Earthquake Geology:A Tool For Seismic Hazard Assessment
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Lecture-37
Compressional Tectonic Environments And Related Landforms (Part III)

Welcome back. So in last lecture we discussed about that how the deformation pattern changes if your strike and depth of the fault changes that is the geometry of the fault. And this was one of the best example which we came across in Himalayas, where we opened up the trench across a very young, active fault scarp, where we were able to see on the east facing wall, there was displacement, clear displacement on the west facing wall, we had folding.

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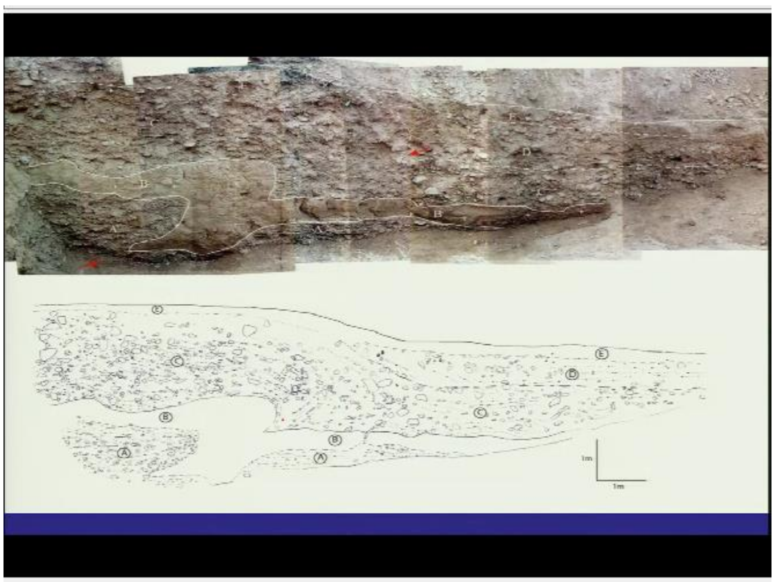

And there is the slide of that which shows and clear cut folding along a trace of the fault here. So this is the fault prank here and we have with this comparatively low at low angle with respect to what we encounter on the east facing wall. So, this is how the variation in the deformation you will come across in different environment. So, fault trans here and the sketch shows that we have a typical deformation that is in fold bend folding or you can say this is fault propagation folding along the tip of the fault.

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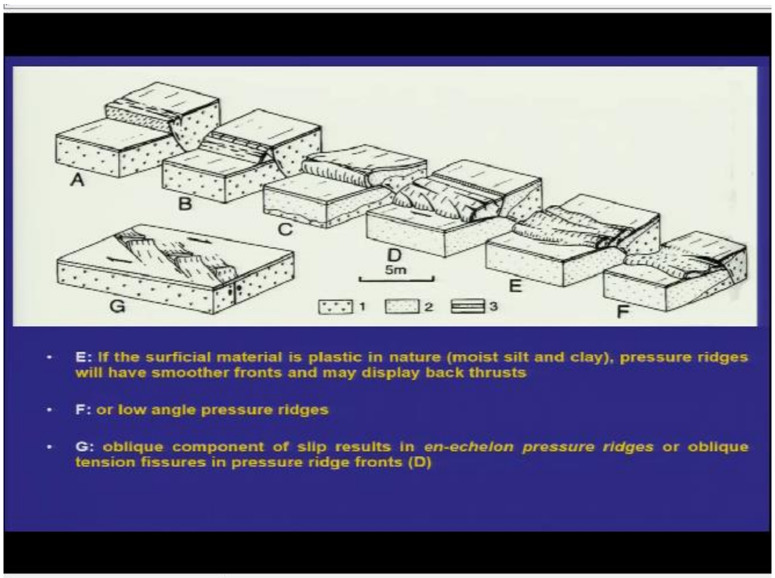

Now, looking at the 2 more signatures, which were encountered along by given by Philip which shows that E you have the if the surface material, so, mainly if you are having the finer deposits like silt and clay, then what you will see is deformation of pressure edges will have smoother front, which has been shown here and may display back thrust also. So, you will have the development of the back thrust.

So, depending on the material that what we have been discussing that depending on the material in the angle of the fault, we will see the different pattern of deformation on the surface. Then, if you have again you will have either deformation of the back thrust and all that or in the case even have a very almost horizontal fault plane which is coming right up to the surface will result into the development of pressure ridges.

