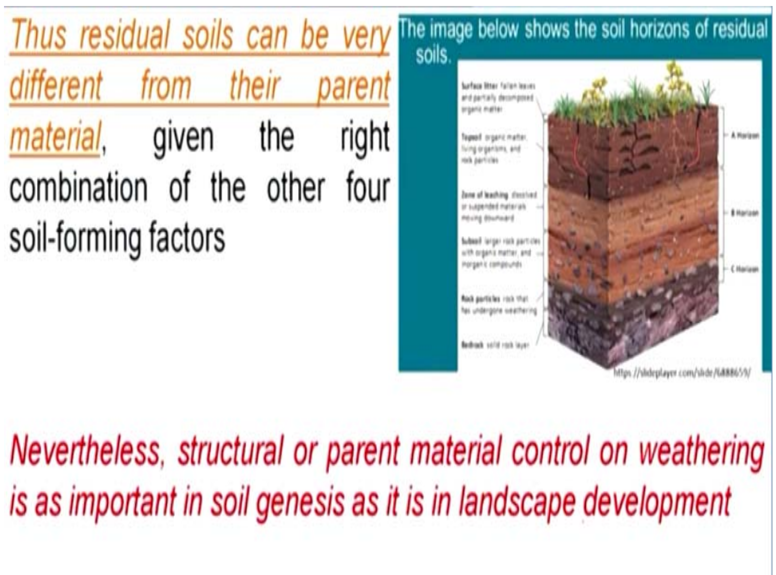


So thus, residual soil can be vary of different form and different characteristics as compared to their parent material, given the right combination of other 4 soil forming factors constant. So that means, structural or parent material control and weathering is important soil genesis and it is also important in landscape development.

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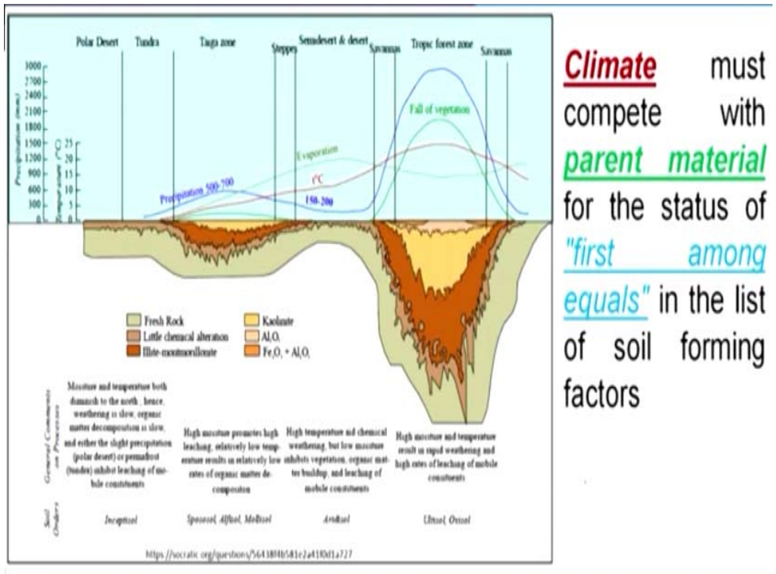


Now after parent material, the climate is another important parameter in soil development and if you compare this parent material and climate, none of these 2 wants to take the second position. So climate and parent material both stand equal, because climate influence the soil composition, the soil characteristics as the parent material. For example, if you see here, climate must compete with parent material for the status of fast among equal in the least of soil forming process.

Now here you see, depending on the climate, few factors has been assigned. One is this blue line in this graph. It represents precipitation and precipitation, now you see, it is varying from somewhat more here, less here and again it is highest here. Similarly, evaporation, here evaporation is less than precipitation. In this part of graph, evaporation is less than precipitation. So that means, precipitation is more, that means, the area remains moist.

It remains water logged. Similarly, in these areas also, see evaporation and precipitation, the difference is this much. This area is water logged. This is moist, but in this case, in this part of this graph, you see, this rainfall is less than evaporation. That means, here more evaporation, less rainfall. That means dry area. Similarly, the third parameter is the temperature. The red line, that is indicating temperature and gradually in this graph, the temperature increases from left to right.

So there are four parameters here, one is this line, it is indicating the evaporation, this blue line is indicating rainfall, this red line is indicating temperature and this green line, it is the vegetation.

So these four parameters, how they influence the soil characteristics, how they influence the degree of soil development, the soil thickness, it has been discussed here. For example, consider this part of this graph. Here moist and temperature, both diminishes to north.

Hence, weathering is slow, organic matter decomposition is low, and either the slight precipitation the permafrost or these tundras inhibit leaching of mobile constituents. Consider the second part of this graph, high moisture promotes high leaching, because water is the most culprit of weathering. So here high moisture content, because here precipitation is more than evaporation, that means high moisture content will be there.

So high moisture content promotes high leaching, relatively low temperature results relatively low rates of organic matter decomposition. That is why thin soil development. Then, consider the third part of this graph. This is first part; this is second part. This is the third part of the graph. In the third part of the graph, you see, high temperature had chemical weathering, but low moisture inhibits vegetation, organic matter, build up, leaching of the mobile constituents.

So that means, here it is high temperature condition. It is succeeding. It is more influencing than other parameters. Even more evaporation will be there, because more temperature and here rainfall is less, is not it? That means, once its temperature is high, it is chemical weathering is more, but to promote this chemical weathering, we should have other parameters also supporting to that, but unfortunately, here other parameters are not supporting.

But if you consider this part of this graph, here high moisture content and temperature results in rapid weathering and high rate of leaching of mobile constituents. So that is why, here if you see thick soil development is there. So this is the ideal condition. If you compare this relative role of these parameters by variation of these parameters slightly, that changes the soil forming process. They influence the soil formation process.

