Geomorphology
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Lecture – 21
Hill Slope Evolution - I

So friends, good morning and welcome to this lecture series of geomorphology and today, we are going to discuss about this hill slope evolution. So, before proceeding we must know what is a hill, what is hill slope and how they evolve through time. So, if you remember our earlier classes, there was weathering, erosion and mass wasting we have covered, so the main idea behind this weathering, erosion and this mass wasting was how they play a role in the hill slope evolution that has to be discussed here.

The weathering, erosion and mass wasting play a major role in hill slope evolution, so for example you as an observer, you are standing away from this hill and you are drawing a profile of this hill, so finally the profile will be like this suppose, you are changing your position from north to south or say somewhere else and you draw the profile of the same hill, so you will draw a profile like this.

Similarly, again after few minutes, you again change your place and you draw a profile and you will see that the profiles you have drawn for the same hill in 3 different places, they are not matching, why? This is because the hill slope are not same throughout their sides, so different sides of a hill show different type of a slope characteristics, the curvature will be different, the height will be different, the profile shape will be different.

So that means, I want to say even if we say the hill slope evolution whenever, you say about the hill slope, so that means for a particular side of a hill we are talking, but if we want to consider the whole hill at a time, different part of this hill, they behave differently, different sides of the slope they behave differently and this difference is due to the geomorphic processes and the rock types, the climate, all those and the weathering erosion processes, they governing around this region.

For say, example you are mapping somewhere in the Himalayas or somewhere else, so this hill, it consist of 2 rock types basically, for example so, the lower part it is a granite body and the upper part it is either shale conglomerate, whatever may be you take and you will see those parts; those up to that height which is representing by the granite in your profile, this slope will be straight, this profile will be straight line.

But if you are coming to the sedimentary portion, the profile will be different, so now the question arises; if we are going to talk about the hill slope evolution, how the hill slopes evolve with time, how they retreat, how they reduced and what are these geomorphic criteria, what are the geomorphic agents, they work together or individually to modify the hill slopes that will be discussed elaborately.

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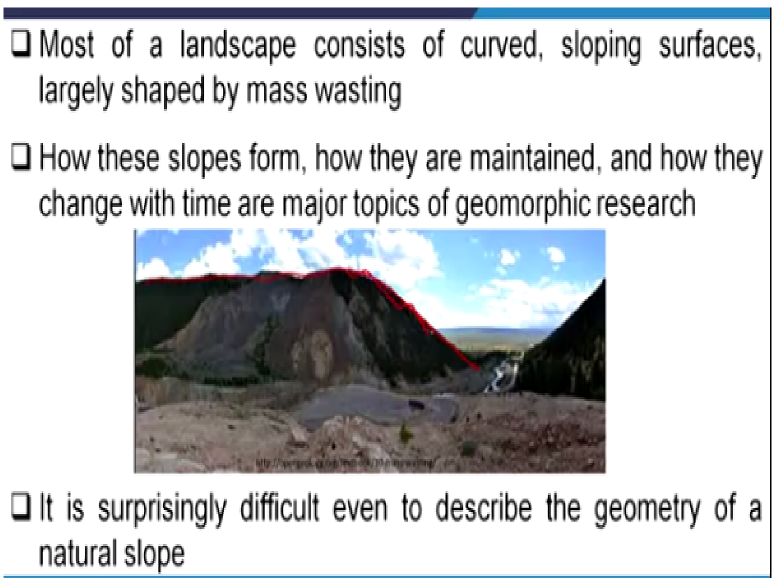

Most of the landscapes consist of curved sloping surfaces largely shaped by mass wasting you know that is the mass wasting, it is playing a major role, either it is in slump type, it is in creep type, it is of avalanches type, anything that means, irrespective of their nature, irrespective of their classification, the main theme of this mass wasting was to reduce the mass, so once we are reducing the mass, that means we are changing something in the profile, the changing in the hill slope profile.

So, once we are changing that means, hill slope is getting changed, so those changes as recorded by geomorphologist systematically through a climate, through a rock types through a weathering agents and through time and those has been discussed here in terms of hill slope evolution. So, now the question arises; if we are talking about this hill slope now the, it comes in our mind that how the hill slopes form, how they are maintained and how they change with time, the major topic of geomorphic research.

So, hill slope formation and slope maintenance; the 2 different things, slope formation may be by weathering and erosion but whether these slope which was during this formation of the hill, that same slope will continue till last or till the monadnock stage or during this evolution, the slope will change. If this is changing, then what rate changing and which fashion it is changing, either it is changing parallely or it is non-parallely.

