Geomorphology
Prof. Pitambar Pati
Department of Earth Sciences
Indian Institute of Technology - Roorkee

Lecture – 22
Hill Slope Evolution - II

So friends, welcome to hill slope evolution class and if you remember in the last class we are discussing something about the hill slope, how it forms and how it retreats and with time we again discussed that there are 2 schools of thoughts, some say, the hill slope is a continued process of weathering and erosion and the hill slope retreat parallelly and this different part of the slope, they behave differently and that is why the hill slope has been classified into 9 segments.

And each segment behave differently in terms of sediment transportation, in terms of retreat, in terms of mass wasting, in terms of water percolation, in terms of deposition, so that is why based on that, we have 9 slope segments. So, the straight segment of this slope below a free space is called talus.

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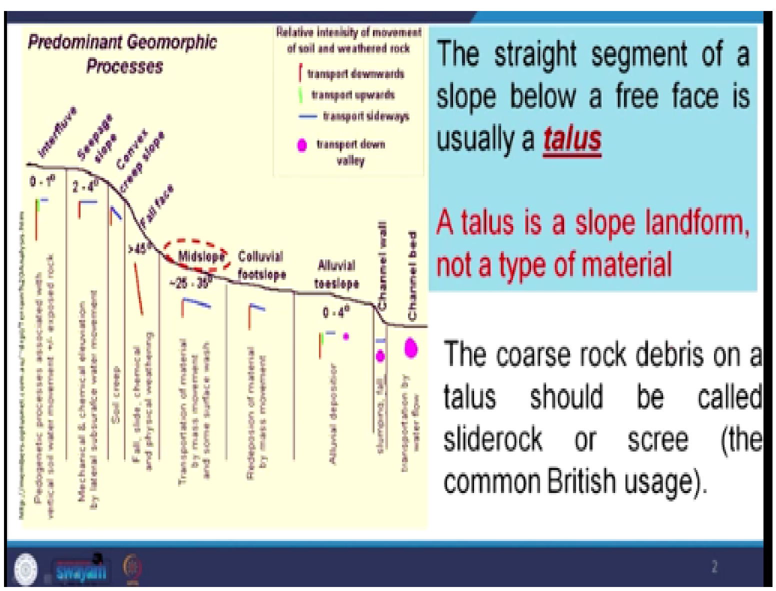

So, talus is a slope land form, it is not of any material, it has to be clear here because many times we do mistakes that whenever we say talus, it is comes in our mind that it is the weathered material that is called talus but it is not true. So, talus is a slope land form not any type of material, so the coarse rock debris on a talus should be called slide rock or scree, so those material which is deposited, which is accumulated on that talus.

Talus means, it is the slope; slope surface, so on which the material will be there, this is called scree or this is called slide rocks, so the angle of talus is a function of many parameters, what are those parameters.

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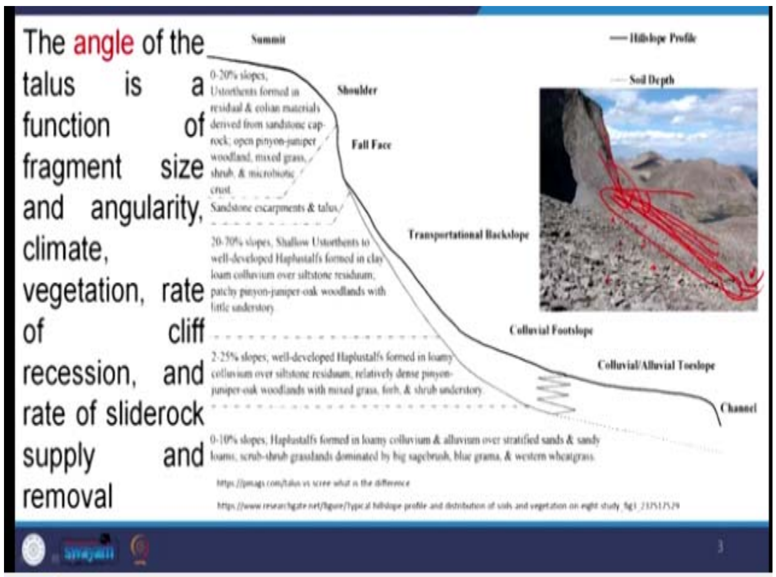

That is the angularity, that is climate, the fragment size, the fragment structure, so the rate of cliff recession and rate of slide rock supply and removal, so all those parameters that define what should be the angle of this talus, for example if you see here this particular photograph, this is the free fall surface here material freely fall down so this is called talus slope.

in talus slope if you see here this materials are lying, so what will be this talus angle; this angle, they define by this material size, material shape, its angularity, then climate vegetation, then rate of talus supply and rate of removal form this river or stream, so all those parameters that define what should be its angle because if you remember, when we are talking something about mass wasting, this fine sand have different angle of repose.

The conglomerate among different angle of repose, this coarse sand having different angle of repose and similarly, if it is wet, it will be different, if it is dry, it will be different, so that is why depending up on this material characteristics either fine material will be here, coarse material will be here, water saturated, unsaturated, then rate of supply and rate of removal from here, so all those parameters that define what should be this angle of this talus.

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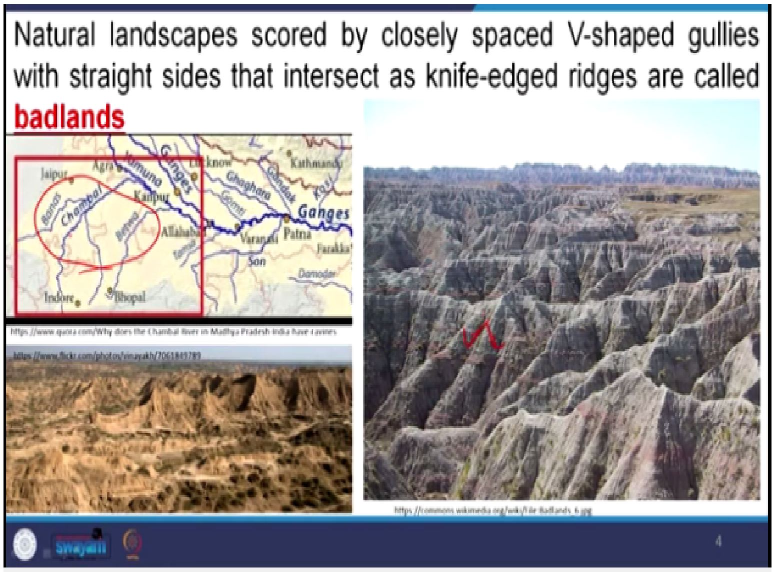

Natural landscapes scoured by very closely spaced V shaped gullies with straight sides and intersect at knife edges, they are called bad lands. Bad land topography, you might have heard about in Indian context near about this Yamuna flood plain, we have this type of bad land in Chambal, in Betwa, so here in this Chambal, Banas, Betwa, in these region, this bad land topography exist, so these are few photographs of this bad land topography.

If you see here, this is V shaped gullies, here V shaped gullies very closely spaced V shaped gullies, they are meeting each other in sharp crest, they are intersected knife edged ridges are called bad land, so these are this photograph of the bad land topography.

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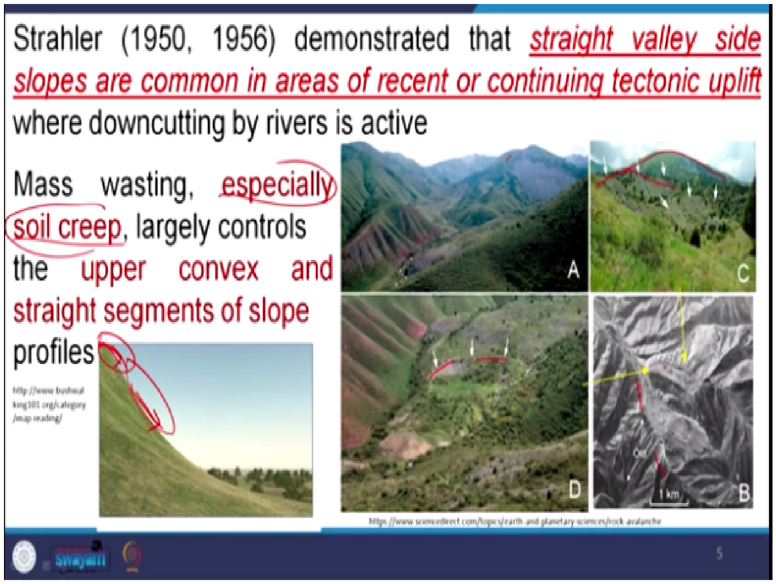

Then the gentleman, Strahler in 1950 to 1956, he demonstrated that this straight valley sides slopes are common in areas of continuing tectonic up lift, where down cutting by rivers is active for example, take this example of Himalayas, if you remember when we are talking something about weathering and erosion, mean that we are comparing 2 profiles; one profile was taken from the Himalayas, another from Eastern ghat.