So that is why, different soils of different thickness, different chemical properties, they varies depending on the precipitation, evaporation, temperature, vegetation cover, like these. So that is why, climate and parent material, none of them wants to take the second position for influencing or defining a soil profile and defining the soil characteristics.

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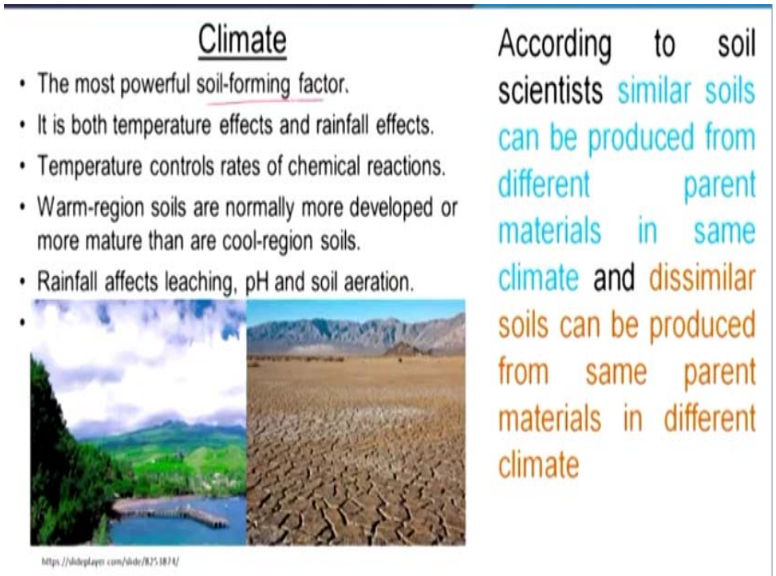


Climate, in briefly, the most powerful soil forming factor. It is both temperature effect and rainfall effect. Temperature controls rate of chemical reaction. Warm region soils are normally more developed as compared to these cooler region counterpart. Rainfall affects leaching, pH and soil aeration. So according to soil scientist, it is very important to note, according to soil scientist similar soils can be produced from different parent material in same climate.

So climate influence is so intense that from different parent material, similar soil can be produced in the same climate. Similarly, dissimilar soils can be produced from same parent material in different climate. So that means, I want to say, climate and parent material both plays important role in defining the soil characteristics.

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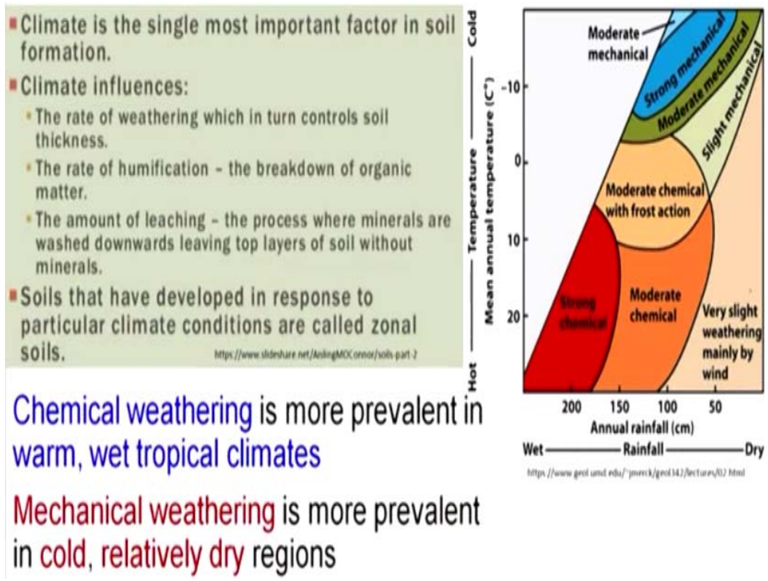


Here again, the old graph, there are different weathering segments defined by our rainfall and this temperature variation. Climate is the single most important factor in soil formation. Climate influences the rate of weathering which in turn controls the soil thickness. Rate of weathering and soil thickness, the more rate of weathering, the thicker the soil and the reverse is also true. The rate of humification that is breakdown of organic matter.

Then the amount of leaching is the process where minerals are washed downward leaving the layers soil without minerals. So that means soil composition will be changed. Soil that has been developed in response to particular climatic condition are called zonal soil, arid zone soil and humid zone soils. So if it is characteristics of a particular climatic condition, that is called zonal soil. Chemical weathering is more prevalent in warm and wet tropical climate.

Mechanical weathering is more prominent in cold and relatively dry region. So that is why, depending upon this climatic condition, different parent material or same parent material in different climatic condition will produce different type of soil. Similarly, different parent material in different climate, they can produce same type of soil. That is why climate plays, important role as parent material in defining the soil formation in soil characteristics.

Then, the third parameter is topography. Topography, it is a changing parameter. So it changes with time like climate. At one place in a geographical location, in a geological timescale, climate may change from different, climate can be changed. So that means one geographic location undergoing humid climate nowadays may be in geological past, it was in arid climate. Similarly, topography also changes with time.

Topographic inversion, we have already discussed in our weathering classes. So topography influences the soil forming process is emphasized more by pedologist than by geologist. For example, suppose we are talking about these photographs or this figure, here if you see, this black colour regions, that is the thickness of the soil. This is the less thick soil or the thin soil is developed, but once you coming to these topographical lows, the soil thickness gradually increases and again decreases at the topographical highs and this becomes zero.

That is why in this region, the R horizon is exposed and this is a flat region. This is a sloping region.

