Earthquake Geology:A Tool For Seismic Hazard Assessment
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Lecture-36
Compressional Tectonic Environments And Related Landforms (Part II)

Welcome back. So, in the previous lecture we discussed mainly on the with large scale structures also as well as what we will see if we are having flat ramp structures or the flat ramp in the compressional tectonic environment.

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And what type of deformation mainly we will see on the surface, that is we were talking about the fault unfolding or fault propagation folding. Now, if you are have looking at the compressional tectonic environment and folding in particular, then you will come across the secondary fault faulting also. So what we see in terms of the secondary faulting and also in this lecture, we will try to look at that if you have the change in the depth of the fault in the compressional tectonic environment.

Then what type of deformation will be seen or the manifestation of that deformation on the surface. So, secondary faulting associated with thrust faulting events, mainly secondary faulting, and other features are seen commonly associated with bending moment fault, flexural-slip fault what we see here, so, you have the bending moment fault and on the surface you see the flexures which are developed.

And they will also show some displacement. So, this is on the crust of the folded material. So, we see an extensional faults here. And bending moment faults are usually related to the reverse faulting where the bending along the fault planes result into the formation of fault on the surface. So there is a typical of that one another example from these are the 2 examples which I am showing from 2001 Kutch earthquake.

And of course, this was not related to the course seismic rupture, but of course, to understand that what will happen in actual co-seismic deformation, then we can take this 2 example to understand the deformation. Now, example best which came up was from the 1918 earthquake of El Asnam and 1978 Tabas-e-Goldshan earthquake from Iran. So, those are the 2 earthquakes from Iran and Algeria, which has given us an idea that how deformation changes if one the there is a change in the strike.

Then second one is the depth of the fault. See, if you have the change in the strike or depth, then you will have a different pattern of deformation, which is seen on the surface. Now, this faults are usually short and projected to shallow depth. So, this basically we are talking about the secondary faults. So, they will not penetrate deep into the crust, but, if we are not able to expose the main fault in trenches then to some extent we can also use the secondary faults to understand the pattern of deformation or we can use this to reconstruct the history of El earthquakes.

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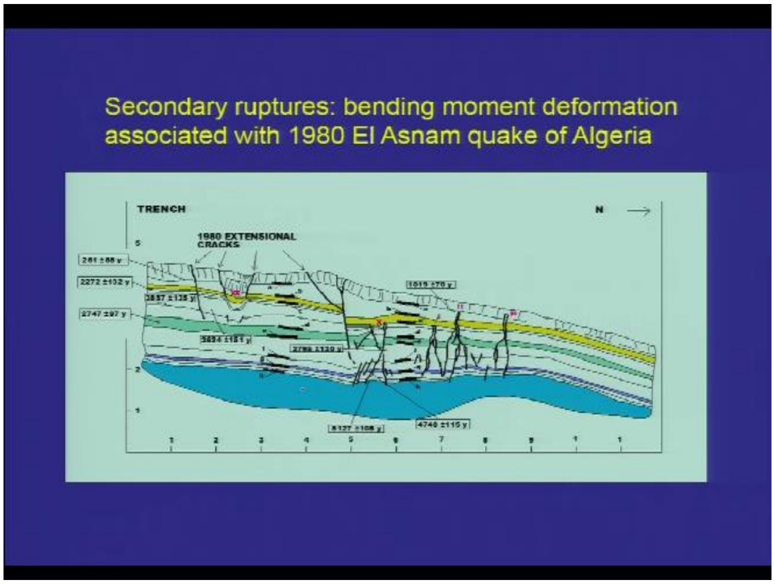

So, this is an example of the trench which was escalated after the 1980 El Asnam earthquake from Algeria, which shows the topography which was developed on the surface because of the faulting or the deformation, but the default did not reach right up to the surface. So, what has been taken into consideration the secondary faults which were developed on along the fault folding and this helped in identifying the different earthquakes in that region.