So, if you remember properly, the profile which was representing the Himalayas having straight crest, straight slopes in both sides, however this eastern ghat having gentle, so that means those areas which is undergoing active tectonism and rivers are active in crosscutting the valleys, we cutting down these valley, in those area are very sensitive for creating of straight slope, very prone to create these straight slopes.

Mass wasting especially, soil creeps, largely control the upper convex and straight segment of the slope profile, here if you see here, these are this areas were active fault scarps are there and here some of this tectonically active part, tectonically active area, it is showing the straight slopes however, if you take the slope here, this is relatively gentler and the upper part of the slope that even this convex part and these straight segment of the slope, it is dominated by soil creep.

From here, soil creeping takes place, so that is why the slope segment which is representing the convex one and representing the straight one having soil slopes, they are very prone to weather for mass wasting by the creep action but if it is tectonically active area, then tectonics is the major process of mass wasting as well as river erosion.

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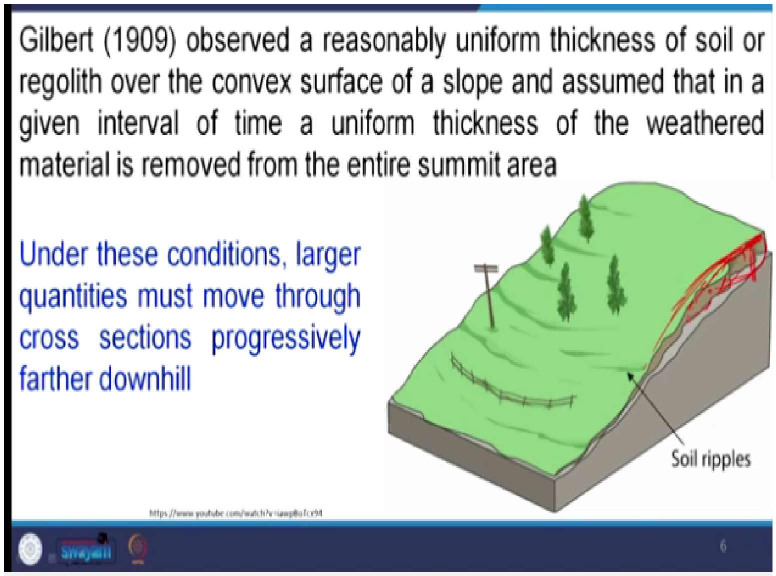

Gilbert, 1909 observed a reasonably uniform thickness of soil or regolith over the convex surface of the slope and assumed that in a given interval of time, the uniform thickness of this material has been weathered and removed away from the summit. Under these conditions, larger quantities must have through cross-section progressively farther hill slopes, so suppose this is a hill slope and here this material is uniform thickness of soil and gravel, something, something is there.

And we should believe that the same amount or these some material has been removed earlier also by geological agents, so that means, we can believe there are much mass or much material, weathered material were existing in that summit and due to weathering, some has been removed and the remnant is there.

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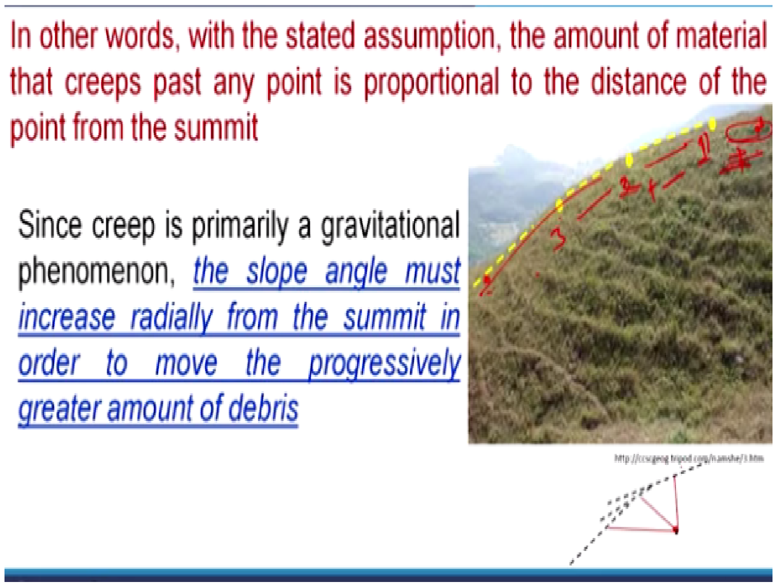

So, in other words with a stated assumptions that the amount of material that creep past any point is proportional to the distance of the point from the summit, it is very important to understand here, for example, this is the summit point and from here, the material has to remove downward by creep action. Now you see the creep, suppose there are 3 observation points, here 1, this is 2; this is 3 observation points for say.

And here the material has to be removed by creep action and it has to go downward, so if this point of observation, the material which will move past of this material only, here the material has to move past, this material plus this material only similarly, at point 3, this plus this plus this so that means, farther we are moving away from the summit, the more material is moving down in through creep process.

So that is why it is written here, the amount of material that creeps past any is proportional to the distance of this point from the summit, so more the distance of point of observation, more material will be added, so that is why it is proportional from the distance of the observation from the summit point. Since, creep is primarily a gravitational phenomenon, the slope angle must increase radially from the summit in order to move progressively greater amount of debris.

So, for example if you see here, suppose this is the centre point and this is the summit point, here this is the angle, here this is the angle and here this is the angle, so that is why it is primarily gravitational phenomena, the slope angle it increasing radially from the summit in order to move progressively greater amount of debris. So, more this angle, more amount of a debris will fall down.

And here less debris, here more debris, here more debris, so that is why creep process, more material will be away from the summit point, similarly more the slope angle, more will be the debris flow, more will be the debris that will removed back.

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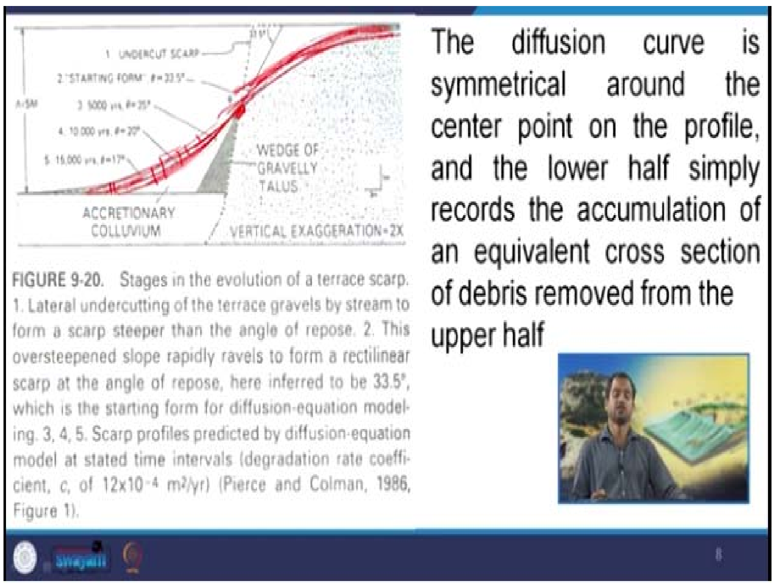

So, the by this way, if we compare the diffusion curve in a creep surface, in a slope surface having dominated by creeps, in that case the diffusion curve is symmetrical around the centre point of this profile and the lower half simply records the accumulation of an equivalent cross-section of debris removed from the upper half, so we have already discussed here, if these slope is a; this slope it is responsible for creep motion.