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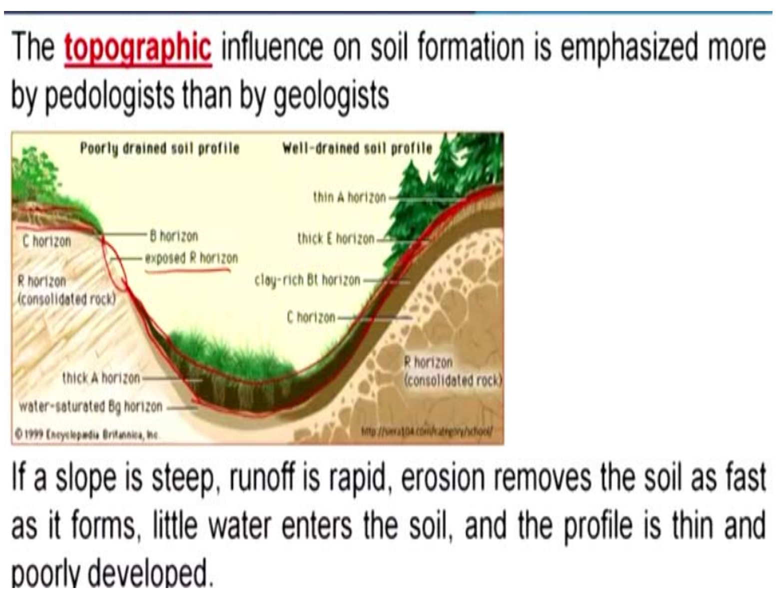


So in the slope, the soil formation is less, but in flat the soil formation is more. So if the slope is steep, runoff is rapid, erosion removes the soil as fast as it forms and little water enters into the soil and the profile is thin and poorly developed. However, if you go to the low lying areas, flat lying areas, the soil thickness will be more as compared to this sloping areas.

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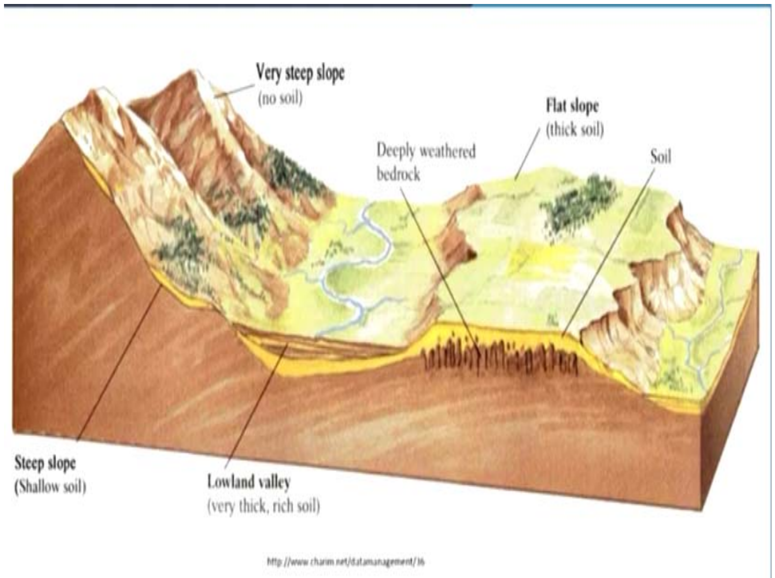


Here, another photograph showing also the same. Here you see, this is flat topography. In the flat topography, we are getting thick soil development and it is a very steep slope, here there is no soil at all. So that means higher slopes promotes less soil development and flat region, they promote more soil development.

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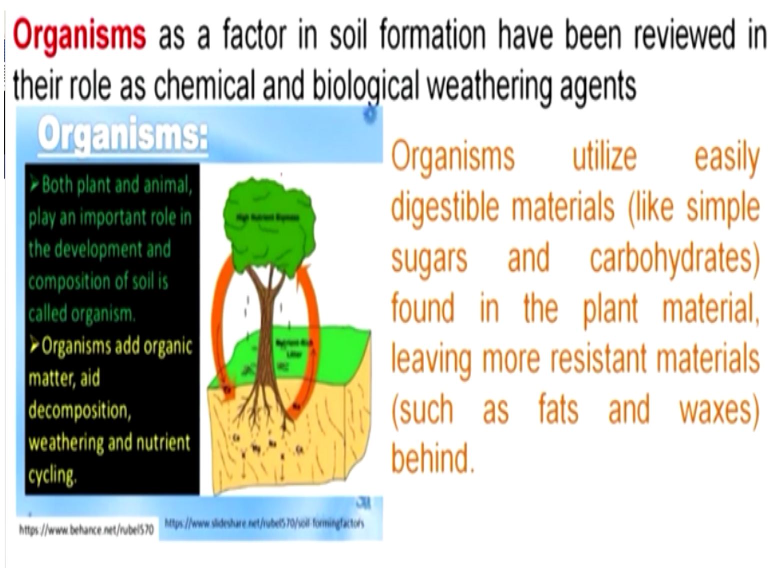


The fourth parameter, it is called organisms. A factor of soil formation have been reviewed in the role as chemical and biological weathering agents. Organisms utilize easily digestible minerals like simple sugars, carbohydrates are found in the parent material leaving the more residual material such as fats, waxes behind. So that means, suppose we have organic influence in that here, so organisms they utilize the easily digestible minerals, easily breaking minerals like the simple sugars, carbohydrate.

So in these region of the soil, this material will be less. However, this more resistant minerals or the most resistant part of the organic matter that will be rich in this area and we have parent material, we have minerals. So now, the most resistant part, they will intermix with the parent material and forming one global, or forming one material a unit cell that is called ped.