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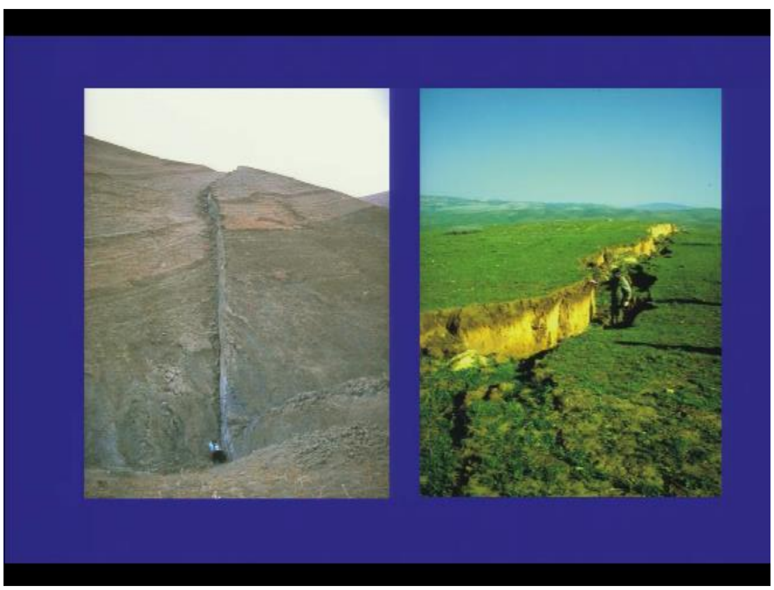

So, you can also have the normal faults which will develop on the surface because of the folding.

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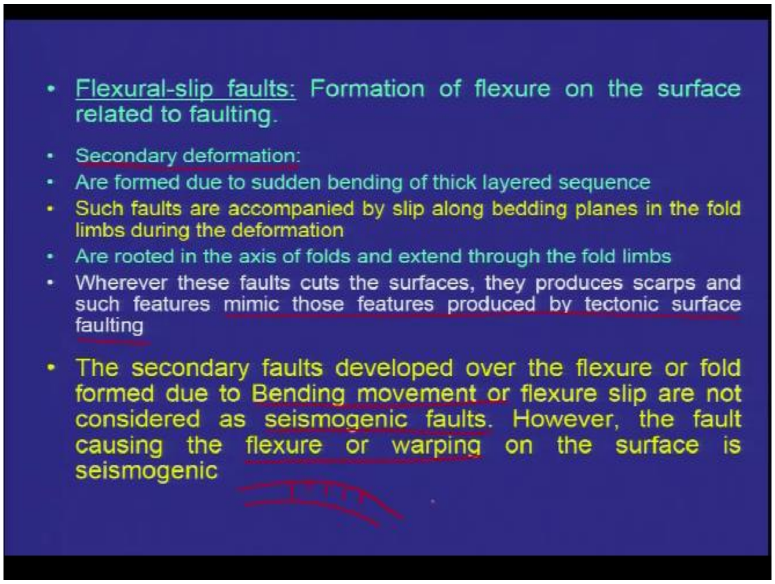

So, flexural-slip-faults formation of flexures on the surface related to faulting. So, this basically we consider this as an secondary deformation and they are formed due to sudden bending of thick layered sequence. Such faults are accompanied by slip along bending planes in fault limbs during the deformation and are rooted in the axis of the fault and extend through the fall limbs, but they will not be deep seated okay.

Whereas this fault cuts the surface, they produce a scarps as we have we were looking in the previous slide. So, they will produce the scrap and such features mimic those features produced by tectonic surface faulting. So, they need to be very careful in understanding whether they are secondary related to the secondary deformation or they are related to the co-seismic. So, the secondary falls developed over the flexure or fold formed the bending moment of flexure slip are not considered as seismogenic faults, okay.

However, the fault causing the flexure or warping on the surface is seismogenic. So, what it says is that you have the folding which is taking place it is or warping or fluctuating is your co-seismic or seismogenic, but the displacement which you see on this flexures are because of the bending moment or the flexure slip and they are not seismogenic, but the folding which has occurred is seismogenic as we were looking in the previous slide, from the trench log of all El Asnam earthquake.

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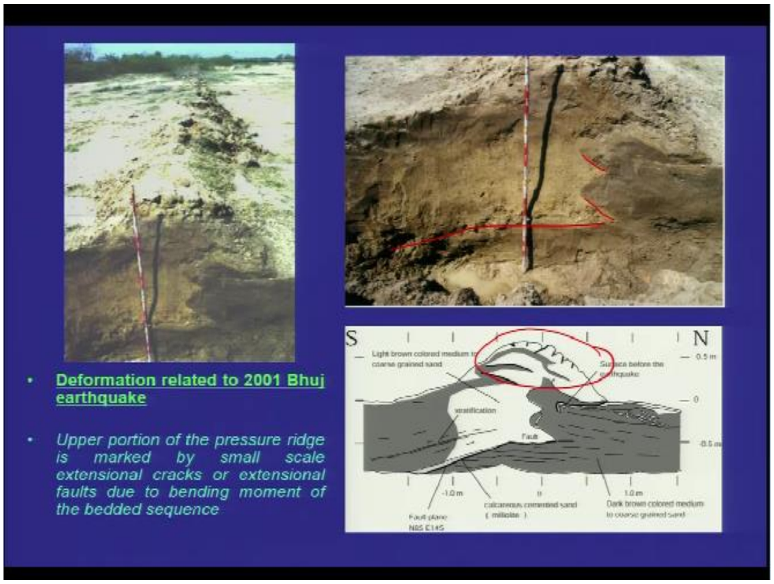