So, the amount of material, this material which is removed from these, from this midpoint, the same amount of material that is depositing here, so that is why the diffusion curve is symmetrical around the centre point, this is the centre point here of this profile and the lower half simply records the accumulation of this equivalent cross-section of debris removed from the upper half, so this amount and this amount will be equivalent but may not be equal but equivalent near about equal.

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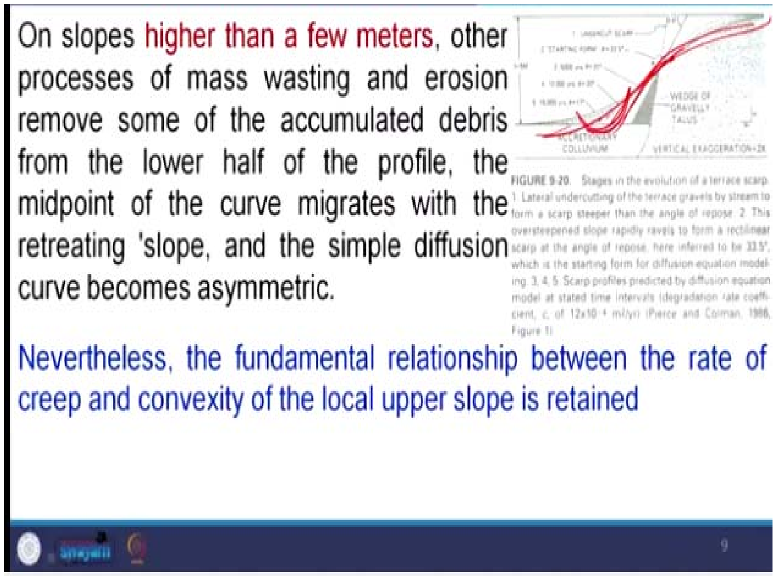

But if the slope at higher than few metres we consider, in that case other slow processes, other mass wasting processes and erosion removes some of the accumulated debris from the lower half of this profile, the midpoint of this curve migrates with the retreating slope and the simple diffusion curve becomes asymmetric. For example, suppose example here, this is a diffusion curve which is symmetric one.

Suppose, we introduce other agents of weathering and erosion either it is tectonics, it is river cut, it is anything suppose, we removed some material from here, so once we remove some material, this slope will retreat like this, this slope will behave like this, so in that case, the midpoint will not be present here, the midpoint will shift from here to here, so in that case that is why, if we are discussing about a slope having few metres high, other processes of mass wasting and erosion that remove some accumulated debris from this lower part, this part, then the midpoint shifts.

And once the midpoint shifts, this curve of the slope, the curve of the slope that will not symmetrical nevertheless, the fundamental relationship between the rate of the creep and the convexity in the local upper slope that remains retained, so that means the upper part if you see here, when removing the material, the slope is going down but here if you see, whatever the slope was here now, the slope also retains here.

So that means, the rate of creep and the inclination angle that means the local topography, the local slope of the upper part, they remains same however, at the lower part it is changing and finally, these curve, the slope becomes asymmetrical.

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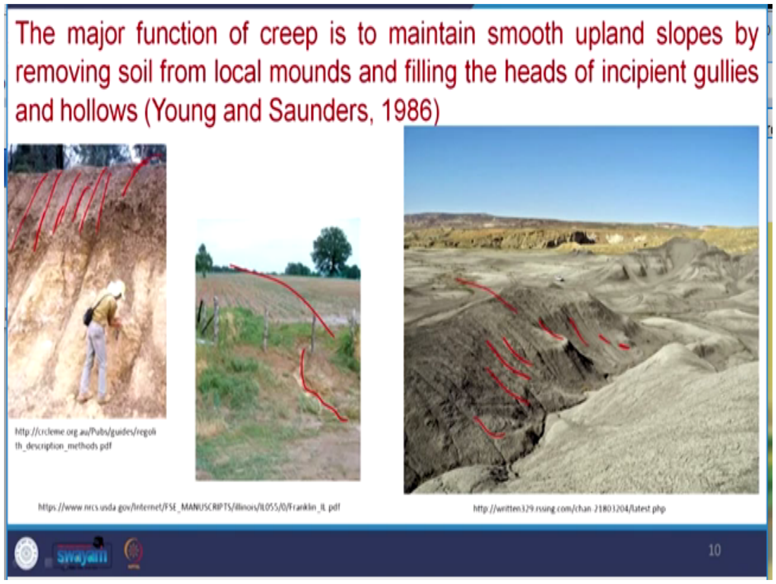

The major function of creep is to maintain smooth upland slopes of removing soil from the local mounds and filling the heads of the incipient gullies and hollows. So, this main work of this creep is to remove material from the upper slope and to create a smooth upland, for example if you see here, here this is the gully forming, these are this gullies, they are parallel to each other, it is forming, here this gullies are forming and this is a convex slope, so this is also a convex slope, this is a convex slope.

So, from this upper part due to the gully erosion, these materials are being removed and that is why this material which has been removed is filling heads of incipient gullies and hollows, so here this local mound is retreating and these gullies are forming and those gullies are removing the material to maintain the slope curve intact.

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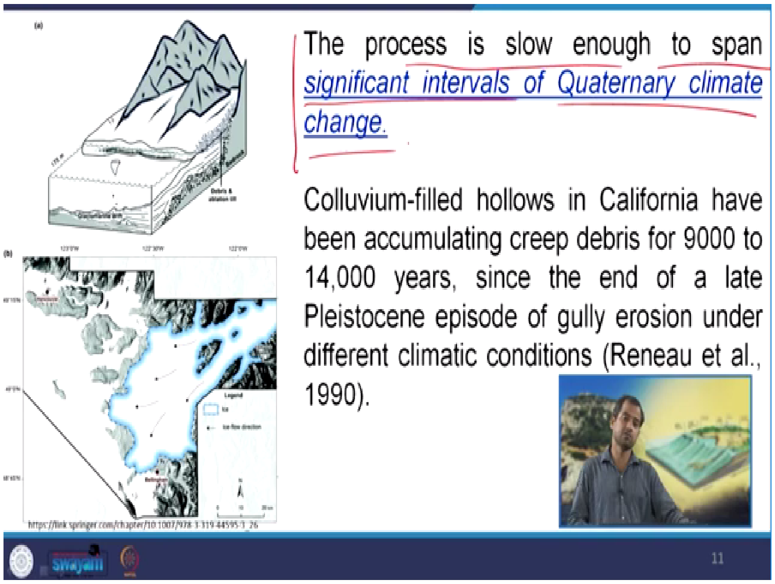

The process is slow enough to span significant rate interval of quaternary climate change; quaternary climate change you might be knowing that in the quaternary, the earth has been freeze and defreeze in different times and different number of times, so this time interval though it is not uniform, though it is not uniform but still some cyclic process is there, the cycle has been maintained. So, those cyclic; the time interval of the cycle which is, which may be large enough the process, if you analyse here; the process is slow enough to span significant interval of quaternary climate change.

So, quaternary climate change is a time interval and the slope material by creep action, it is also takes time, so this is this time maybe slow enough to that means, as compared to this time interval of a climate change, so that means, one is process, another is response. So, climate change is a process, another climate change is another process but within that the response from one climate to another climate change, whatever the climate change, whatever the slopes that modified during this climate change.

After the retreat of the glaciers, that slope has to be maintained, this process has to respond to that climatic change, so that means here, the creep if we consider the creep, the response is very slow in terms of modifying the slope as through this process of climate change, these slope were modified. Colluvium filled hollows in California have been accumulating creep debris 9000 to

14,000 years and the end of the late Pleistocene episodes of gully erosion under different climatic conditions.

So, that means, climatic condition if you say, it is suppose, for example, we are taking 10,000 years, if glacial to non-glacial, again inter glacial, glacial, between the interval is for example, say 10,000 years but this examples are from California, it said from last 9000 to 14,000 years, these gullies are accumulating this material and this is due to creeps, so that means, it is a very slow process.

Even if one cycle of climate change is coming to another cycle of climate change but through the time span, this creep process is not fast enough to modify this response, to modify this process, modify the slope, so that means, it is imperceptible very slow process and it is going on very slowly and it is very inactive type of mass wasting process and through which the it is continuously modifying the hill slope, the upper part but it is very slowly.