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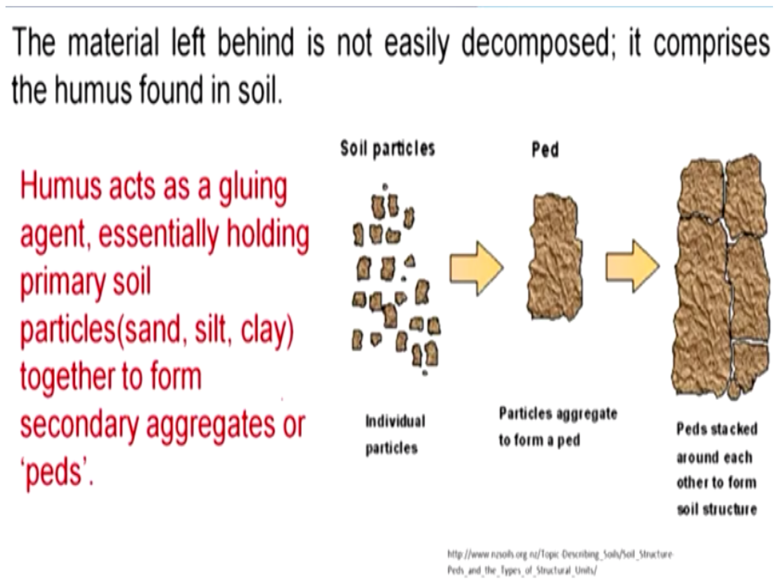


So those materials, which is left behind is not easily decomposed, it comprises the humus found in the soil and these humus particles, they interact with the rock particles or the minerals and if you see here, this is called soil particles or is called ped. So humus act as gluing agent essentially holding the primary soil particles, sand, silt, clay together to form aggregates that is called ped and ped is the unit soil particles.

When we talk about pedology, pedology means, it is the unit soil characteristics, unit soil particles, it is a mixture of humus and this soil particles like sand, silt, clay, they mix together forming a shape. This is called ped and if you see the individual soil particles, particles aggregate to form ped and ped are stacked around each other to form soil structures. So that means, here starts our pedology, the soil science.

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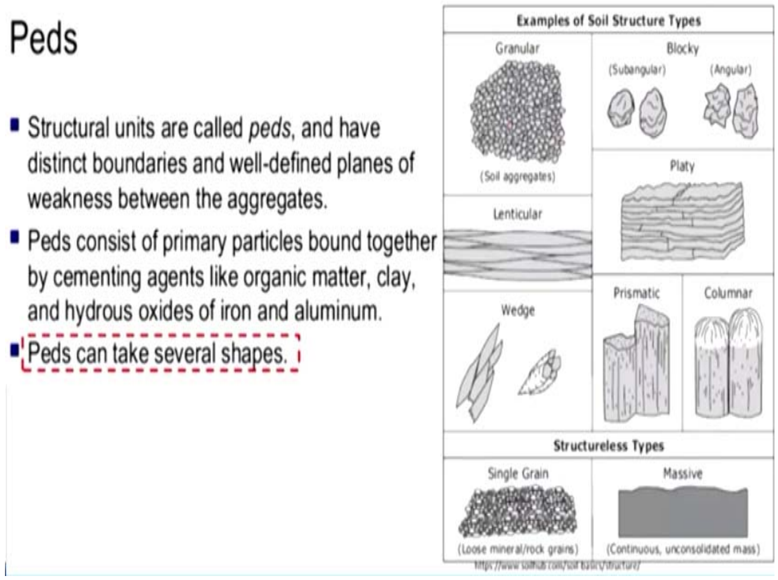


Peds, that is the structural unit are called peds and have distinct boundaries and well defined planes of weakness between the aggregates. Ped consists of primary particles bound together by cementing material like organic material, clays and hydrous oxide of iron and aluminum. Peds are taken several shapes. So whatever we are talking about the peds, their shape varies and there are different parameters that define what shape a ped will take.

So the peds may be of granular shape, small grains, granule type. Sometimes peds are like that. the peds may be blocky, blocks. See within that blocky, there will be subangular blocky or angular blocky that means if angles are very well defined, then it will be called angular blocky or like angles are not very sharp, it is subangular blocky. Similarly, platy, platy means plate type of appearance. That means the peds, they are plate like.

So plate like may be due to compression. It is compressed like that or it may be due to this clay mineral, due to presence of clay minerals as the binding agent. Clay minerals has inherit property to be flat, plate like. So ped may be like this. So lenticular, lenticular means lens type. Lens type if you see here the peds, it is of lens type. Similarly wedges, these wedge. Then prismatic, like prisms, columnar, columnar like, then single grained or massive.

So that means depending upon the geological condition, depending upon the climatic condition, depending upon the degree of compaction, so the soil structures vary in their shape like from granular to massive, blocky, subangular blocky, angular blocky, lenticular, platy, like that.

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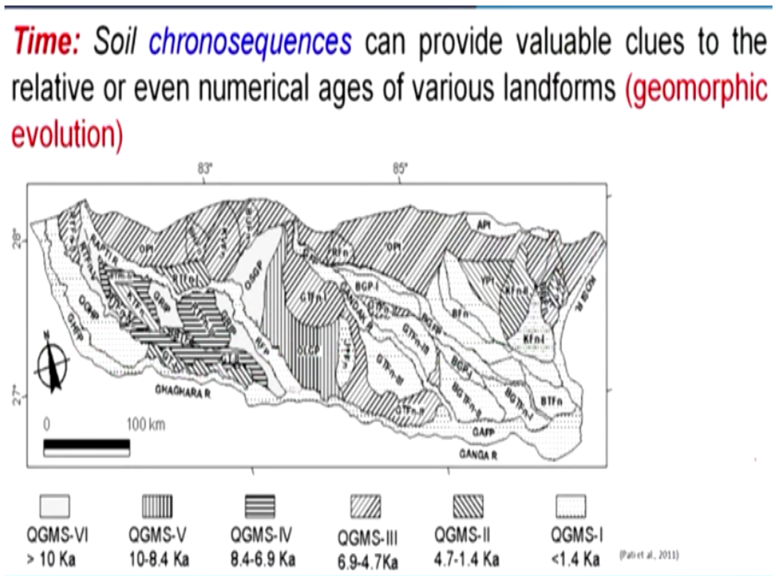


Then, the fifth soil forming process, soil forming parameter it is called time. Time we cannot change. Parent material we cannot change. So all other three factors that change with time. So arrangement of soils in time, it is called soil chronosequences. So that means, I want to say, suppose in a particular area, we confine our study. So all soils in that area, they are not formed at the single geological time.