Then if you have an oblique component, so, if the strike changes along the fault, then you may come across a development of multiple pressure ridges, which are termed as en-echelon. So, you will have the default which has seen here and they are stepping with respect to one another. So, in this case we have the left step over, which has resulted into the slightly thrust as well as what we see is the strikes emotion. So, we see an oblique tensional cracks and ridge with develop.

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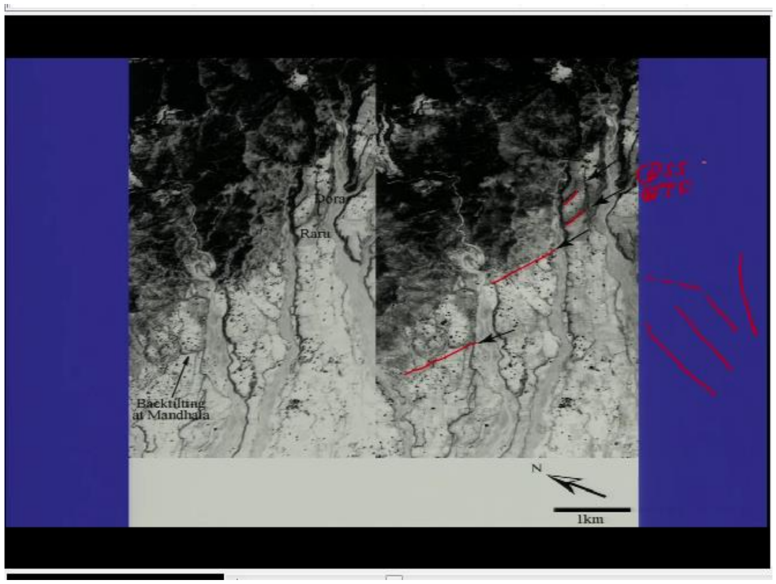

Now, if as was, I have shown one example, from the northwest Himalaya, that within the frame of 20 kilometers, we had like we encountered faults, mostly thrust faults. So, what we had like we had the frontal fault and then we had (()) (03:50) thrust and then we have we got one strikes default. Now along the birth heart thrust we had like styled these things in this strike of the fault which resulted into the development of en-echelon fault okay.

So, these are what we were looking at the previous one. So, on the surface you will come across the en-echelon faults scarps which had developed along the en-echelon faults. So, we have like within the thrust environment we came across as defaults like this okay. So you have one fault here another fault here, third one is here, and fourth goes somewhere here. So this was again, what we see is the left step over of the fault.

So this shows slightly oblique deformation, which includes along your strike step and second also thrusts faulting. So, this is an stereo photograph of the same area. So, you see the same features on both the photographs on the left as well as on the right.

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Now structures and evolution of thrust faults scarps, if we look at.

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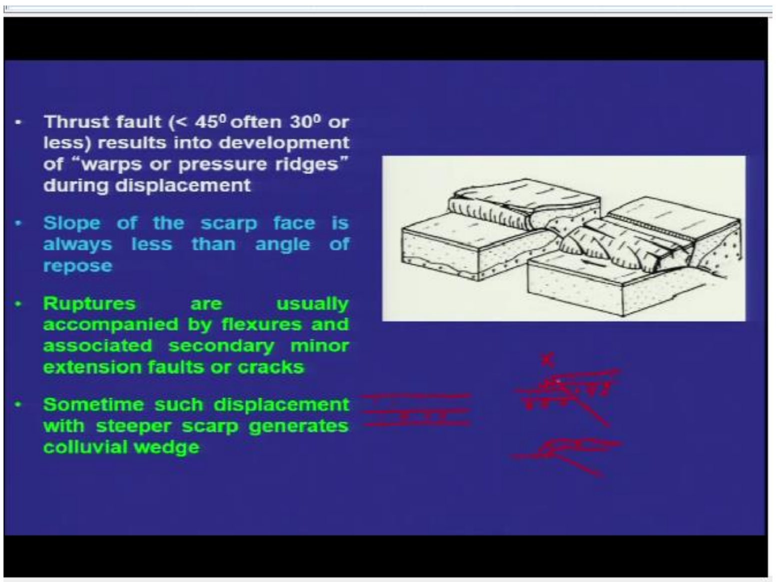

Then what we see is the finally, this one, okay, so we have the thrust faults, which are usually we take less than 45 degree or often 30 degrees or so. And that is again in a compressional tectonic environment, this will result into development of war or pressure ridges during the displacement. Now the slope of the scarp face is always less than the angle of repose. So, you will not see a very sharp scarp in such cases where you are having thrust faults.