And if we localised, so that has to be discussed here, so it is surprisingly difficult to even describe the geometry of the natural slope. So, now the question arise is; if it is difficult then how the hill slope is defined so far, so that depends upon the scale for example, suppose you are standing away from this hill, for example, this figure, it is the photograph, so you are standing away from this hill.

So, you are drawing a profile, so profile will be like this, it will go like this and it will, so for example here, this profile will be like this removing and finally, it is coming down, okay. Now, you come to closure to certain close, so that means this profile which is drawing here, those profile will be like this, there will be again changes, again you are coming closure and closure, then there will be curvature within that.

So, that means, I want to say the more close we go, the more closely we approach, the slopes shape or the slope behaviour is changing, so that is why it is difficult to define a slope properly in mathematical form, which order of polynomial it will be, so that depend on the scale we are looking at. The more closure we look, more order we are adding to the polynomial, the mathematical equation.

So, that is why defining a slope that means, at slope for hill, natural slope I am talking not the mathematical slope, so defining a natural slope around the hill slope or around the hill, it is not only difficult but also a there are the matter of concern about certain factors, so in this class we will discuss about those factors which are responsible for those hill slope evolution.

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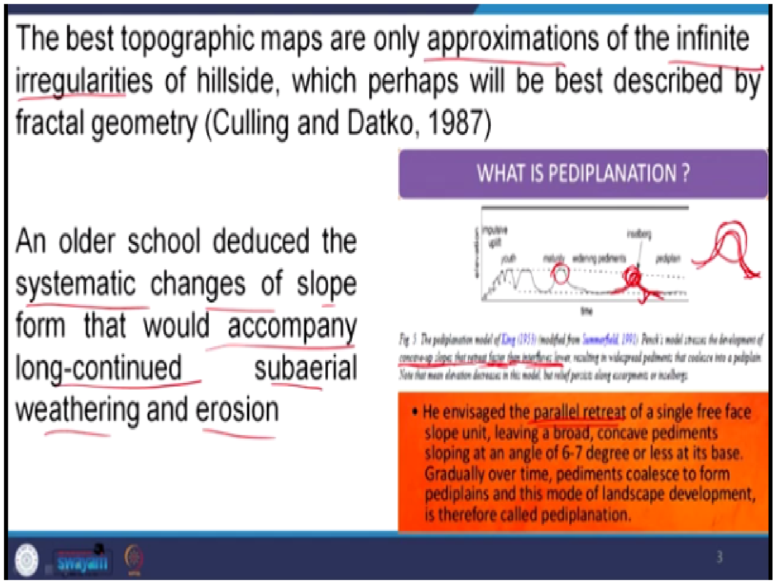

So far, the best topographic maps are only the approximations of infinite irregularities that has to point, that has to be noted here which infinite irregularities that what is the irregularities; this irregularities in terms of climate, in terms of lithology, in terms of slopes, in terms of structure, in terms of weathering, in terms of types of weathering, so all those parameters, all those factors that influence the hill slope evolution.

And then factors which are acting along the hillside that defines what type of a slope is going to be happen, so which perhaps the best described by this factor on geometry, so that is the probability, okay. So, an older school of thought is there that these some geomorphologist, they believed that whatever the slope we are looking at, those slopes are this continued action of weathering and erosion, if you see here, the systematic change of slope from that would accompanied by long continued sub-aerial weathering and erosion.

So, sub-aerial weathering and erosion, mass wasting, these are responsible for this hill slope evolution, for example, suppose you confine yourself with this figure with is look inside, so here you see this is; if we remember properly, it is representing the Penck's geomorphic model, what this Penck's geomorphic model says? It says the evolution individual slope rather than the whole landscape at a time.

So, here if you see, Penck's model stresses the development of concave of slopes that retreat faster than the interfluve lowers, it is very important to know, this model says the retreat of concave slopes for example, if you see here, this the hill slope and this is a concave slope, similar this is a concave slope, Penck's model says these retreat of this concave slope is faster than the retreat of a interfluve, so this is an interfluve, this is an interfluve.

So that means, say the concave slope is retreating very fast as compared to this interfluve, that means the interfluve is acting as a water divide, so once the interfluve acting as a water divide, in a geological cross-section of the slope, it will remain like this as it is here, so this Penck's model says, resulting the widespread pediment formation. So, if you remember or we are talking about something at pediment or pediment means, it is an erosional form, remnant; erosion or remnant of this in.