So that means we have soils, some of the soils they are developed on the older parent material, some of the soils developed on the younger parent material. So if we arrange those soil development or arrange those soils with time in a particular area, so this stratigraphic arrangement of development of soil with time, that is called soil chronosequence. So soil chronosequence, it indicates the geomorphic evolution of an area.

For example, if we take this study particularly in the Ganga plane here in this figure, it is shown. This is river Kosi and this is river Ghagra and here will be river Ganga Samar and here Yamuna Samar, okay. So now, our study indicates these are the different soil, these are the different geological features or geographical area, which is defined by different soils. For example, if you see here, this symbol indicating the soil, which are developed more than 10,000 years back.

So that means, this area or this geomorphic unit indicating soil, which was developed greater than 10,000 years ago. Similarly, this geomorphic unit, it is indicating the soil, which was formed 10,000 years ago and this and this, so that means in an area when we are going for geomorphological mapping, we characterized that these soil were formed in 10,000 years back and again later from 10,000 to 8400 years ago, these soils were formed.

Suppose this soil, it was formed from 10,000 to 8400 kilo annum. Similarly, this soil 8400 to 6900, then 6900 to 4700 and 4700 to 1400 and less than 1400. So that means I want to say if you stratigraphically arrange this soil forming processes or the stratigraphically arrange the soil geomorphic unit, this will be the younger one. It will be in the top and this will be older one, in the bottom. So that means this we call soil chronostratigraphic sequence, soil chronosequence.

So that means, geological processes, which are acting here, they are the younger geomorphological processes and here these are representing older geomorphological processes. So that means, how geomorphic process varies from one place to another place. That can be detected by the soil chronosequence, by mapping of this geomorphological events or geomorphological features.

So soil chronosequence of area that also indicates the climatic condition in this past, the tectonic scenario in the geological past, the parent material; it was there in the geological past. So that means I want to say the geomorphic evolution of an area can be well established through soil chronosequence and soil chronosequence is nothing, it is time best arrangement of the soil in a particular area.

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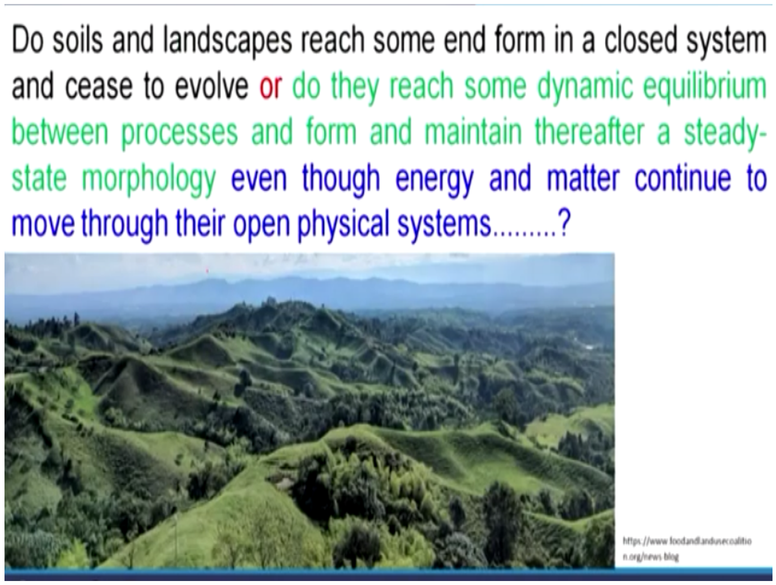


Do soils and landscapes reach some end in a closed system and cease to evolve or do they reach some dynamic equilibrium between the process and form, maintain thereafter in a steady state morphology, even though energy and matter continues to move through their open physical systems. So now the question arises. If we have parent material, we have climate, we have topography, we have the geochemical processes going on or these organic processes going on.

So soil formation will take place. Now the question arises. Whether this will continue forever or there will be some stoppage. There will some full-stop. To what extent soil can evolve. So soil formation will continue until and unless their area is cut off from the main atmospheric conditions. Once it becomes cut off, so that means a new process is covering it up, new sediment is covering it up, then this soil formation cease to operate.

Because it is cut off from the atmospheric condition and that soil becomes paleosols. So from Precambrian to recent, if you analyze the geological cross sections, there are many paleosols horizon reported. However, the paleosols characteristics varies with time, varies with parent material also. So paleosols, which is developed in the granitic gneiss, migmatites in central Indian shield may not be of same characteristics that will be developed in the Aravallis.

Similarly, the paleosols, which has formed in proterozoic sandstone of Pranhita–Godavari basin may not be of same characteristics in the Vindhyan basin. So that depends upon the climatic condition and the time. So that means, I want to say the soil formation, it is a closed process system, in a closed system and an open system. So the soil formation, it will continue until unless it is cut off from these systems.

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A basic issue of pedology is *whether soils continue to evolve as some function of time, which might be linear, logarithmic, or exponential, or whether they reach equilibrium with land-surface lowering so that a "steady-state" soil profile and weathered zone move downward through the rock masses as the surface is lowered*................?


A basic issue of pedology is whether soil continue to evolve at some function of time, which might be linear, logarithmic, or exponential or whether they reach equilibrium with land surface lowering, so that a steady state soil profile and whether zone move downward through the rock mass as the surface is lowered. So this question has to be answered to. What are the factors that influence the stoppage of soil forming process.

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Recent studies show that even *soils several million years old continue to evolve* (Machette, 1985; Harden, 1986-1988; Harden et al., 1991; Birkeland, 1992, p. 276; Markewich et al., 1994).