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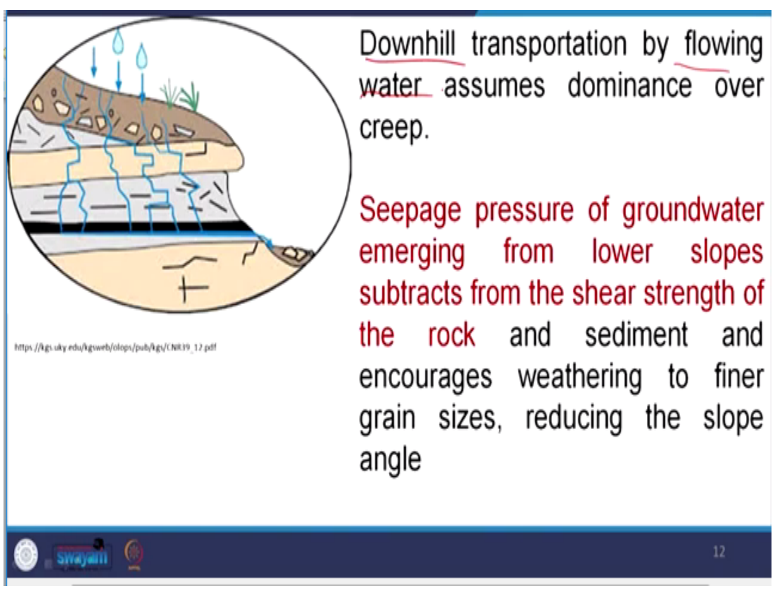

Now, downhill transportation, it is also by flowing water assumes dominance over creep here, if you are going to downhill, here downhill transportation by flowing water assumes to be dominance over creep, so the upper part of the slope dominated by creep, once just going down to seepage slopes, here the seepage water, it is decreasing the strength, so that is why weathering starts or weathering promotes.

So, seepage water or seepage pressure of groundwater emerging from the lower slope subtracts from the shear strength of these rocks and sediments and encourage weathering, so the upper part it is creep dominated, then lower part, it is the seepage slope, here seepage is dominant, due to seepage, these rock strength which is decreasing, this decreased rock strength is promoting weathering and erosion and removal of the material from the slope.

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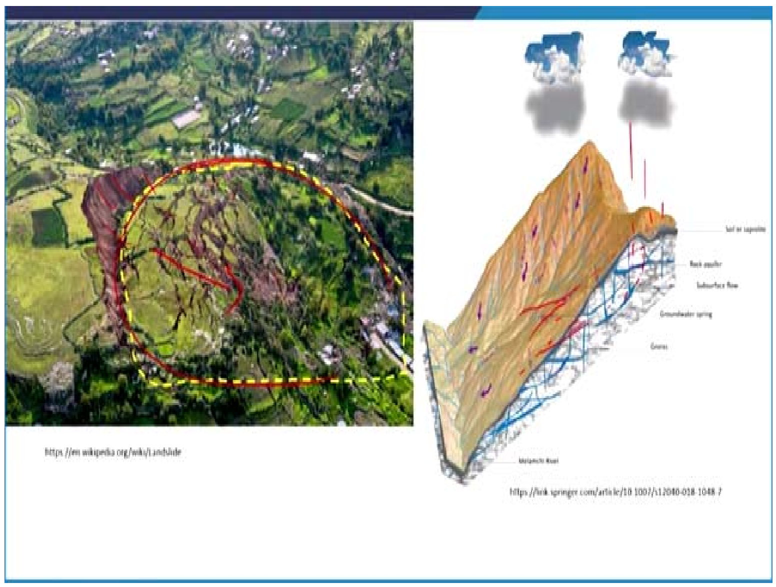

And if you see in these 2 photographs here, you see this seepage water, due to seepage water, this part of this mass it is moving down to hill, this is seepage water, it is accelerating the mass wasting. Here if you see in this model, it is rain water, it is percolating downward and finally, this water is coming up here, it is coming up somewhere and seepage water is there, seepage is here and due to seepage, weathering takes place here.

So, surface water alone cannot weather very deeply until unless, seepage water is added to it but seepage water, the main work is it decreases the cohesive strength of this system, so that is why the material start to move, okay

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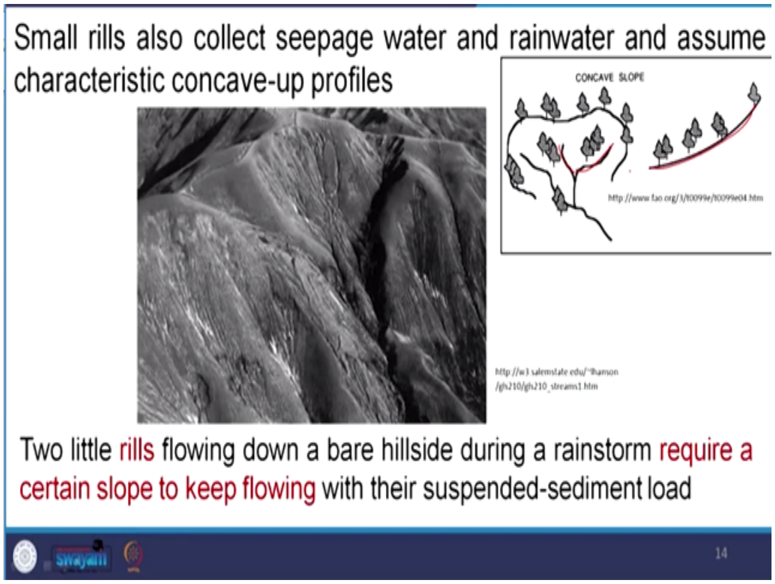

Small rills also collects seepage water and rain water and assumes characteristics of convex up profile, for example here, these are the rills, this is rills, the showing this concave up topography. So, they collect water from the surrounding and takes the concave up slope, so 2 little rills suppose, they are moving downward in a barren rock hill slide, then requires a certain slope to maintain to their suspended load.

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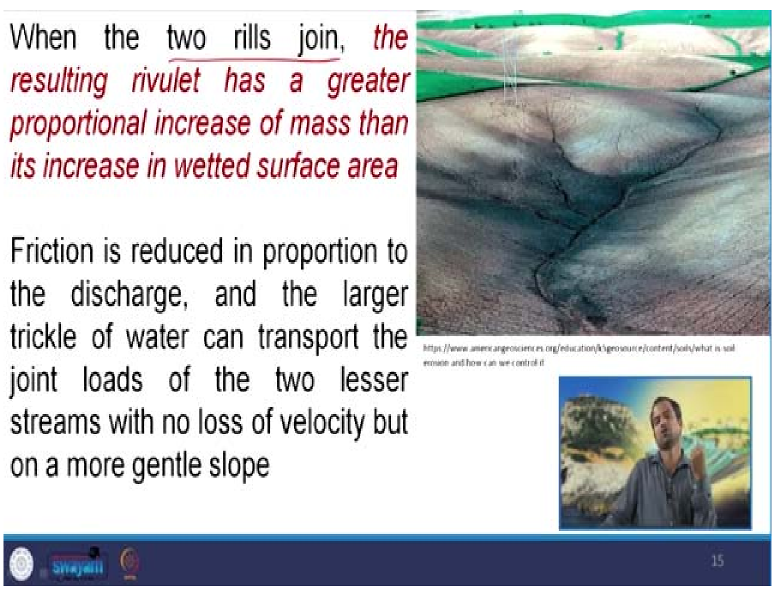

So, if 2 rills are joining for example, when 2 rills join, the resulting rivulet has a greater proportional increase of mass, than increase of its wetted surface area, so mass is more as compared to surface area, friction is reduced in proportion to this discharge and the larger trickle of water can transport the joint loads in the 2 lesser streams with no loss of velocity but on a more gentle slope.

So that means, once 2 rivulets are joining, here more material, more mass is accumulated rather than this strength but still this system, this rivulets, this transport this material downhill.