In the next class, when we will talk about this arid zone geomorphology, details of the pediment will be discussed there but here just to remember you, this pediment is nothing it is just an erosional remnant of this older rock. So, now you see if it is eroding down and here is a pediment; this is the pediment form and this is the monadnock or inselberg it is forming so, with time more and more slopes will retreat, more and more inselbergs will form.

And finally, the pediment will coalescence with each other and form a pediplain, is not it, so that means, Penck's envisaged that parallel retreat of single free space, parallel retreat of single free space slope unit leaving a broad concave pediments sloping at angle 6 to 7 degree and is or less than at the base gradually, over time pediments coalescence to from pediplains and this mode of landscape development is therefore called pediplanation.

So, pediplanation, the process pediplanation it includes many things like weathering, erosion, mass wasting, tectonism, so all those things it is responsible but the all these things if you compare this the whole figure here, in every case this slope is retreating irrespective of their influences, weathering it is influencing, erosion influencing, tectonics it is influencing, river it is influencing but the main theme is that this slope is retreating.

But the rate of retreat is different at different places for example, if you see this graph, you can find, here the rate of retreat will be different, here the rate of retreat will be different, so the final product is the pediplains, the pediments, the coalescence of pediments giving a pediplains, so it is the planation; pediplanation, the process is called pediplanation. So, pediplanation is a process by which hill slope evolution takes place.

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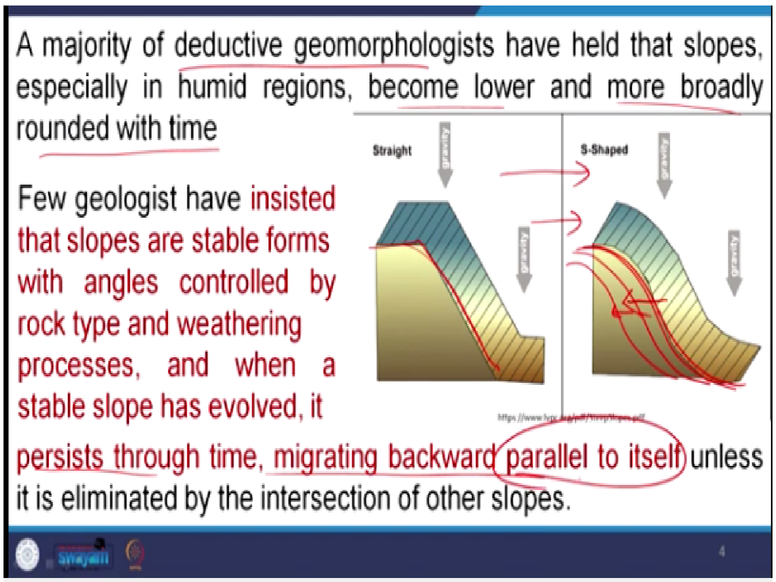

So, these group of geologist which is termed here in the literature that is deductive geologist; deductive geologist means those believe deduction, reduction of the system, removal of this material from the system and it is deductive geomorphologist have held that slopes especially in the humid region becomes lower and more broadly round the with time. Here, if you see humid region that means, climate is taken into account.

If you remember when we are talking about weathering and erosion, climate plays an important role, for example, in humid region, chemical weathering is more pronounced, in arid region, it is physical weathering is more pronounced, so here those of geologist, they believe, that the humid region this planation or this hill slope retreat becomes lower and more broadly rounded with time. Suppose, for example, here confined in this particular figure, this is a hill slope which is mostly planar.

But with time it is looking the S shaped, so that means this is that especially in humid region, this hill slope evolution or this deduction process becomes lower and more broadly rounded with time. Few geologists insisted that slopes are stable forms with angles controlled by rock types and weathering process and when a stable slope as evolved, it persists through time migrating backward, parallel to itself, unless it is eliminated or it is intersected by others slopes.

That means you see suppose, we have a slope here and the slope finally with the time it is converted to this type of slope now, if we are retreating it that means, the slope has to migrate in this way, so here a group of geologist they think, the slope that is retreating parallelly that means parallel retreat would be there, that means in a next stage of time, this slope will be like this, in the next stage of time, the slope will like this.

So that means, each and every point of this slope for example, here this point is parallelly migrating this way, this point is parallelly migrating this way, so that is, it is called, this is called parallel retreat of slope, so it is can be severe, it is persist through time migrating backward, parallel to itself unless it is eliminated by the intersection of other slope; other slope again comes with scale.

Other slope for example, if I were looking at this scale, we are getting this type of slope, again we are zooming it, it is like this, it will be like this, similarly again zooming it, it will be like this, so that means, suppose there is a fault scarp formation in time, during this slope retreat suppose there is a fault scarp formation; fault scarp formation means, this slope will be cut by this other slope.