Such long-term weathering must have been in progress during very significant late Cenozoic climate changes

*In soil chronosequence,* a succession of coastal or river terraces, glacial moraines, alluvial fans, or other landforms of *progressively greater age but with similar parent materials, vegetation, slopes and climate,* are shown to have *soil profiles with progressively greater development*

Research studies show that soils of several million years old continue to evolve. Such long term weathering must have been in the progress during very significant late Cenozoic climate change. It is very important to understand. Suppose, for example, we have soil of Precambrian time, but that soil that was cut off from the main body, so that becomes paleosols. So paleosols, do they evolve? They can evolve, if they are exposed to a particular climatic conditions.

They are exposed to a particular climatic influence. For example, we have late Cenozoic climatic change. There are many times this earth has been freezed and defreezed. So paleosol is there, but it is totally cut off from the main body, cut off from the atmospheric climatic change. So that means, it will not be influenced, but once they are exposed or this climatic change is influencing to certain depth, within which the paleosol is confined, then it will change.

So that means, such long term weathering must have been in progress during very significant late Cenozoic climate change. So those climatic change events, which are influencing to certain depth from the R surface, if the paleosol is lying within that, so that means it will influence its characteristics. Otherwise, the soil will be in isolated form.

So in soil chronosequence, a succession of coastal or river terraces, glacial moraines, alluvial fans, and other landforms of progressively greater age, but with similar parent material, vegetation, slopes, and climates are shown to have soil profile with progressively greater development. It is very important. So here, this is shown in these photographs.

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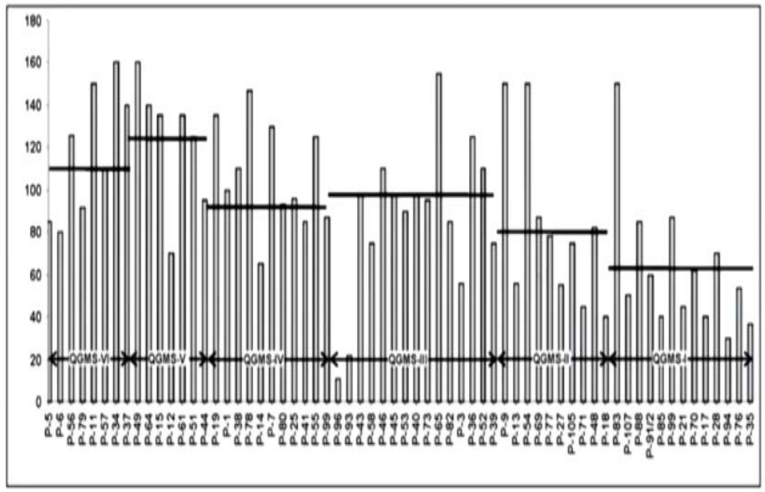


Variation of solum thickness with time in the Ganga plain (Pal et al., 2011)

Now you see, we have parent material same, climate same, vegetation same, chemical activities or the geochemical activities same, organic matter same, but time is different. Now you see here, if arranging the soil formation process or the soil profiles with time, here we are, in this way we are decreasing time. This is increasing time; this is decreasing time. So here time is 0 and is time 10,000 years, 10k years. So now you see, there is a gradual decreasing trend of soil thickness.

So that means, I want to say, provided that there will be parent material same, climatic condition same, this organic matter evolution same, but if the time is changing with more time, we are developing more thick soil. So that means, the thickness of the soil provided that all other parameters remain constant, the thickness of the soil, it is indicating the degree of stability of an area. So more thicker the soil, more the area is technically stable and more time is involved, more thicker soil will be formed.

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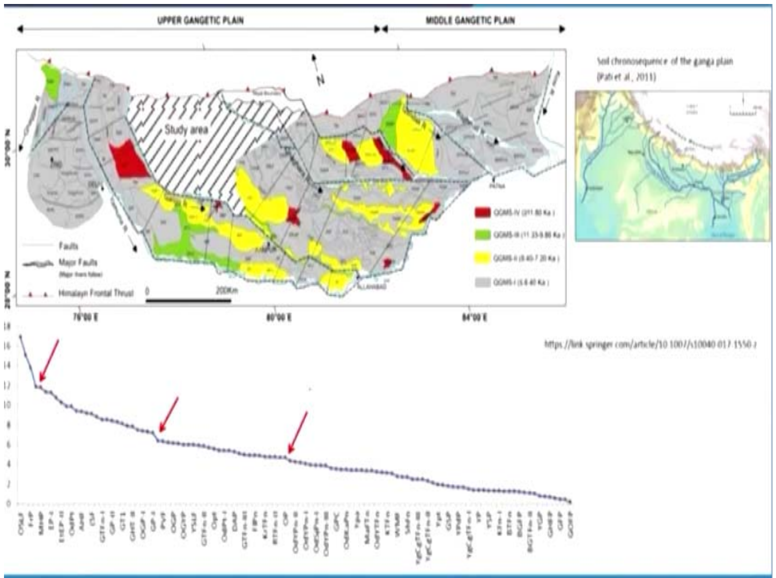


Here is a classical example of soil in the Ganga plain. Now you see the soils are arranged with their time that is of the age, this red colour part, they are indicating soils of more than 11.8k that means it is the Pleistocene Holocene boundary, it is the Pleistocene soil and this soil green colour is indicating this is the timeframe, yellow colour this is the timeframe and grey colour this is the timeframe and if we analyze the thickness, this time or this timeframe that creates a thick soil as compared to this, this and this.

So that means, with lowering time, the soil horizon thickness is also decreased. This is seen here. That means, more time more thick soil, less time less thick soil or thin soil. There are certain breaks within the timeframe. So for example, this is the slope and this is the slope break, here and here, here these are the slope breaks recorded. These slope breaks that indicates the tectonic stability. That means, this area, this part the soils are formed.