So scarp faces I am talking about that if you have suppose, you have an horizontally deposited sediments. And if you deform this for example, if you are having a very sharp fault, which will fault scarp, which will develop of course in a hard material. So, this will not be seen in the soft one, but if you are having this face, so, that what is been really trying to explain here is that we will not see this, you will not see this type of scarp here.

Rather you will be able to see the fault scarp which has developed something like that. So, you will have the folding, because the material is very soft and this will be less than the angle of repose that we have discussed in the one of the lecture, which where we talked that if you are having the slope angle of the that is the scarp slope is around 30 degree or so then it will become stabilized. Now, the ruptures are usually accompanied by flexures.

And associated secondary minor extensional cracks, so this we have already discussed in one of the example whichever showing was of course, the secondary deformation, but that on a larger scale the mechanics remains the same. So, you have the extensional cracks which will develop on the surface of the scarp. Sometimes such displacements with steeper scarp generates colluvial wedges. So, if you are having slightly the scarp is steeper in the sense then you will see deformation of colluvial wedges at the base.

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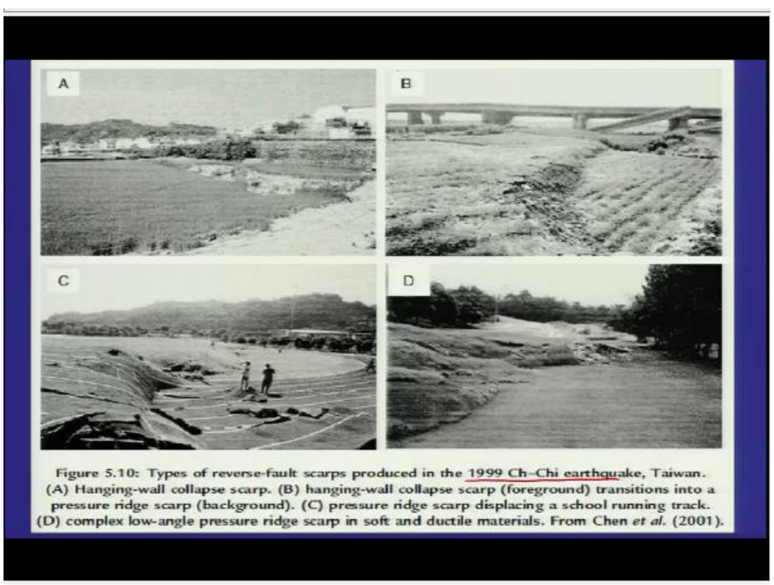

So, this was the example which we looked at in the beginning also that we have slightly sharp, steeper scarp and then we have the colluvial material which is sitting at the base of this scarp. Few more examples so, type of reverse faults scarps produced in 1999 Ch-Chi earthquake of

Taiwan, which shows one the hanging wall collapsed. So, if you see here the hanging wall is collapsed and the whitish portion which you see is because of the collapse material.

Second is B you have the hanging wall collapse scarp foreground and transition into the pressure ridges. So, you have the scarp initially came the material came on the top with a slightly sharper scarp. But then you have the scarp material which has faulten down and been dragged on the surface. Then you have the pressures ridge, typical pressures scarp displacing in a smooth running track.

And then we have in complex scrap, complex low angle pressure ridge scarp and soft and ductile material. So, these are a few examples, which shows that the pattern of deformation changes along the strike within the same environment and along the same fault in a single event.

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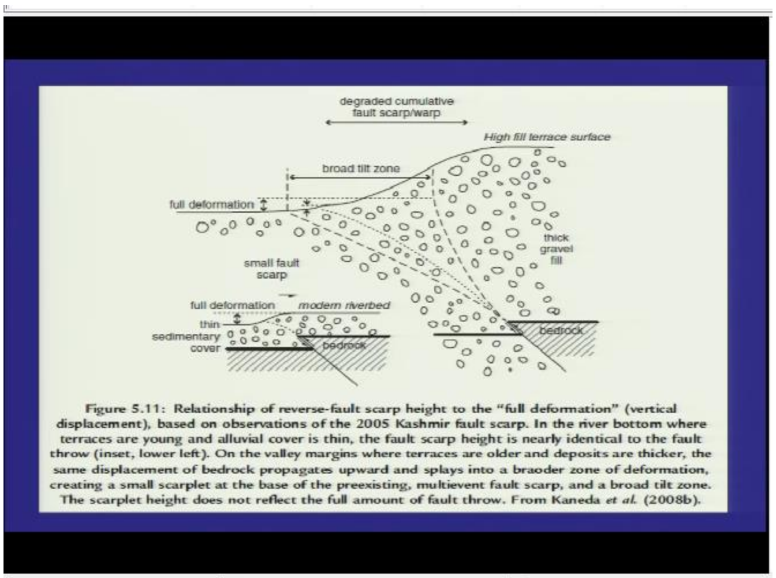