So, that means, this group of geologist believe this parallel retreat will continue until, unless it is cut by other slope for example, this is a fault scarp or a river rejuvenated, it cut the slope from here, so it will not be disturbed until, unless other agents, other type of slope it is interacting with the existing slope, so that parallel retreat will continue but what extent this school of thought is true, let us discuss here.

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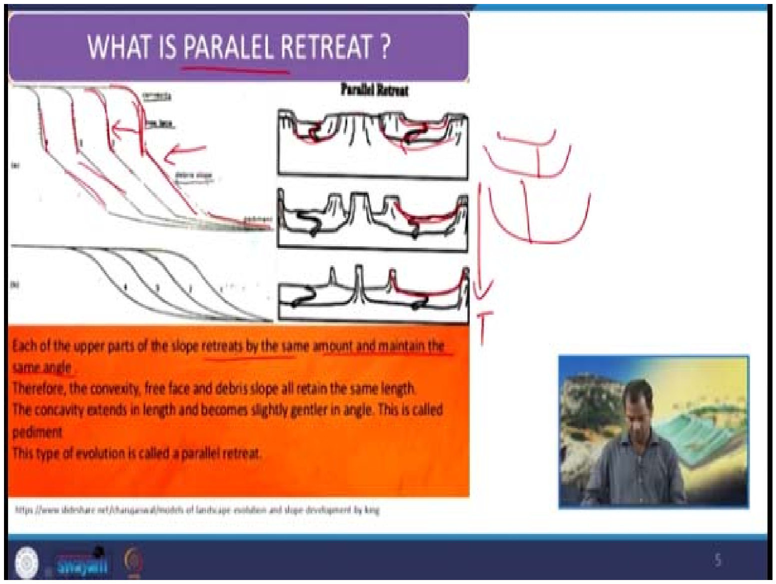

Now, for example here in this figure which is this is described what is this parallel retreat, now see here this is the profile of a valley here, a river is flowing through, here is a river is flowing through and with time, if you see the valley is lower this much earlier, this was this valley depth and now, this is the valley depth. Now, again with time, this is time increasing, here again with time, the valley depth is there.

So that means, if I compare, first it was like this, then second it was like this and third it was like this, so here this parallel, this is parallel this, so it is parallel retreat. In parallel retreat, if you see in this side of the slope also, you see this is the slope, this is convex then this is free space, then this is debris slope or talus and this is pediment. So, here also, once this slope is retreating 1, 2, 3, 4, once it is retreating, see this is parallel to this, this part is parallel to this.

Similarly, this part is parallel to this, this is parallel to this, so that means it is every point of a slope, every aspect of a slope, it is retreating parallelly, it is called parallel retreat, each of this upper part of the slope retreat by the same amount and maintain this same angle, therefore the convexity free space and a debris slope, all retain the same length, the concavity tends to length and becomes slightly gentler angle, this is called pediment.

This type of evolution is called parallel retreat, so that means parallel retreat has certain characteristics, those characteristics are here that each point of this slope that is retreating parallelly, reducing parallelly, the concave slope it is also parallel, the convex it is parallel, the free space, it is moving parallel, so by this way if we compare the slope with time, then these slopes can be seen that each part is reducing parallelly, so that is called parallel retreat.

It is one school of thought that believe that the hill slope is evolving parallelly and this is called parallel retreat, suppose we have fault scarps, which is a fresh fault scarp here, will be steeper than the angle of repose, so if this fresh scarp or the slope which is steeper than the angle of repose, so if you remember our last class, when we are talking about to mass wasting, if something more than the angle of repose which cannot be stable in the slope.

So, that means it has to move down by mass wasting by weathering or erosion, so a fresh scarp will be steeper than the angle of repose but when it is abandoned, the scarp ravels or collapse back.