So, again coming back to the portion from catch region, so, what we saw is that we have the slip which has occurred along this to have the ramp here and then you have flat here. So, you see the folding on the top and on the surface we were able to see some flexures of the displacement which was been observed and you can see one is over here and along with that, he will also have the bad thrusting okay.

So, we have the secondary faults which have developed here, but the main fault is sitting somewhere over here like this. So, what we were able to fix up based on this, this sketch here, which has been shown. So, you have the ramp here and the flat and then you have the secondary antithetic faults and also some displacement was been seen along the extensional part which has occurred on the crest of the fold.

So, deformation related to 2001 Bhuj earthquake again this was the secondary one. So, the upper portion of the pressure ridge. So, what was developed here a typical pressure ridge, which is been seen in a couple of co-seismic ruptures. So, the pressure ridge and on the surface we saw the extensional cracks. So, this is what you see here the extensional cracks were developed and this was due to the bending moment of the bedded sequence.

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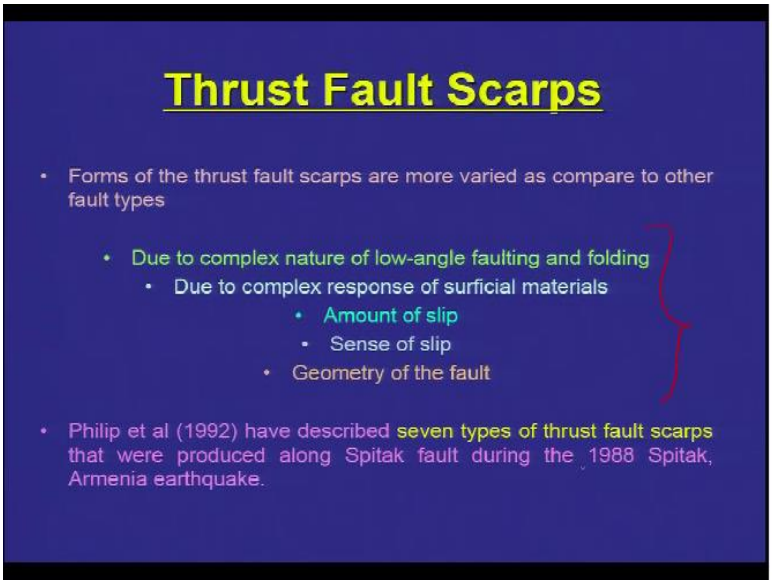

Now, thrust faults scarps form of the trust faults scarps are more varied as compared to other fault types. And this will be due to the complex nature of low angle faulting and folding one, then due to the complex response of the surface material amount of slip on the fault, sense of slip, geometry of the fault. So, based on this you will see in nature that you would not have different type of deformation or the surface manifestation degrading thrust faulting environment okay.

So in 1992, Philip and his team have described 7 type of thrust faults scraps that were produced along the Spitak fault during 1988 in Armenia and this is one of the best example which explains that because of this parameters, okay. The nature of low angle faulting and folding response of the surface material, amount of slip, sense of slip and geometry of default. So, the depth changes, amount of slip changes.

And depending on what indeed in which area the faulting is occurring, then that will result into a different type of fault scarps okay. So, 7 types of fault scarps have been described from a single event.