Figure 5.11: Relationship of reverse-fault scarp height to the "full deformation" (vertical displacement), based on observations of the 2005 Kashmir fault scarp. In the river bottom where terraces are young and alluvial cover is thin, the fault scarp height is nearly identical to the fault throw (inset, lower left). On the valley margins where terraces are older and deposits are thicker, the same displacement of bedrock propagates upward and splays into a braoder zone of deformation, creating a small scarplet at the base of the preexisting, multievent fault scarp, and a broad tilt zone. The scarplet height does not reflect the full amount of fault throw. From Kaneda *et al.* (2008b).

So, this is an example again of the, you have the material where your having the steeper scarp for faults were coming right up to the surface and you are hanging in planting out gentler scrap.

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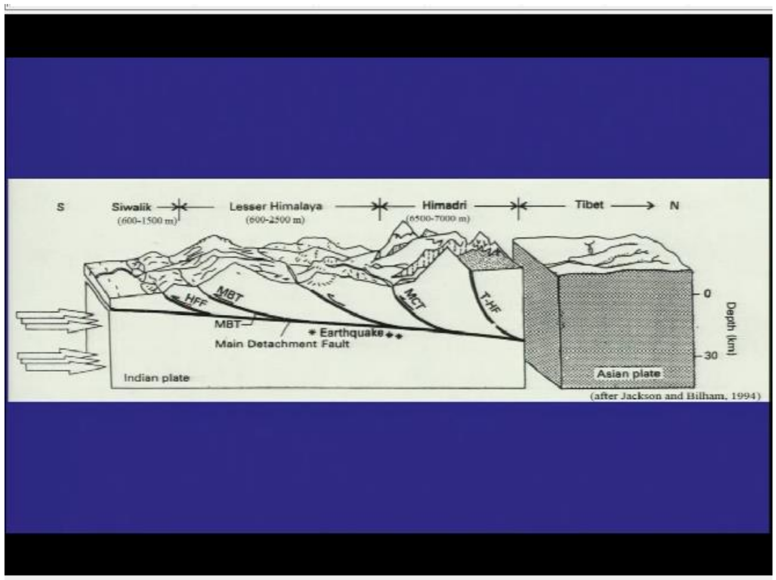

So, if you recall that what we discussed about the decollement or detachment in Himalayas, so, mostly the main fault systems we are having a thrust fault system, this is your MCT and then you are having in branching out fault which belongs to city and then you have MBT and HFT.

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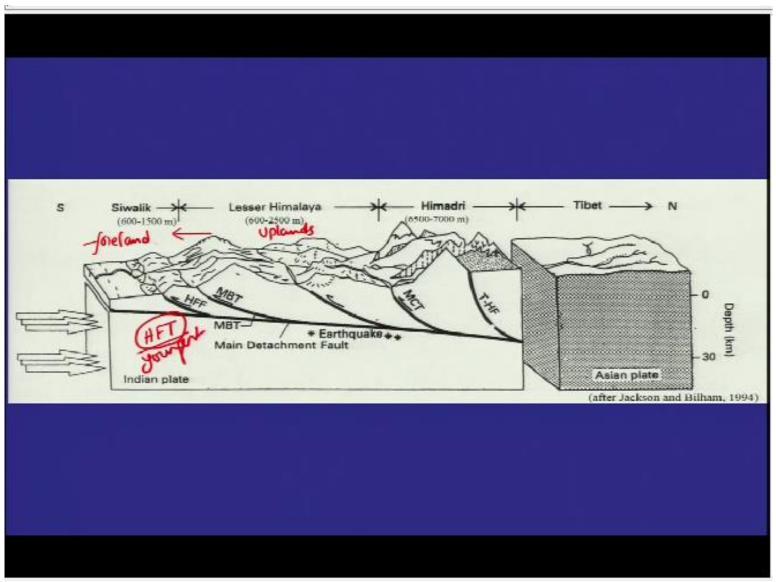

Now, with this what we can judge that if you recall that this is the previous slide here if you look at that what it was been suggested that in a typical steady state model, the initial faults which were developed at the time of the collision, and the overriding plate started deforming. So, we had like, this is an (()) (10:16) and then we are having MCT. So, when the MCT was developed, we never had this faults system in different parts.