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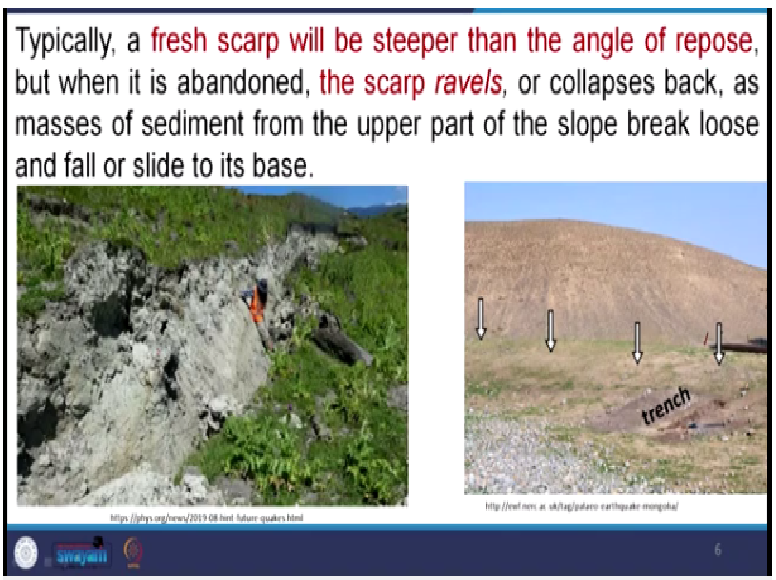

If the masses of sediment from the upper part of the slope break loose and fall, slide to the base, now you see here, this is a photograph of a fresh fault scarp and you see this slope is straight but here this is a fault scarp which is old now, you see this is getting eroded and finally, this material is deposited here, a fault scarp which is younger that means it is a straight slope here, the angle of repose is more in that case, material try to move from here.

And the movement that depends upon the slope position, either that will be fall or that will be creep or that will be flow or any type of movement that depends upon the material involved, the water saturation condition, the slopes or that but irrespective of the region, irrespective of the region, irrespective the methods, the main theme is that the mass from this upper part of the hill slope, they comes down and deposit at the base.

So, this is called accretional, this process is called accretion, slope accretion: accretionary slope, accretion means addition, where adding material at the base of the slope and removing the same material from the top, it is called accretional process.

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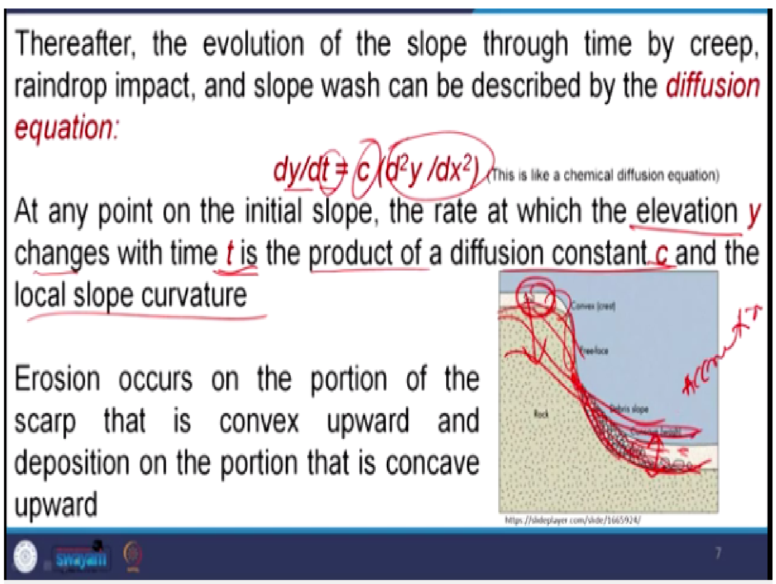

Thereafter, the evolution of slope through time by creep, by raindrop impact, by slope wash can be described by diffusion equation, why? It is simply can be compared with the chemical diffusion, so what is this; this is the rate of rate, time, t is for the time and y is change; that is the elevation change, this t is for time, and c is called local slope curvature or diffusion constant. So, here dy by dt equal to c into d square y by dx square [$dy/dt=c\ (d^2y/dx^2)$].

That means, at any point of initial slope, the rate at which the elevation changes with time is a product of diffusion constant c and the local slope curvature, so that means I want to say at the initial type of slope formation, newly slope, new fault scarp, newly river cut slope at initial time, the rate of the retreat of the slope is more and it is proportional to the product of diffusion constant c and the local slope curvature, this is local slope curvature, this is diffusion constant c with respect to.

Erosion occurs on the portion of this scarp that is convex upward and the deposition occurs at depress which is concave upward, we know it though convex upward, this type of slope, here erosion will takes place, erosion may be by creep, may be by slope, sorry may be by flow, any procedures, any methods involved, so material will reduce, remove from there, so that means, the slope retreats, the elevation changes.

And those material which is coming from this convex part, it will simply move down and will deposit at the concave part, so here material may be removed by free fall, here material may be removed by creep but here you see this is the debris slope or it is talus and this is concave slope, here these things are material deposited, so these part is called accretionary slope, accretion; accretion means addition, the material been added here.