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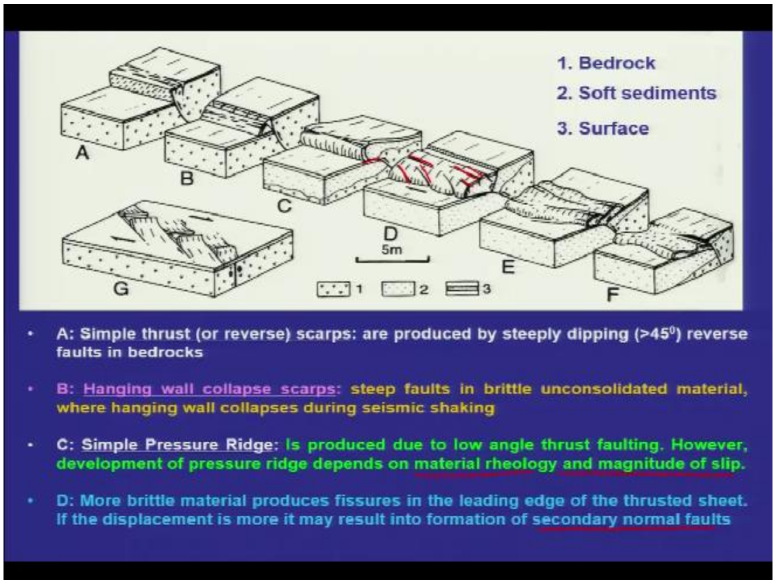

So, let us see quickly what we are able to learn from this okay. So, this all 7 A B C D up to G away from the same faulting event. And you can easily make out that you have the different due to different material and also the geometry of the fault you see different type of deformation on the surface even you will come across the defaulting, like what we see in the strikes defaulting environment.

So, this marks all the default. So, you have one going like this and other is on the surface here, there is an bending here is taking place as well as it shows the back thrust developed and here also you have the fault going here and then back thrust has developed back thrust we are usually talking when they the depth of the fault is opposite or is not in the same direction where the main fault depth is in this direction.

And the third the depth of the back thrust is in exactly the opposite direction. So, this is again and very typical of all bent folding and very high angle fault here and then depending on the material, you will see whether the extensional cracks will formed or not and if you are having some objects slip because of the strain in the strike then you will come across the strikes defaulting moment.

So, let us see one by one what it says okay. So, one is here we considering the material and the bedrock. So, what it is been shown here is your bedrock here. So, this deformation is has occurred in the bedrock, then you have the soft sediment which has been seen here. So, you have the bedrock here, here is also it is shown bedrock, but what we see is the bedrock and then you have the soft sediment.

So, what typically it shows is that in the bedrock, the fault has remained almost with high inclination or the depth and then as soon as it goes into the soft deposit, it bends and similarly, it has been shown here. So, it has a very sharp high inclination and it bends here, okay. And third is your surface okay. So, you have the surface here. So, as soon as it comes to the surface and it becomes almost flat or the inclination is reduced the depth reduces okay.

So, this should be kept in mind when we are opening the trench and trying to identify the contact. So, A is the simple thrust or reverse that okay. These are produced by steep dipping greater than 45 degrees reverse faults in bedrock. So, in bedrock, you will come across a very sharp scarp whereas, in the soft sediments you are not looking at those okay. So, B is the hanging wall collapse scarp.

So, you have the displacement coming up and then we are having the material which could collapse So, scarp a material is collapsing So, steep faults in brittle, unconsolidated material, where hanging wall collapse during seismic shaking, because you will have the displacement and along with that you have strong ground shaking that will result into the collapsing of the material here.

And of course, along with that, this collapse material will also show some extensional cracks which had developed here or the extension faults okay. C is a simple pressure edge which is produced due to low angle thrust faulting. So, you have a very low angle thrust faulting, which is coming here. However development of pressure which depends on the material rheology and the magnitude of the slip also.

Then D what you have is the brittle material produce fissures in the leading edge okay so, you have the development of the fissures on the leading edge of the thrusted sheet. If the displacement is more it may result into formation of secondary normal faults okay. So, these are all secondary normal faults which are been seen.

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Now looking to the E part okay. So, this is an example of what we are talking about you have a very sharp and some portion you will see the collapse material. So, this again will depend on the material okay. So, you have the fault plane here and then you have some collapsed material here. So, reverse faults scarp produced this was in 1971 San Fernando earthquake in California. So, A what you see is the hanging over hanging scarp with the fault plane of almost 65 degrees.

And this is what has been shown the fault plane, the fault scarp and then B is your collapsed material. So, this is your all what you see is the collapse material.