So, this was the frontal fault. And then progressively, what we see is that deformation has moved towards the foreland. So, this is your foreland side and this is your upland. So towards the foreland, what we see is the young sequence in terms of the faulting events or when the fault started moving. So, the youngest one is this one. So, this is HFT or FFF because some of the some researchers they believe that the Himalayan county thrust which we usually have proved have been able to prove based on the paleoseismic studies.

But in some areas it shows strike motion, so, it is better to call fault and then we should not give the nomenclature of thrust to this. So, it depends on the groups to group that how they have classified. So, HFT is the youngest fault system in Himalayas.

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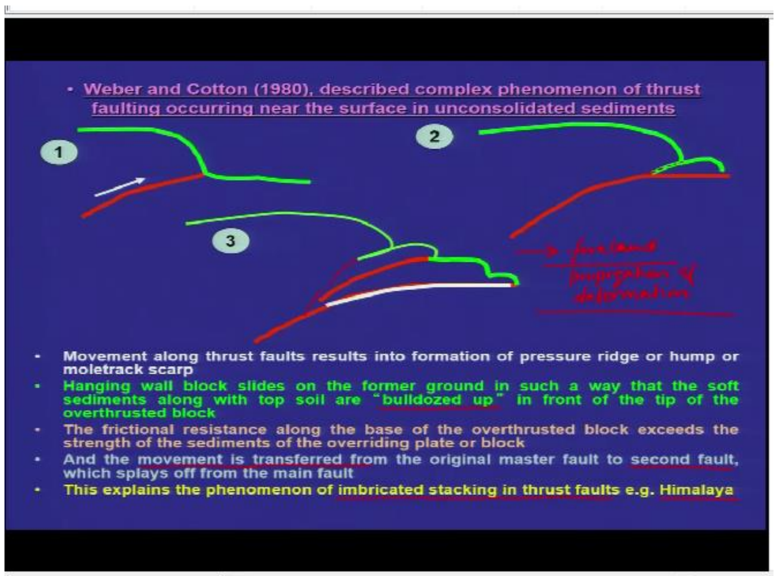

Now, this can be understood well by the model which was been proposed by Weber and Cott in 1980 describing complex phenomena of thrust faulting occurring near surface in mainly in unconsolidated sediments. So, what it says is that the movement along the thrust faults result into formation of pressure ridges or humps or more tracks scarp. So, first we have like movement along this fault, then you will be able to see a development of pressure ridge or a moletrack.

And then second the propagation of the tectonic movement will be seen in the foreland side. So, earlier this it was along this one and now it has been taken up by this fault here. So, the hanging wall blocks slides on the former ground. So, the contact between the ground here below and above. So, this part will mark the contact of the former ground. So, the hanging wall blocks slides on the former ground in such a way that this soft sediment along with the topsoil is bulldozed up okay.

So, this is an bulldozing effect, which is been experienced and seen in Himalayas. So in the front of the defaulted or the over thrusting block, we will have the bulldoze material. Now, the frictional resistance along the base of the over thrusted block, so along the base of the overt rusted block. So, this forms the base of the over thrusted block it exceeds the strength of the sediments of the overriding plate or the block.

Now, this is one of the reason why you will see that is there is a propagation of the default okay, so initially it was on This one here, then it was been transferred to this and then finally, it has been moving along this one. So, this keeps taking place and so, the movement is transferred. So, the tectonic movement is transferred from the original master fault to second fault which splays of from the main fault.

So, this is typical of the imbricated fault system. So, the moment will keep on transferring from the previous older fault to the newer fault and the deformation will keep progressing towards foreland. So, this is what this very common phenomena which we observe and the reason is because of the frictional resistance along the base of the over thrusted blocks. We we perform this small experiment to understand this phenomena.

And we were very well, we were able to pick up the deformation pattern which shows the fold and propagation of deformation. So, this explains the phenomena of imbricated stalking in thrust faults, that is the best example is your Himalaya.

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Now, if we look at these structures and the evolution of the reverse faults scarps.