So, removing here and adding here, so finally that means, if I removing something and adding something, we have a midpoint of the slope, the midpoint with time does not change like this, if I removing the material, we will moving it down and we are adding the material but the position of the midpoint will be somewhere.

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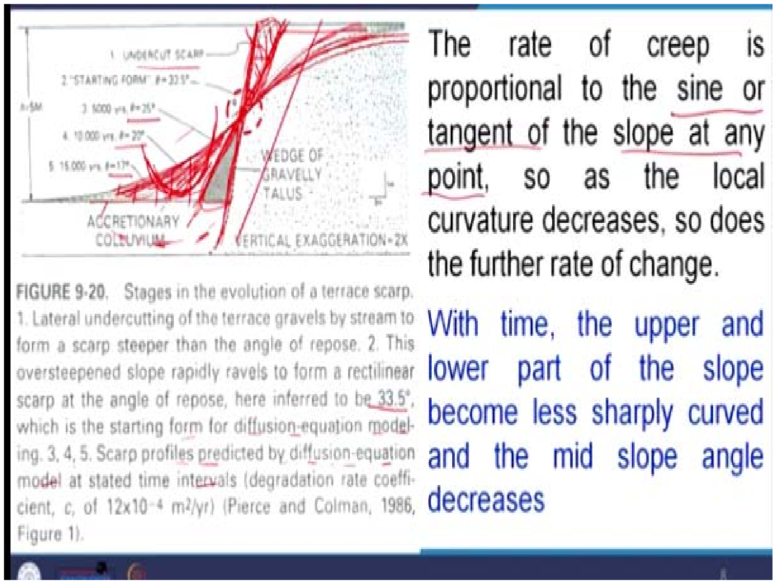

So, here it is return, suppose for example, in this particular figure suppose, this one if you see, one; the stages of the evolution of terrace scarp, first; lateral undercutting of terrace gravels by stream to form a scarp, steeper than the angle of repose, here this is, this is one, this is under cut scarp, river is cutting, here the river is flowing somewhere and it was flowing somewhere, so it is cutting and forming a slope which is surface is like this.

Then second; this is one number, so 2 this is; what is 2, these over steepened slope rapidly ravels to form a curvilinear scarp at an angle of repose here inferred to be 33.5 degree, for example here once this is the fresh slope which was formed by the river cut, now due to retreat of the slope with time, it has reached up to this position that means, this much material has been removed and once this material is removed, it has to go to the down slope site.

So, those removed material now, it is deposited here forming the talus at the talus slope, so now if you, in the third, suppose the angle of repose is 33.5, so here this angle of repose was more, sorry the angle was more, so that means, if the angle of repose is 33.5 degree, above which material cannot be stable here, so that is why this part of the material, this amount of the material removed from this place and it is getting deposited here, which is the starting form of the diffusion equation model in 3, 4, 5 scarps, profiles predicted.

Scarp profiles predicted by diffusion equation model will be there with the time interval, so that means, first this was the position, then this was the slope position, then here you see this was the slope position, then this is slope position and this is slope position, so that means here, earlier it was 33.5 degree, then the angle of repose, it reduced to 25 degree, again with time, it reduced to 20 degree, again it reduced to 17 degree, for this particular figure given.

So that means, with time, with retreat of slope of evolution of slope takes place, the material is removed from here and deposited at the lower part of the slope are this is called the accretionary portion or accretionary slope. So, the rate of creep is proportional to the sine or the tangent of the slope at that point, so as the local curvature decreases, so does the further rate of change, so here the local curvature gradually changing and changing.

With time, the upper and the lower part of the slope becomes less sharply curved and mid slope angle decreases, here you see the angle mid slope angle is decreasing and this becomes less sharp, earlier it was sharp like this again, gradually sharpness decreases, again sharpness decreases, again sharpness decreases, similarly this side again sharpness decreasing, decreasing, decreasing.

So, this is the way how the hill slope retreat back and this retreat will continue until and unless, it is super imposed by another slope changes for example, suppose again the fault scarp reactivated, so that means, this slope will not there, this will be again somewhere like this or a river which is creating here again removes this material, so once this part of these material is removed, that means this slope has to respond.

So, in order to respond this slope, whatever this process is going on that will change accordingly, so the slope shape will be also change, the slope will change, the amount will be change, so that means, it will continue until unless it is superimposed or intersected by other slopes.