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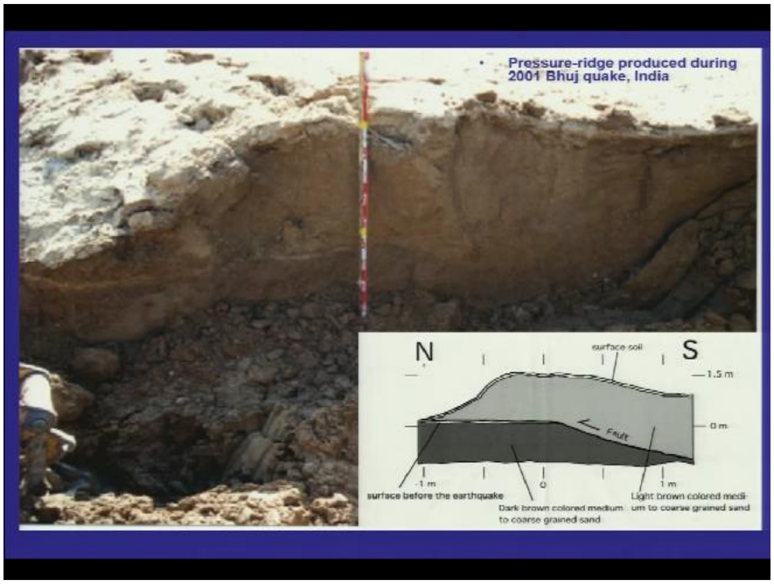

Again coming to the pressure edge which we discussed in the previous lecture. So, you have the cracks which have been seen on the displacement on the surface okay and this is because of the bending. So, again the depth of the fault has played an important role.

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Now, coming to this part this is an trench which you open so, you have you can see the scarf here this is up and this is down and very beautiful scalp can be seen here and this is an typical thrust faulting environment from Himalaya, we opened up the trench here. So, this is the backhaul which has been shown here and this was the trench site. So, what we saw is very interesting that is changing the depth has shown us the different.

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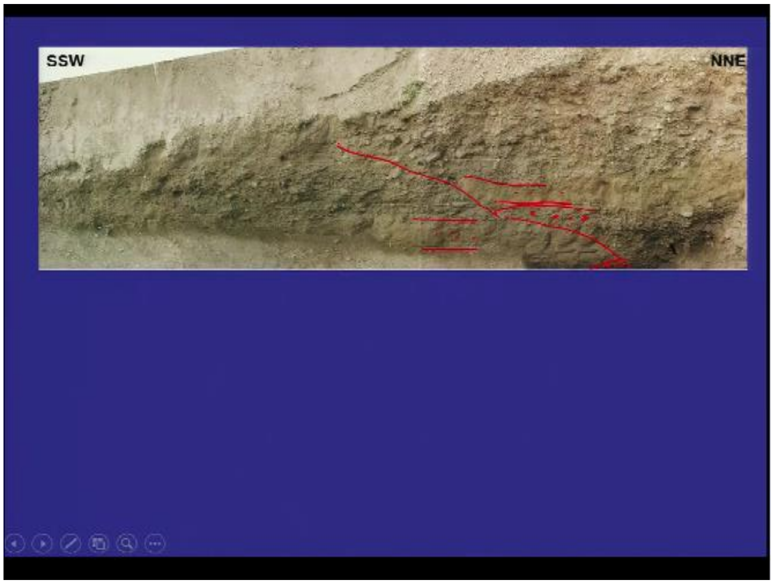

So, different deformation pattern okay on the same fault and the trench revert if we take was not more than 3.5 to 4 meters. So, this is the like for example, the fault trench like this and trying very straight and the trench was open across this one. So, this distance was around 3.5 meters. So, what we saw let me explain you here in this photograph. So, the trench wall which we saw clearly shows that there is an displacement of this layer.

So, you can easily pick up this layer here, this is a sandy unit and this is an sandy unit. So, it goes somewhere here like this. So, you have a displacement of this unit and you have gravel over here. So, this gravel sits somewhere over here, you have and goes right up to this here.

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So, we identified different (()) (18:36) like B has been seen here, this is B here, this one is B and this is B here, and then we have C which is over here. This one is C and this one is the D which is capping unit of C and then we have E here. So, the fault trench A along this contact here, this we can easily make out it goes like this over here and then most further up. So, there is unclear displacement, which we were able to observe on the east facing wall.

This is the close up of this part here. So, fault is angle here and then it gets into the low and then becomes high angle here. So, again a very typical of ramp flat and then getting into the ramp. So, just remove those lines so, that you can easily make on that were exactly the fall costs. So, this is the contact here, which has been shown.