Some geomorphic process was involved. This area some soils are formed, some geomorphic process was involved and these breaks that is the sharp break in this graph that is indicating, that means this area was tectonically stable period. Because in Ganga plain, it is a tectonically active region. Here, the soils are formed in a particular area and once it is cut off from the main atmospheric condition that means it is buried from the younger sediment when the soil formation stops.

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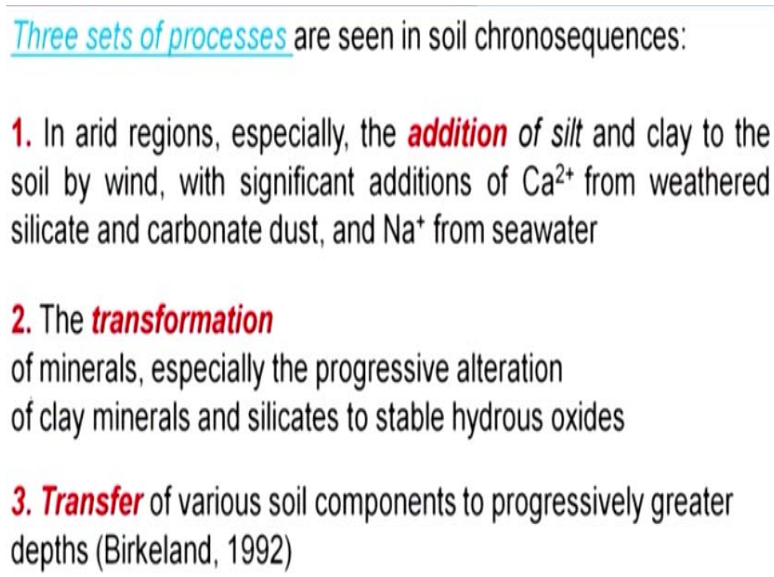


So three sets of processes are seen in the soil chronosequence. First in arid region, especially the addition of material takes place. In arid region, addition of material. Addition means, what is adding? Addition of silt and clay to the soil by wind with significant addition of $Ca^{2+}$ plus and weathered silicates, carbonate dust and $Na^{+}$ from sea water. So in arid region, these materials are added with silt and clay.

Then second process is the transformation of minerals, especially the progressive alteration of clay minerals and silicates to stable hydroxide. So this is the transformation process. The third is the transfer to various soil components and progressively greater depth. So three sets of processes are found in soil chronosequence. First is addition, second is transformation and third is the transfer and finally a soil sequence is formed.

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Chronosequence and desert soil can be based on the extent of secondary mineral accumulation, especially the calcium carbonate and sodium. So here the desert soil, it is based on the chronosequence, is based on how much material is added. The more material is added, the more old the soil is. Similarly, in alluvium the calcrete development. The more the calcrete developed, the more thicker the calcrete horizons, the more older the soil is.

Because if you see, calcretes have different stages and first is for less time, then more and more time increases, these different stages are developed. So that means, calcrete is a massive shallow accumulation of soil carbonate that may be for a meter or more thick and may effectively control the scarp formation. So in arid region, this addition of calcium carbonate, it indicates the degree of soil development or the time of soil development, the more material is added, the more old the soil is.

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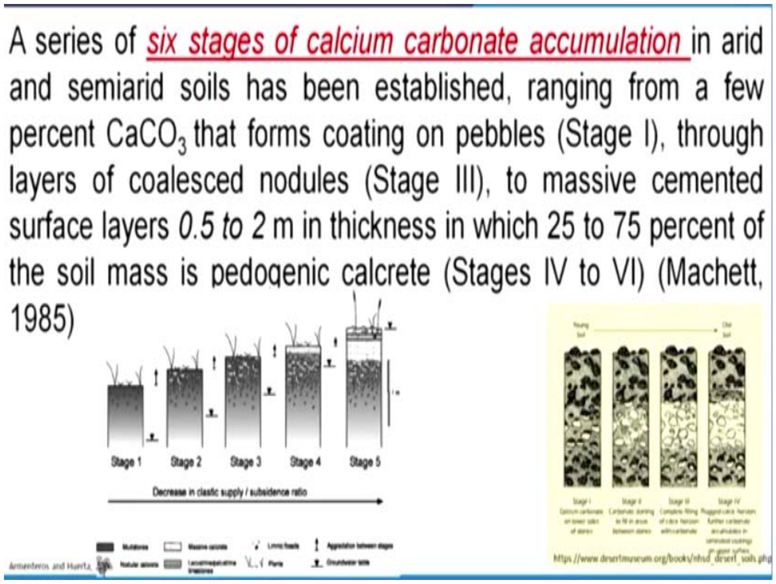


A series of six stages of calcrete development has been discussed here, starting from stage 1 to stage 5. If you see here, in stage 1, only some calcium carbonate granules are developed with stage 2, more and more granules are added to it, and third these granules are added with each other, and fourth there are coalescence of that and fifth there is complete development of horizons. So these are the different stages of calcium carbonate horizon development in the soils.

In arid, semi-arid soils has been established ranging from few percent of CaCO3 that forms coating on the pebbles. That is on stage 1. So stage 1, it is representing the coating, thin coating on the calcium carbonate on the pebbles. So layers of coalescence of nodules that is stage 3 to massive cemented surface layers 0.5 to 2 meter thickness, which 25-70% of the soil mass is presence in the calcrete that is stage fourth to sixth.

So these are the degree of development of calcrete. So in arid region, these calcrete development stages or the calcrete development thickness, developed calcrete thickness that depends or that says, that indicates how old the soil will be. More older the soil, the more degree of calcrete development is there. Stage 1 soil ranges from Holocene to Pleistocene, stage 4 and older calcrete horizons are found in land surface that ranges in age from 1 lakh years to several millions of years.