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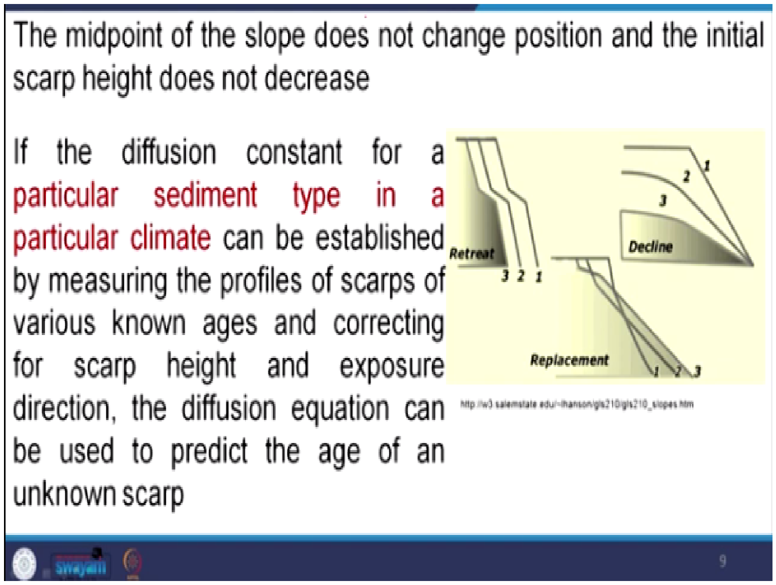

So, the midpoint of slope does not change position and the initial scarp height does not decrease, so this is one model, if diffusion constant for a particular sediment type is a particular climate can be established by measuring the profiles of scarps of various known ages of various rock types corresponding for a scarp height and exposure direction, the diffusion equation can be used to predict the age of this known scarp.

So, for each that is why the geomorphologist has to work hard that means, for each rock type, they have to monitor what type of a slope retreat mechanism is working there, for each climate and rock types, how the slope is behaving, similarly, for a particular tectonic environment, how the slope is retreating, so that means with number of observation, with large number of observation, if we can generalise this idea, that yes the diffusion equation will be like this.

Because diffusion equation that is climatically controlled, tectonically controlled, rock type controlled, weathering type controlled, is not it, slope controlled, dip controlled, altitude of the rock controlled, so that means all those parameters if we take into account and finally, come to a conclusion yes, this is the scenario and diffusion equation for this particular environment can be these.

So, that can be used everywhere in the world to define these to age or to get those type of slope when the retreat started when it is stopped, what it is the age of the slope that can be concluded there.

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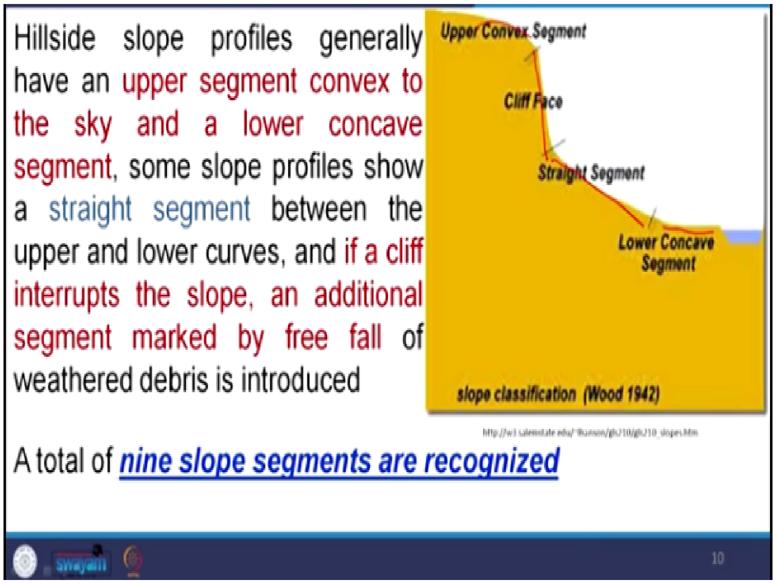

So, hill slope profile generally, have a will have an upper segment convex to the sky and a lower concave segment, some slow profile show a straight segment between this convex and concave one and if a cliff interrupt the, slope an additional segment is marked by free fall of weathered debris is introduced. So, depending up on that, depending up on the segments what type of slope in which part, total 9 slope segments has been recognised.

For example, here this side, it is concave up slope, here it is a free fall slope, it is a straight slope, here it is a concave up slope similarly, each segment can again be subdivided depending up on some parameter, so that is why this division and sub division, by this division and sub division, total 9 slope segments have been recognised. What are those 9 slope segments? And that will be discussed here.

And each segment behave differently to sediment transportation, each segment behave differently in terms of slope retreat, so that means, slope retreat here will be definitely different than the procedures or the mechanism of slope retreat theory, if a rate of retreat here will be definitely different from the rate of retreat here and will be definitely not similar, a same at the rate of retreat here.