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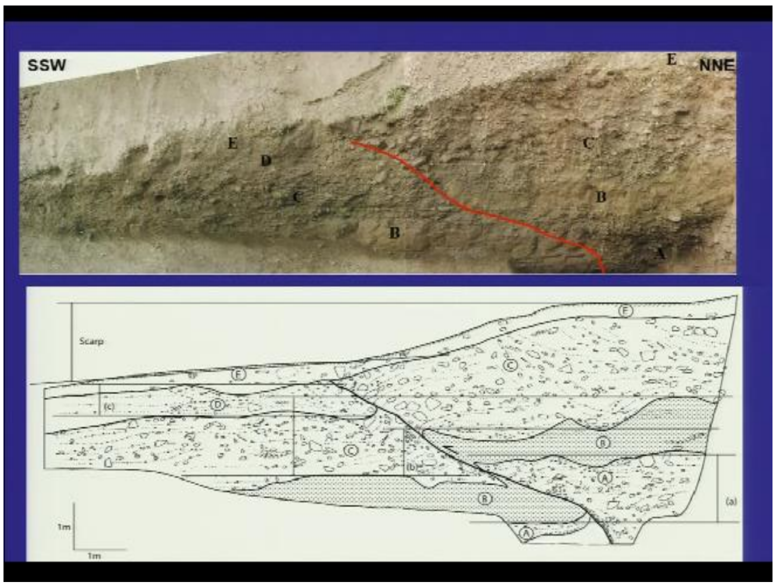

Now, what we observed on the other wall before going to that there is the sketch of this one so, you can easily compare now the different units. So, these are the boundaries which have been shown here, the erosional contact between the gravel unit and the sand unit here and then the fall contact which runs here which goes right up to this one here and then final the capping of the recent event which took place along the C okay.

It is been shown here that is E, so E is the surface present surface we have and then it is capping C here. So different units which we have marked here, and the same units have been shown in the trench lock. So, this is typically of what we were talking about the fault propagation folding okay. So you have the folding of is taking place along the tip of the fault, okay, typical of that, which we were able to pick up from the pattern of gravel layers, which got folded. So, even if we can see the folding here.

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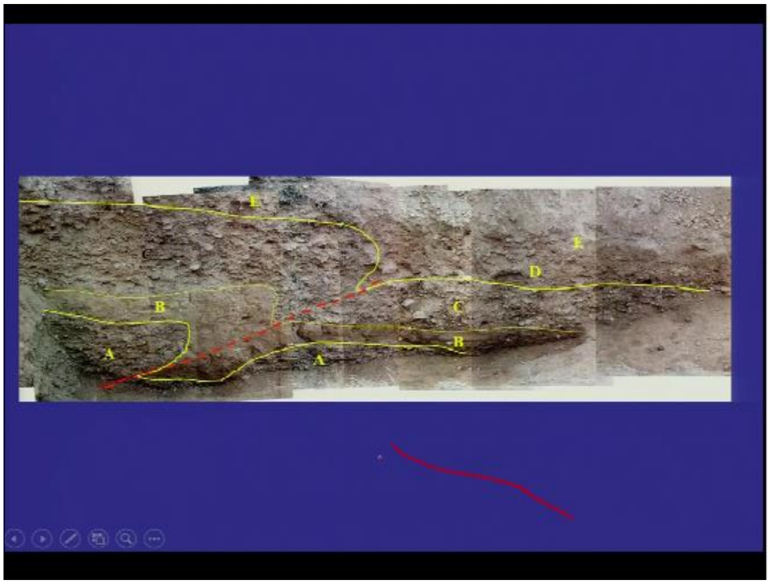

Now, as I told that on the other wall that is the west facing wall, what we came across was an very interesting feature. So, we were not able to see the displacement as it was been observed on the east facing wall, but we saw the folding okay. So, you can see easy the folding this layer is here. So, if I put the units here, this is your A, so which is running like this and then they are the contact has been seen here.

So, we have them B which goes like this goes like that here and then this is the contact between the C and B. So you have C unit here and then you have the D and E. So if I put the lines here that will make you more easier to identify okay. So this is what we see the folding okay and this is because of the very low angle fault which goes along this one. So, this is your other fault, but on the other wall, what we were able to see was in clear cut displacement because we were having the comparatively high angle fault here.

So, within the distance of even 3 meters, we were able to pick up the change in the deformation pattern, okay. So, this is what we need to keep with us as an part of the training that if depth changes, that is the geometry of the fault, amount of slip and the material, then even have the change in the pattern of deformation. So, with this I will stop here, and we will continue in the next lecture.