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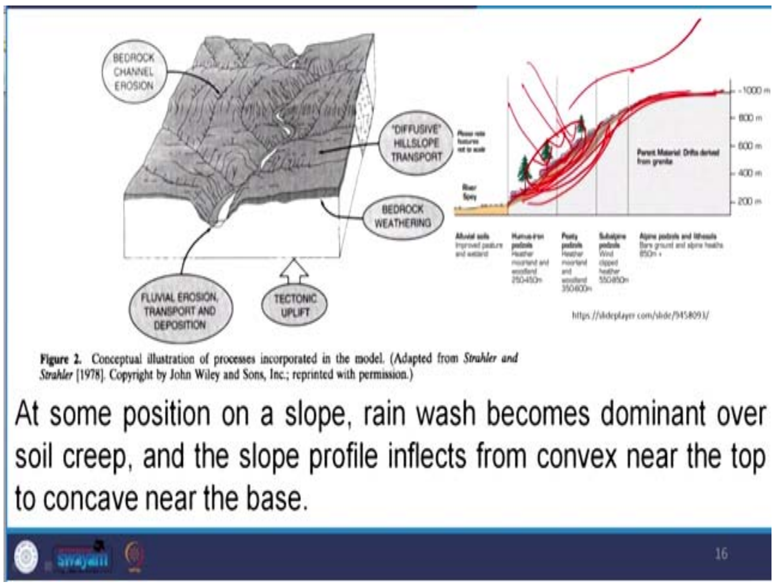

At some position of a slope, rain wash becomes dominant over soil creep and the slope profile inflects from convex near to the top to concave near the base, so here for example, if you see suppose, this slope; at this part of the slope for example, it is more prone to rain water, so rain water wash slope is there, so once rain water wash slope rate; slope is there, the rate of removal of the material is more here.

Once the rate of removal of the material and is more here, the total system it will be concave up, this side is convex up, this side is concave up, so the rate of weathering will be more and finally, this inflection point will be move somewhere here because earlier, if this is the slope, this was the inflection point. Now, this inflection points of; this was the slope, this was the inflection point, one were; once we are removing this material here and finally, the inflection point is shifting its position.

So that is why, at what portion of the slope, what type of removal mechanism is responsible and that is why ultimately, the characteristics of the slope it changing from the top to bottom.

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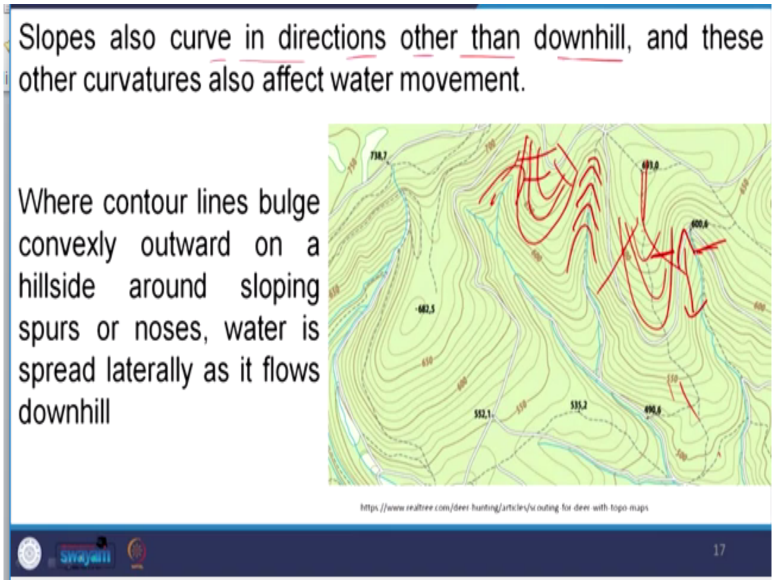

And that also influenced by paleogeography for example, if you see, slopes also curved in the direction of other than downhill, how; suppose, for example, this is the downhill, this is the downhill direction and in the downhill direction, these are the valleys, these are the valleys, but similarly, not only in the downhill, this side also we have different slopes, this side also, if we are moving laterally, the slope is also changing.

So, these other curves affect the water movement, suppose water was moving here, this type of nose what is coming up, this will affect the water movement, so water will move this way or this way, so when contour lines bulge convexly outward on a hill slide around sloping spurs or noses, water is spread laterally, you see that we are discussing here, when we have a convex slope like this, it is coming as a nose.

So, instead of water accumulating, water will spread, so these are called water spreading slopes, water is spreading but here these slopes there water accumulating, so 2 types of slopes we have discussed; one is for water spreading slope, one is water accumulating slope. Now, water spreading slopes that will the slope in that case, the slope profile will be different and water accumulating slope, the slope profile will be different.

So that means, overall when you are talking something about slope on scale of looking, overall for us, if we are standing outside, this is the hill and this is the slope, simply we are drawing line but once we are going and closely observing that this slope even divided in 2 parts; one is we have water accumulating slope, another is water spreading slope, so that what scale you are looking that matters.

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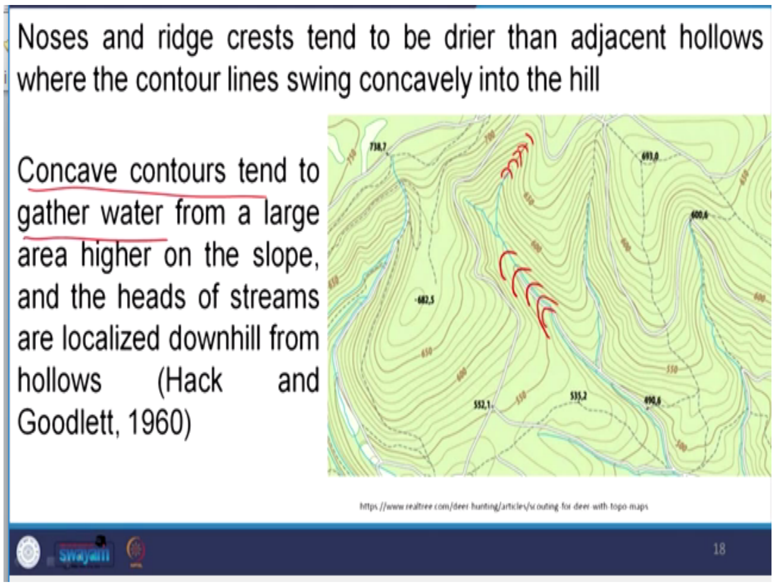

Noses and ridge crest tend to be drier than adjacent and hollows, where the contour lines swing concavely into the hill. Concave contours tend to gather water here if you see as we are discussing, concave contours here, concave contours, it is concave downward, so concave contours they gather water from a large area higher on the slope and the heads of stream are localised downhill from these hollows.

From here, this is concave contour, this concave contour that is is gathering water and finally, this stream start to originate.

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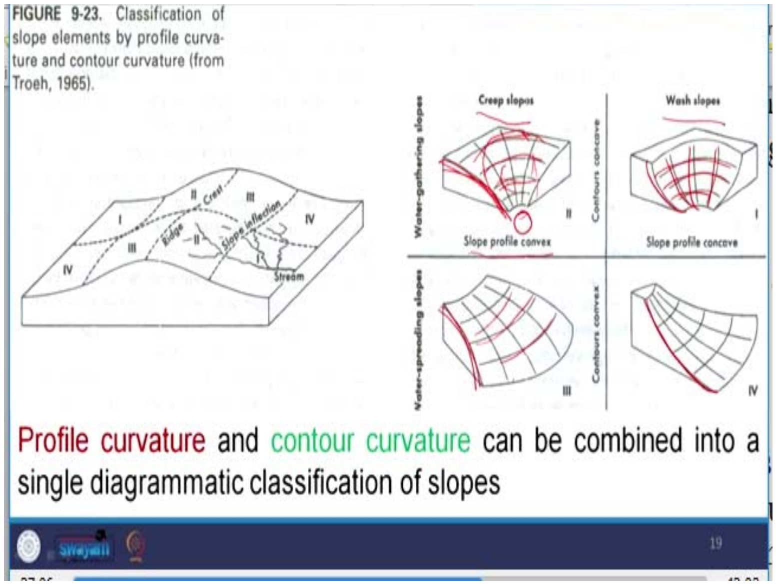

Profile curvature and contour curvature can be combined into a single diagrammatic classification of the slope, here if you see, this is contour curvature, this contours are here and this is profile curvature, so by looking this contour curvature and profile curvature, 4 types of slope has been classified; one is creep slopes, wash slopes, here if you see slope profile is convex either of this case, you see this is slope profile, it is convex.