That is why the hill slope changes with time, for example suppose, at the present condition, this is the profile of the hill slope, now suppose here the river is flowing, the rate of erosion of the river increases. For example, once the rate of erosion increases, this part will be move like this, so once this part will move like this, this will automatically respond to this part, so it will down like this.

Similarly, once it is suppose, this is a talus slope, a sediment is deposited here, once this part is removed, so sediment automatically remobilise, it will move here, so this slope changes, this slope changes again, so that means, I want to say any segment of the slope, if it is affected and it is retreating, it will definitely affect the other part of the slope, so that is why the slope retreat at one part of the slope, it is definitely changed the rate of retreat or the change the characteristics of the slope on the other part.

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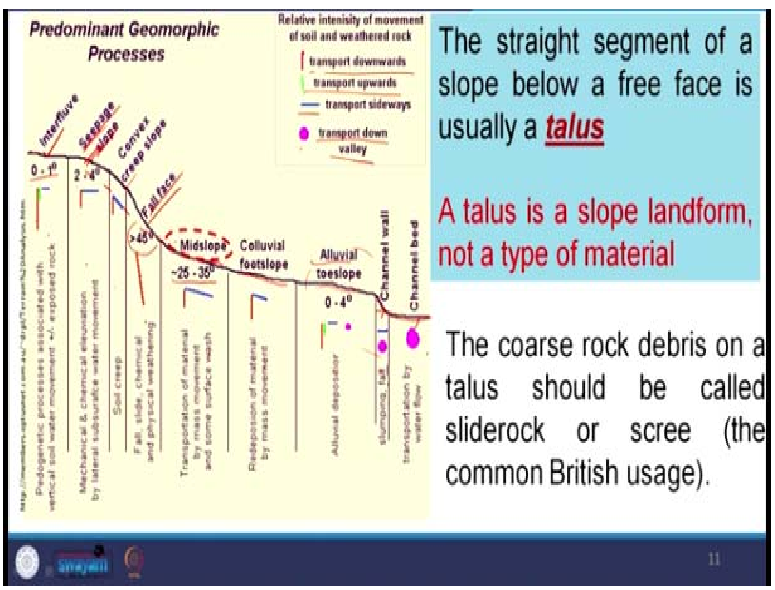

So, this is the 9 segments of the slope we are discussing, here this is interfluve, this is 1, 2, 3, 4, 5, 6, 7, 8,. 9, this 9 segment of the slope, so starting from the top we have interfluve; interfluve means, it is separating 2 different fluvial scenarios, 2 different fluvial basins, is not it, it is called interfluve, then seepage slope; here seepage occurs, so that seepage water that will move downward that will be somewhere emerge here.

If you remember when we are talking something about this seepage pressure which is influencing weathering, so it is a seepage pressure, it is a positive pressure, it is influence, it add the weathering agents, it will strengthen the weathering agents, so this is called, this part it is called seepage slope and if the slope is; slope amount is concerned, this interfluve 0 to 1 degree that means, it may be flat or maybe gentle dipping.

Similarly, seepage slope will dipping 2 to 4 degree, then comes to convex or creep slope is the convex slope, here creep movement is maximum, creep movement you know we are talking something this slow perceptible movement of creep of material downhill that is called creep movement. Then this is fall face which is free fall occurs, material freely fall from the slope only the air resistance is the resistance.

Similarly, mid slope here, this angle here you see 25 to 30 degree and fall face it is angle is 45 degree, then colluvial foot slope, then alluvial toe slope, then channel wall, then channel bed, so these are these 9 slope segments that has been divided on a slope and here you see this colours, transport down valley. Here, transportation is the major phenomena here; transport down valley, then here this blue line, this transport side way, the side way transportation is there.

Then green; transport upward you see, because interfluve transport upward, then transport downward, the red colours this transport downward, so that means I want to say these 9 type of slopes are there, every slope face can be divided into these 9 types of slope however, the length of each segment will be vary at different slopes and different part of the slopes. Suppose, for example, here this channel length if the channel is wide, this part will be more wide.

If the slope is very steep, so this part will be less or this part will be like this, if interfluve is very high, this part will be more, so that means, though these 9 types of slope segments can be divided, the length vary depending upon the geographic position, depending up on the geological set ups. I think we should stop here and we will meet in the next class to elaborate the slope segment in a different ways, in a different parameters, what are influencing the slope segment, how individual segment will evolved with time that will be discussed in the next class. Thank you very much, thank you.