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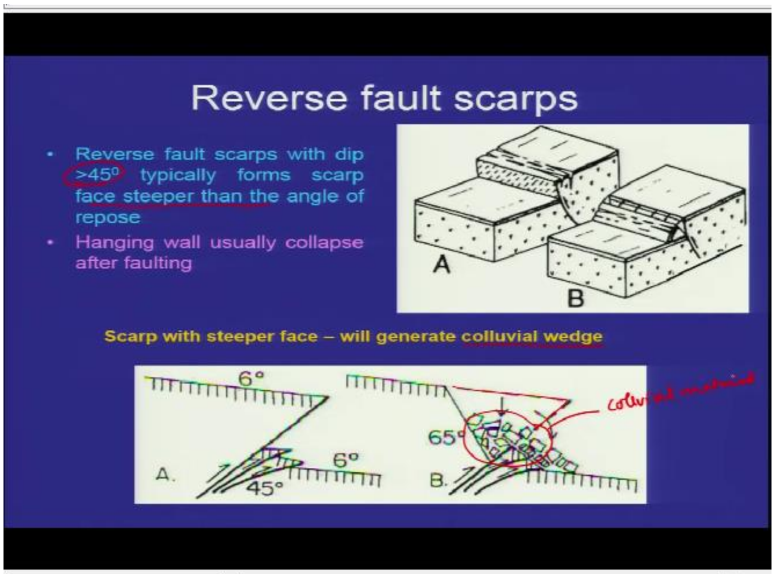

Then reverse faults scarps, we usually take that the dip is greater than 45 degrees and in case of the thrust faults we were having less than 45 degrees. So typically forms scarps with steeper faces. And the angle of repose will be comparatively higher. So, hanging wall usually collapse after faulting the scarp which has been formed in case of the reverse high angle greater than 45.

So, you will see the collapse of the faulting here, the scarp with this steeper face will generate colluvial wedges. So, in most of the case areas where we are having very steeper faults scarp face because of the high angle and that is you are having the reverse fault within 45 degrees, then you will bound to see the collapse of this scarp which has been shown here, this portion and you will have the later followed by the deposition of the colluvial material.

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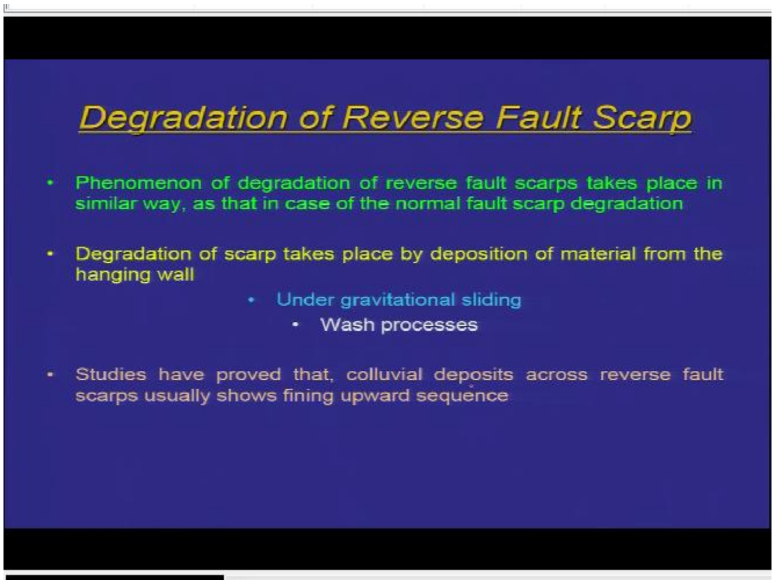

So, you can also try to go back and look at these slides or the lecture which we were talking about that what is the importance of the colluvial deposits, that can also help in identifying the ancient earthquakes or the old earthquake signatures in the trench. Now, degradation of reverse faults scrap, similar to what we have discussed in the normal faulting environment, the phenomena of degradation of reverse fault scarp takes place in a similar way as that in the case of the normal fault scarp degradation.

Because the ease and again will remain the same that you have the steeper faults scarps if you are having then the scarp will become stabilized when it reaches the angle of repose. So, you have like 30 degrees or so, then it will be stabilized and you will have the deposition of the colluvial wedge and the wash slope material and all that. So, very much similar to what we discussed during the normal faulting environment.

So, degradation of scarp takes place by deposition of material from hanging wall goes under the gravitational slide. So, you will have the larger blocks sliding down on the free faults scarp surface. So, then we will have the wash process okay. So, studies have proved that colluvial deposits across rivers faults scarps usually shows finding upward sequence. So, you can have the coarser material first and then cap by the finer deposits.

So, this part is more or less similar what we have discussed. So, the scarp studies and the what we study in the trenches, the colluvial material helps us in identifying the events to some extent.