But in other part here see, slope profile is concave but here though it is convex but still contour is like this, so it is a water gathering slope, here water spreading slope, though this slope profile is convex till here water gathering takes place in this area, water gathering takes place but having this same slope here but here this water spreading takes place, is not it? So that means, again we are increasing the scale.

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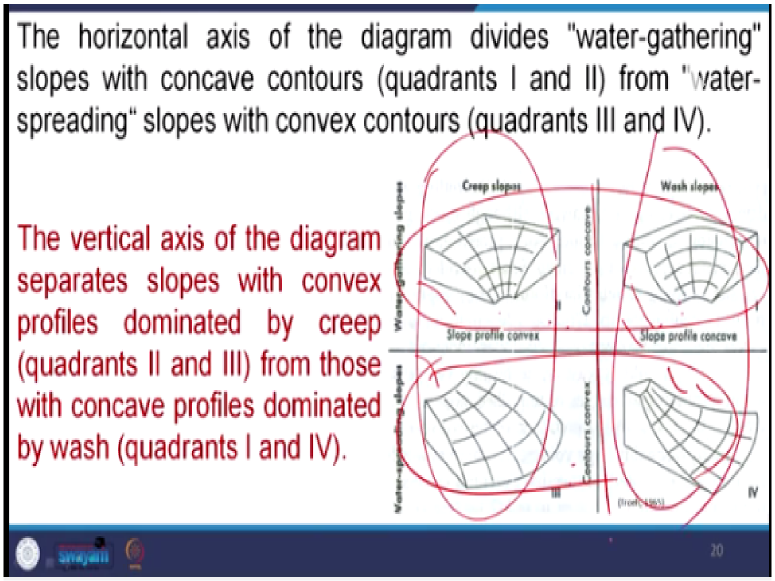

The horizontal axis of this diagram divides the water gathering slope with concave contours quadrant 1 and 2 and from the water spreading slope with convex contour quadrant 3 and 4, the vertical axis of this diagram separates slopes with convex profile dominant by creep, quadrant 2 and 3 and this is the creep action dominant and from those with concave profile dominated by wash slope.

So, here this side creep is dominant, here wash slope is dominant that means, water wash slope is dominant, here this is water, these 2 they are water gathering slopes, these 2 having water spreading slopes. So, here these 2 that is concave slope profile, so that means irrespective, either it is convex up slope or concave up slope, the contour also playing another role here, either it will, water will be gathered or water will spread.

So, now let us discuss about the mode and rate of slope retreat, which rate this slope is retreating, what is the mode of retreat?

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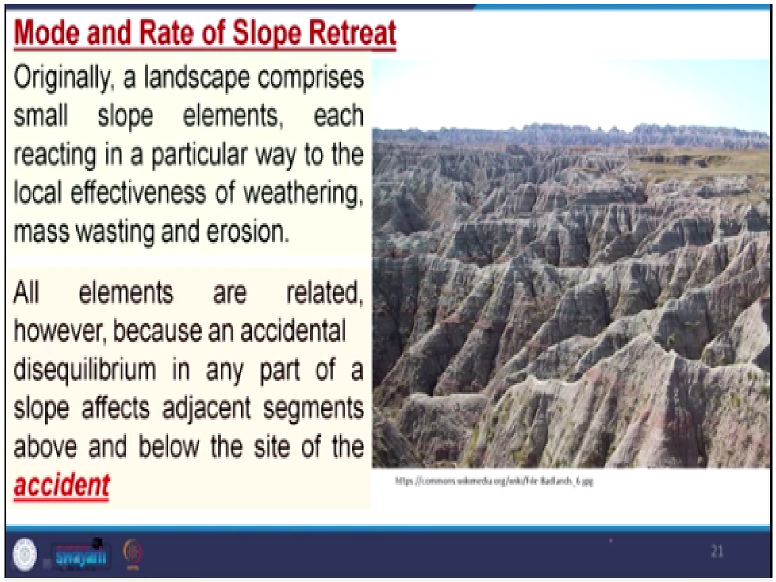

So, originally, a landscape comprises small slope elements, each reacting in a particular way to this local effectiveness of weathering, mass wasting and erosion, all elements are related however, because an accidental disequilibrium in any part of the slope affect adjacent segment above and below it, so this is called the site of accident.

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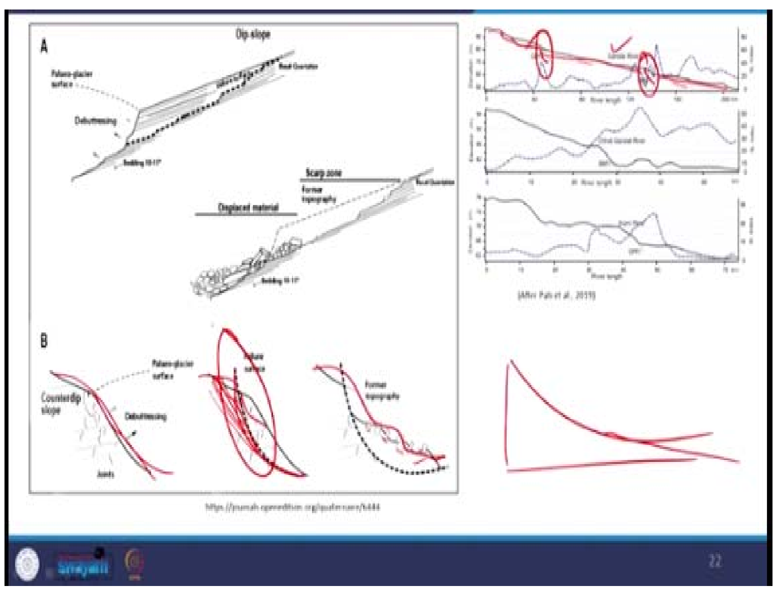

For example, that means, I want to say, suppose we are dealing with a slope and through the slope, suppose these equilibrium has been maintained, so the slope is like this but suppose, at certain point of time there is mass wasting, removal of material, so for us earlier the slope was like this now, the slope will be like this. So, now the material has to be removed here because the slope has to be maintained.

So, with time again, this material which is removed from here that will be deposited in the lower slope, so that means, now see the slope shape is changing, the slope profile is changing, is not it, so that means, some accidental inclusion either it is a mass wasting, it is a landslide or it is may be due to faulting for example, here if you see, this is the slope profile of a particular river that is Gandak river, longitudinal profile of a Gandak river.

Ideally, the longitudinal profile of a river should be like, concave up, it is like this but here if you see, this concave here is a fault, then it is going down here is a fault, then it is going down, like this, so these are the accidents, so once accidental happening is there along a slope, so slope has to respond; the material, the processes has to respond to that accident, so that is why the slope profile that changes with time.

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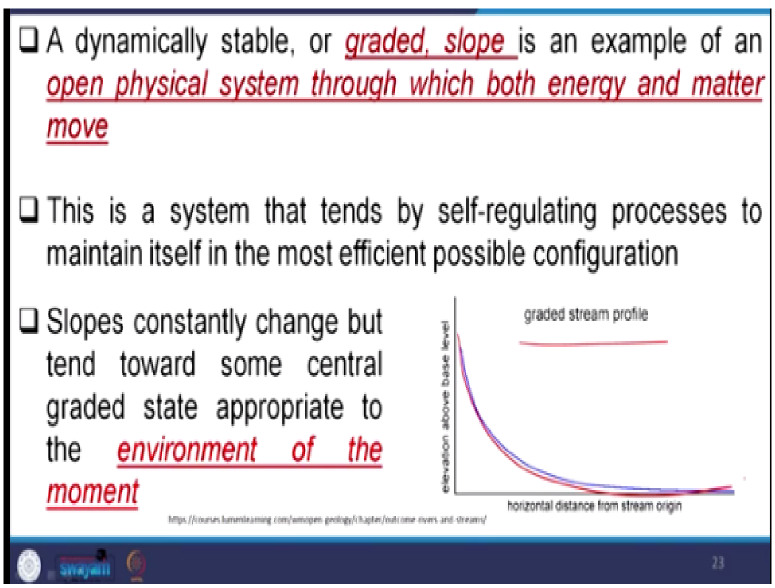

A dynamically stable or graded slope is an example of an open physical system through which both energy and material move, this is a graded stream profile, you see this is a graded slope where the energy and material both are moving, this is a system that tends to self-regulating process to maintain itself in the most effective possible configuration, so nature always wants to make it plane, to make the system slope, to make the surface smooth.