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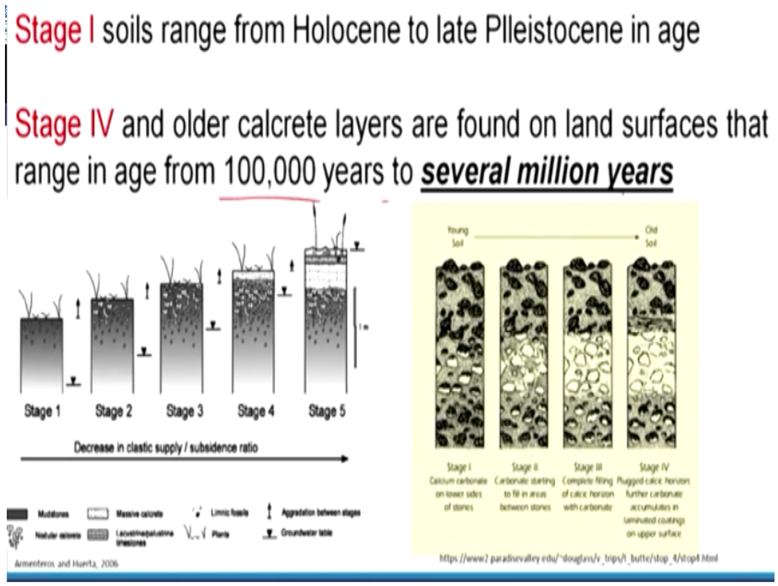


So these are the development of calcium carbonates. This is the characteristics of the soil which is characteristics of arid region.

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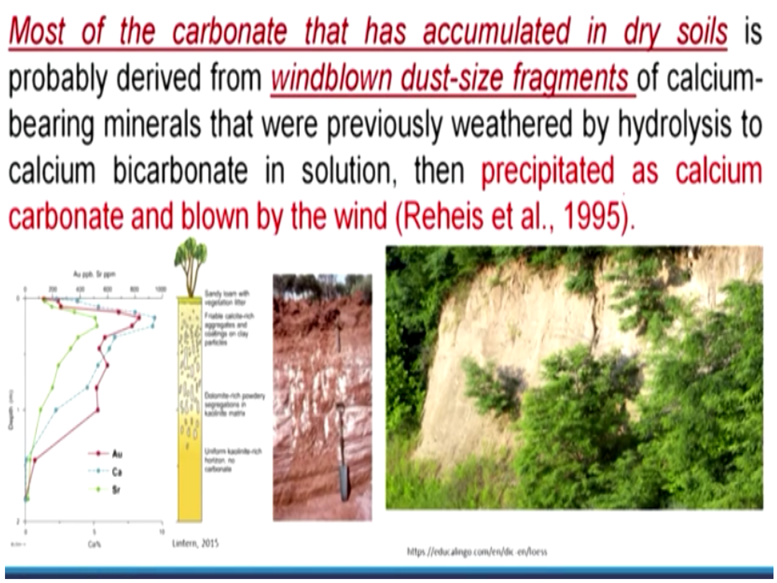


Most of the carbonate that has been accumulated in dry soil is probably derived from windblown dust size fragments of calcium bearing minerals that are previous weathered by hydrolysis to carbonation in different carbonate solutions and precipitated as calcium carbonate and blown by wind. So whatever the calcium carbonate in the soils, many of these cases the calcium carbonate is not in situ. Once upon a time, they were weathered somewhere else.

As a dust, they were transported by wind action or transported by water action, and now they precipitated with suitable climate, they are precipitating within these soil pores. So that is why a calcrete horizon has been developed. Now if you go to this Ganga plain in Gandak region, the paleochannels, if you analyze from the satellite image, that will look like white appearance. So this is nothing rather than the calcium carbonate precipitation.

So in this catchment area, we have calcium carbonate rich rocks and this calcium carbonate it is dissolved within water. Now, once it comes to this Gandak region, due to evaporation of water, these calcium carbonate is precipitating and forming calcrete horizons there. So more thicker the calcrete horizon, more older the soil is.

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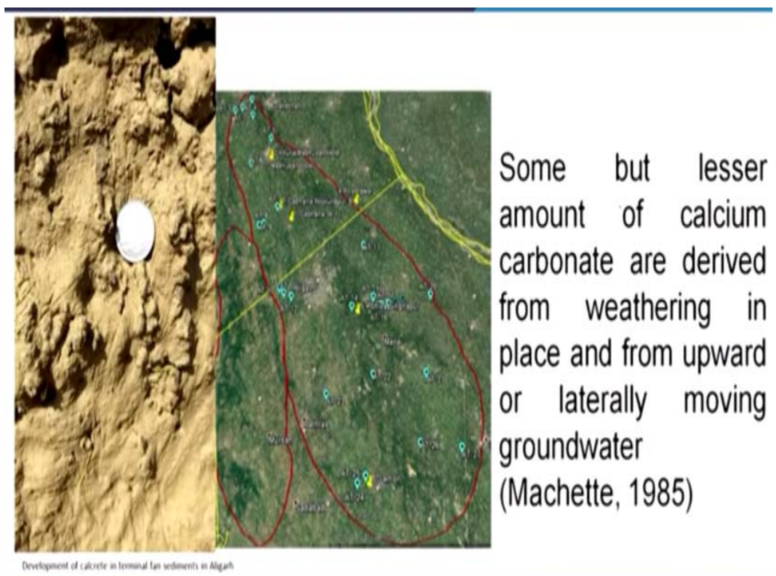


Similarly, here if you see these are the calcretes, these are the calcretes developed in a terminal fan. This is Aligarh terminal fan. It is from here; this is from Aligarh. Somewhat lesser amount of calcium carbonate are derived from weathering of place from upward or lateral movement of groundwater. Though we have calcrete horizons developed, but maximum calcrete horizons, they are not in situ origin.

They are transported once upon a time, but less amount is precipitated from the rock itself from the alluvium itself. So here, I stop and in the next class, we will talk about the soil classification. Thank you very much.