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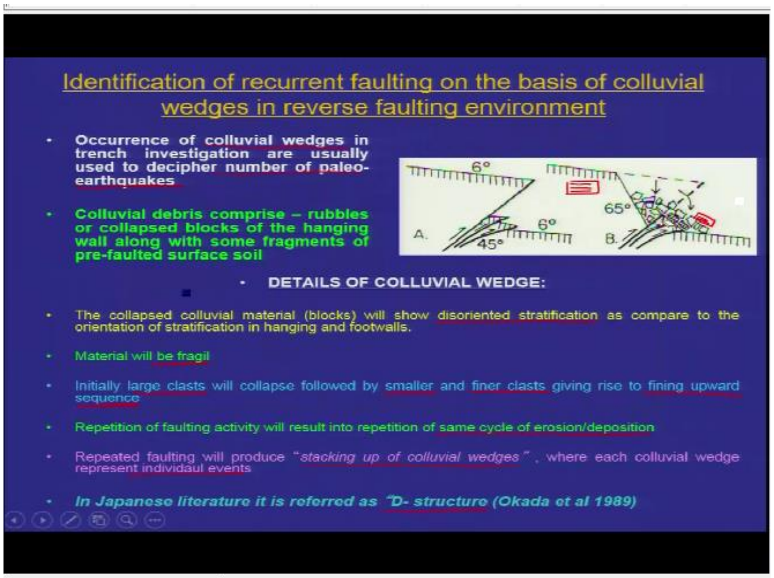

Now identification of recurrent faulting on the basis of colluvial wedges and reverse faulting environment. One example we have already looked at in the normal faulting environment. So this is the case in the reverse faulting environment. So what we see that the occurrence of the colluvial wedges in trench investigations are usually used to decipher number of paleo-earthquake okay. So colluvial wedges we use to decipher the number of paleo-earthquake. Colluvial debris comprises rubbles or collapse blocks of the hanging wall along with some fragments of pre faulted surface soil.

So usually this material will comprise what has been shown here that he will have the material paleo-earthquake from this scarp which is also bringing the material from below as well as you will find the some blocks from the pre faulted surface that is your soil. So, details of colluvial wedge if you have to consider then what we will look at as that collapse colluvial material blocks will show disoriented stratigraphy.

Now, this is important one, so, if you compare this for example, this block here then the sedimentary structures which you will find here will not be the same but of course it may so some sedimentary features which are absolutely not in the same pattern or the orientation okay pattern may remain for example you are having here that slightly horizontal surface here, but here you will find that they are seen something like that okay.

So, disorientation and stratigraphy will be seen on the fault blocks on the base of the scarp okay material will be fragile, because it has been eroded from the intent blocks. So, this portion will be fragile as compared to what we will see here and on this side of the fault on either side of the fault and initially largest class will collapse followed by smaller and final class giving rise to finding upward sequence for what we were talking in the previous one that we will usually see a finding upward sequence.

Finding upward sequence usually what we talk is that we have the coarser deposits and then kept by the finite one. So, this sequence will say we will say then fine upward sequence. So, you even have the coarser sediments in size and you will have finer sediments kept by it. So, we see usually a finding a upward sequence. So, there are a few very important part that we have disoriented stratigraphy, which will be seen in the colluvial material.

Then the material will be comparatively fragile, and we will have finding upward sequence. So, we will have the largest clasts, then smaller and finer clasts giving rise to finding upward sequence. So, repetition of faulting activity will result into repetition of same cycle of erosion. So, that means that we will keep having if we have the similar deformation, which will take place in the next event, then again we will have deformation of the colluvial wedge.

So, this cycle will be repeated, but in some cases where we are having very homogeneous material, this becomes a little bit difficult. So, repeated faulting will produce stacking of colluvial wedges. So, you will have stacking of colluvial wedges, where each colluvial wedge will represent the respective or individual faulting. In Japanese literature this has been referred as D structure.

So, basically what we see is and typically D structure here. So, this has been termed as D structure which helps us in deciphering the individual events.