So that is why, any accident occurs in between this all these process; geomorphic processes they respond together and finally, they always try to make it peneplain. Slope constantly change but tends towards some central graded state appropriate to the environment of this moment. Then, what type of environment, if it is slope suppose, slope is retreating but what rate it will be retreat, that depends upon the climate that depends upon the rock type that depends upon the rate of production of the material and rate of removal like that.

All those things obviously, that is proportional to the weathering and climate and something tectonics, like that, so that means, slope constantly change but tend towards some central graded state, approximate or appropriate to the environment of this moment, so always and always, the slopes always try to come to the graded state that is why this mass wasting continues, the weathering continues, the hill slope retreats and all those things happened.

So, the ultimate aim of nature to make the system graded, so questions that have been stimulated generations of geo morphologist, concern that, retreat of slope at a river valley deepens and widens. Are slope profile stable, migrating backward, parallel to themselves? or Do slope angle decrease through time as summits are lowered? so these questions have been asked for decades to study the nature of the slope retreat.

For example, if you see here, this is the present day profile of 2 rivers, it is in young stage or youth stage, in the mature stage, if you see this is a profile that means, the valley becomes more wide as compared to its depth.

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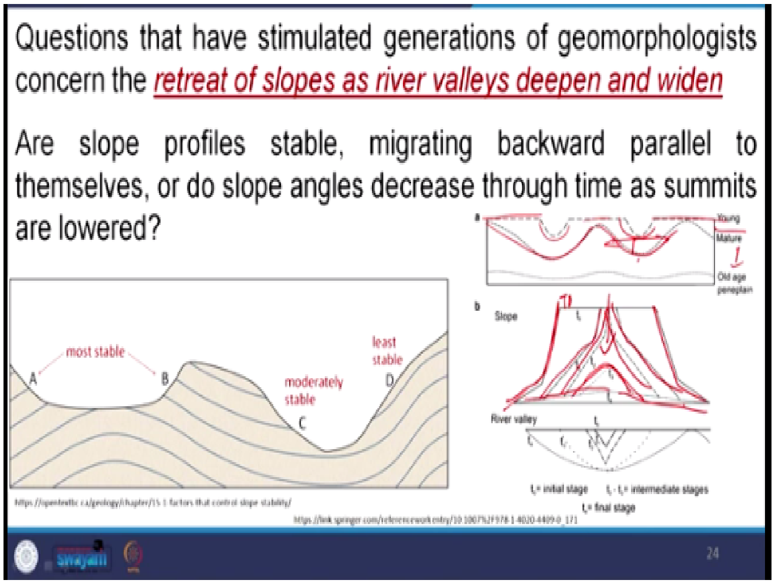

Similarly, here in the T0, suppose this is the profile of slope, this is T0, the time 0 now, if we allow it to respond, the geomorphic process to work, so with time with T1, the slope will retreat like this, then with T2, the slope will retreat like this similarly, this side of the this hill, the slope will retreat like this and with time, this height of this hill gradually decreasing and finally, it will come to peneplanation stage.

So that means, I want to say slope retreat with time always slope try to comes to a graded state and those slopes are retreated with different phenomenon and different part of the slope somewhere creep is dominated, somewhere rain wash is dominated, somewhere groundwater seepage is dominated, somewhere gravity is dominated, somewhere the streams and rivulets they are responsible, so that means, irrespective of those geomorphological agents or geological regions, the main aim is slope is retreating.

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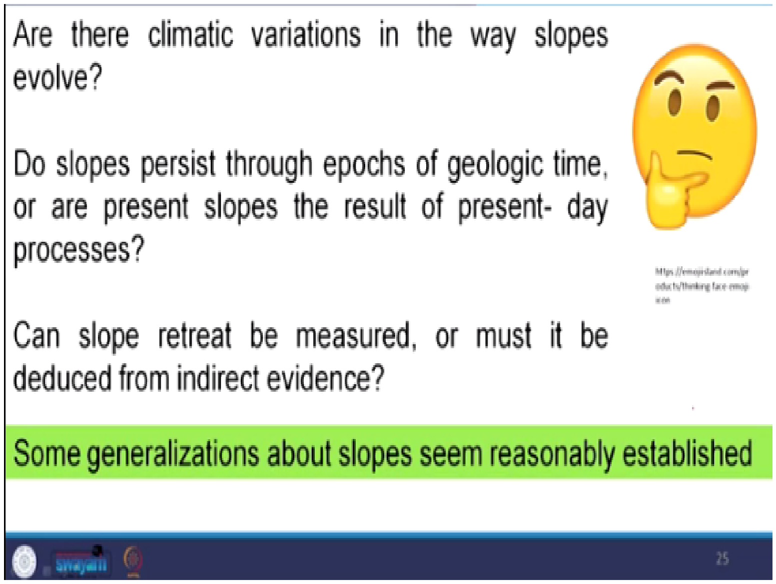

And always and always, nature wants to create a graded slope to make it peneplain, so are there climatic variation in the way slope evolve, do slope persist through epochs of geological time or are present slopes the result of present day processes or it is acting past processes? So, nowadays if you analyse the hill slopes of different rocks, different segments you will see, different processes are responsible for this hill slope evolution, that does not mean whatever the processes dominating at that part of slope now, the same process was continuing in the geological past, may or may not true.

Suppose, for example, in the Himalayan terrain if you move, sometimes this area was totally glaciated, so present day the means sea level if you say, near to this present day sea level, there are many buried channels which are representing the ancient glacial valleys, so that means and nowadays, those valleys now are occupied by this fluvial system or the rivers, so that means, at this same geographic location, different agents they have worked in different geological times to make the system peneplain , to make the system graded.

So, another question; can slope retreat be measure or most it be deduced from indirect evidence, is not it, some generalised slope stability or the some generalisations about the slope seem regionally be established, those are these studied by this davis geomorphic cycle, the penck's geomorphic cycle, then other geomorphic cycle, all those geomorphic cycle they say about the retreat of slope, the reduction of slope.

So that means, this retreat, this models, the retreating models, slope models that remains a established, that has been generalised based on certain observations, based on number of observations, based on some simulations, so that means, those questions has to be established here. So, here if you see, this retreat of slope, that is the T0 again, the slope is very straight slope, very sharp.

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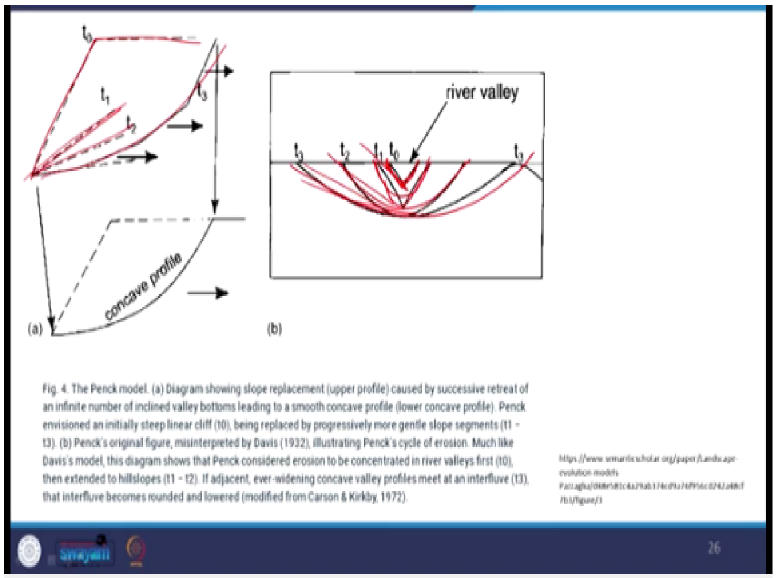

And with time, you see the slope is reducing here with T2 is reducing here and finally with T3, this is reducing here, so earlier the river was here T0 and with time, the river valley evolution is like this and river is getting wider and deeper here, so that means, it will continue you see, earlier this slope was very straight but nowadays it is getting smoother and smoother, so this is the way of slope retreat takes place.

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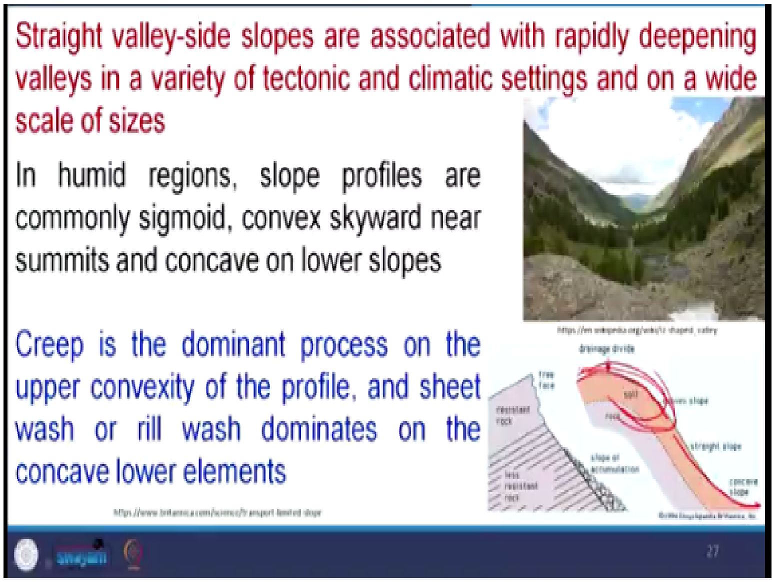

Straight valley side slopes are associated with rapidly deepening valleys in a variety of tectonics and climatic settings and on a wide scale of size, in humid regions, slope profiles are commonly sigmoid, convex skyward near summit and concave near the slope, here you see it is convex skyward and here concave at below, this is mostly, typically a slope characteristics of humid region.

Creep is the dominant process on the upper part as we have discussed here, this region is dominated by creep action, the upper convexity part of this profile is dominated by the creep action and sheet wash or rill wash, dominated at the concave portion of this only here, this concave portion is dominated by this, the rills are generated here and this first order streams, they generate from here.

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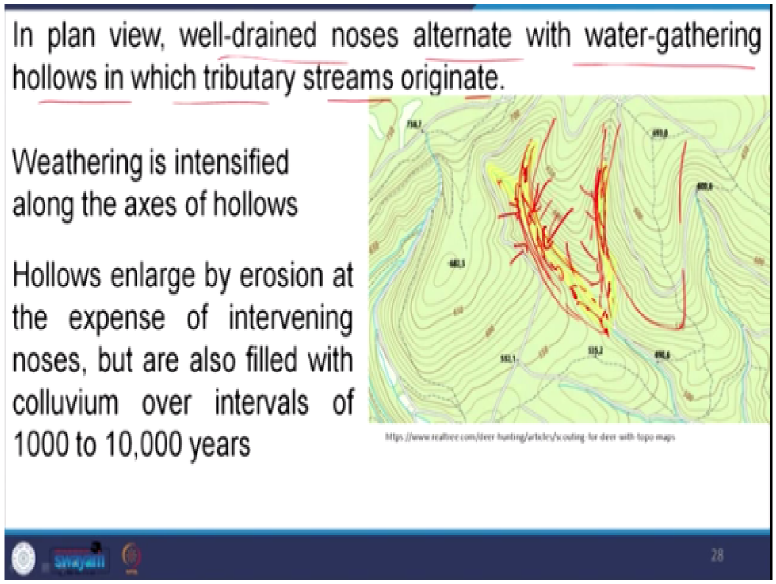

In plan view of a hill, if you see here this plan view, it is well drained noses alternate with water gathering hollows in which tributary streams originate, here this noses are here, these are the noses, these are the noses and in between we have hollows and this hollows there water gathering hollows. Weathering is intensified along the axes of hollows here, these are the sides of weathering and erosion, a removal of this material first.

So, once we want to establish the hill slope retreat, so these are the potential places where the hill slope retreat can be studied directly, hollows enlarge by erosion with time and the expense of intervening noses but are also filled with colluvium over interval of 1000 to 10,000 years, here to important to note it there. Though they are retreating, though they are the sides of weathering, but with time they are also filled of the weathered material.

And the weathered material comes from the side so that is why, once these are the sides of weathering and to respond this weathering takes place from here and here, here, so ultimately the whole system is responding.

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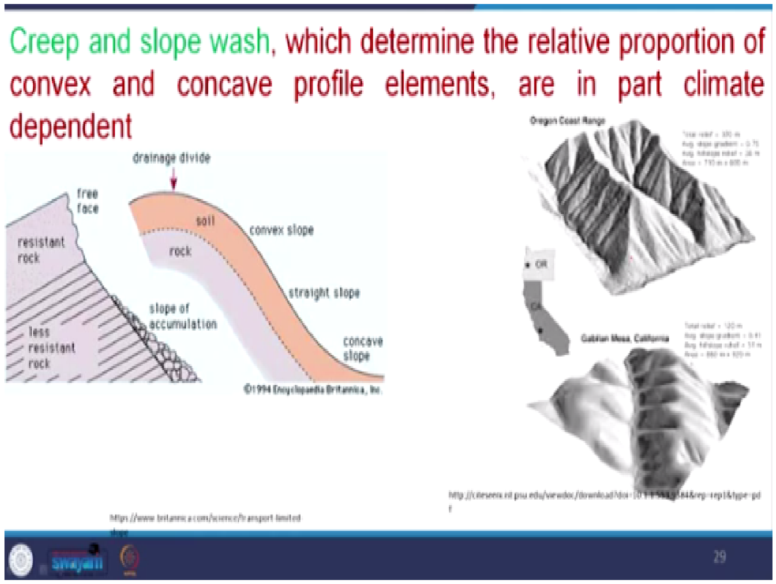

Creep and slope wash which determine the relative proportion of convex and concave profile elements are in part of this climate dependent, so climate also plays an important role here.

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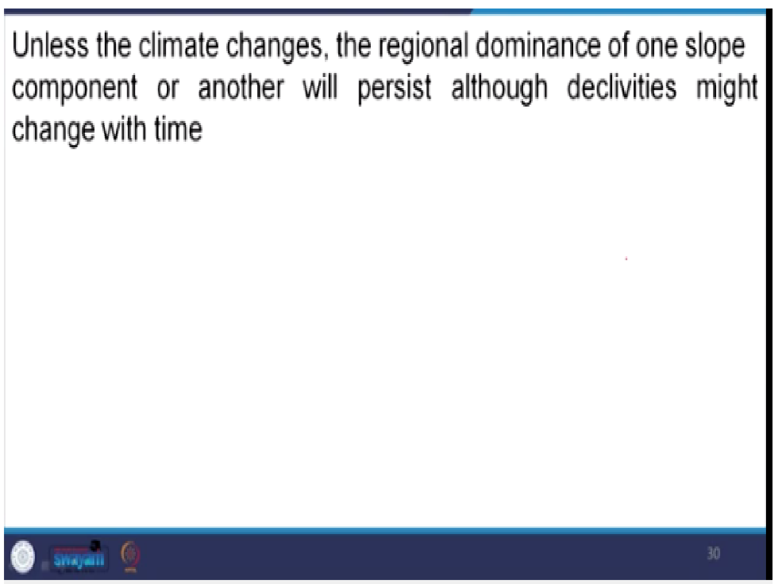

So, unless the climate changes, the regional dominance of one slope component or another will persist although, declivities might changes with time, so that means, climate change, tectonism, mass wasting, the nature of the sediment, nature of the rock material, all those combinely work together to define what should be the slope profile and the slope retreat is due to climate, it is due to tectonism, it is due to this weathering and erosion agents, due to mass wasting like this.

So, this way hill slope retreat, hill slope evolved, so this is all about your hill slope evolution and this is the end of the story, we will meet in the next class, thank you.