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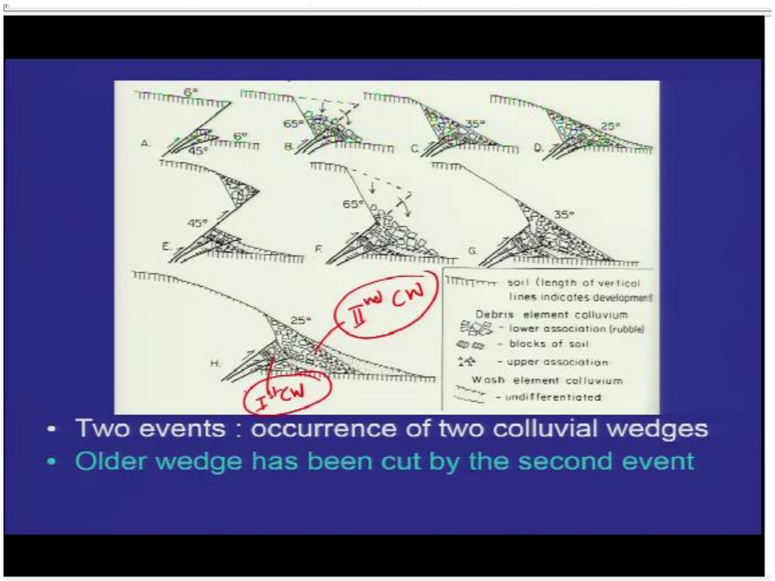

So, this shows the sequence of the events. So, let us view one by one. So, basically this whole this is the final one which is been encountered in the trench and this shows that the along this fault 2 events have occurred and occurrence of 2 colluvial wedges older wedge has been cut by the second event. So, let us see that okay. So, first earthquake resulted into the deformation of the scarp and the movement was been observed along the branching out faults also, which displaced the soil here as well as it has displaced the soil here also.

So the maximum displacement, so this is the major fault along which that the displacement took place and then followed by the erosion. So you will have the deposition of the colluvial wedge here and after this and finally, what you will have is this the slope and the final material coming and depositing and stimulation of the free face of this scarp. So, you will have the capping of that.

And then finally, you will see that there is at deposition of the layer here, which has been shown. So, next soil layer is been shown here okay. So, until they what we had like, so, if you compare this, then we had the earthquake took place so, after the deposition deformation of this soil and then kept by the colluvial material and then the next phase of deposition and deformation of soil gap is whole sequence.

That is the sequence of faulting as well as the colluvial material, another earthquake along the same fault and also the second subsidiary branching out faults, what we see is that definitely this will displace the whole sequence here. So, it will displace this portion as well as it will displace this and that what is been shown here. So, you have again the displacement of the on the same fault resulting into the displacement of the hanging wall here.

And the colluvial material which was sitting here also got displaced as well as the soil which was formed final capping was also displaced here. And then again there will been face of the deposition of the colluvial wedge because of the erosion of the collapsing of the steeps scarp here. So, this is the second colluvial material which are the second colluvial which was formed and compared to what we were looking at the first one.

So, again the same process takes place and we have the deformation or the deposition of the soil here and they also have deposition of the material and the formation of the soil and the finally, what we see is this one. So, you have the sequence coarser finer and then capping of the soil here. So, during the next another event, if you and we say that there will be another event here, then you will have the displacement of this whole sequence.

So, again another. So you have the first colluvial wedge here and this is your second colluvial wedge. So based on this also, you will be able to judge that at least there were 2 events along this fault.

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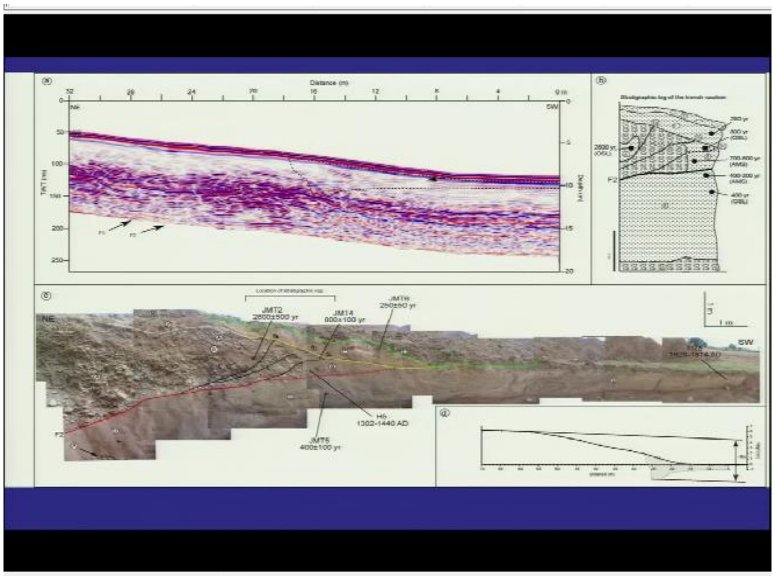

Now, this is the trench which we opened across one of the young fault in Himalayas, which shows the comparison between the GPR profile which we took and the exposed sequence in the trench. So, if you have the deformation along very low angle fault, then the pattern of deformation will be different. I will stop here. We will continue in the next lecture.