Earthquake Geology: A Tool for Seismic Hazard Assessment
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Lecture - 31
Extensional Tectonic Environments & Related landforms (Part – I)

Welcome back. So in previous lecture, we discussed about the field techniques and as I told in few of my lectures that we will keep explaining and discussing about the field observations and all that, when we are talking about the individual environment, that is your individual tectonic environment, whether it is extensional tectonic environment, compressional or strike step.

Apart from that, as I mentioned in one of the lectures that we are doing our best to give you a few lectures on the technique part, that is mainly the usage of instruments in the field for mapping or carrying out the geophysical surveys and all that. So we are trying our best that if possible, we can do the videography of those labs and try to give it to you. So that it is explained in the better way. So let us move ahead with the new topic today on extensional tectonic environment.

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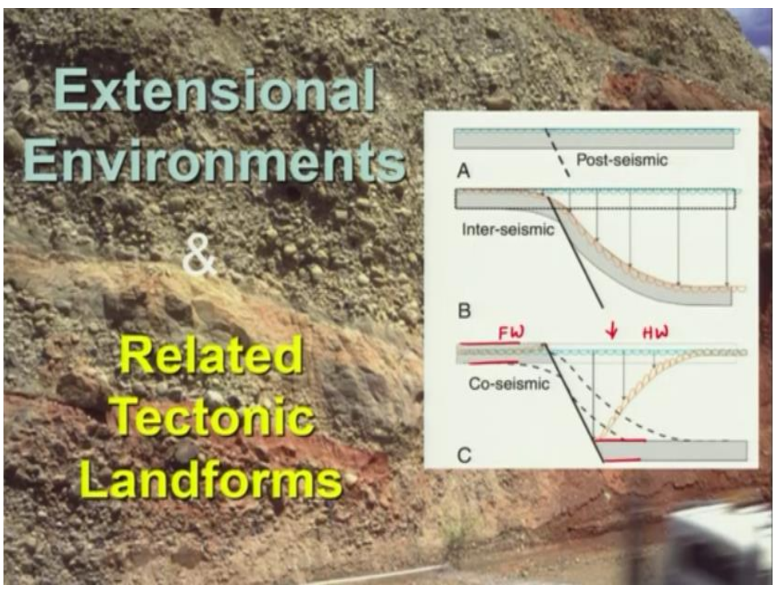

So the picture which you see here is a very simple one, which shows what you have like the post seismic surface and during the interseismic, probably it will keep pending and finally what you see is that it will rupture or displaced and that is your core seismic. So if you recall this part, which we discussed in the beginning that is the elastic rebound see and this is bending here, which has been shown. So this was the surface which has bent here and finally it got displaced.

So normal faulting what we see is that one block will move down with respect to the another one. So this is your of footwall and this will be your hanging wall. So this layer has moved down along the fault here. So this happens during the core seismic. So the interseismic, the deformation will keep going on and you may come across deflexure in the deposits or the sediments of the rock strata and then finally it breaks.

So let us see and that what we have in the extensional environment and related tectonic landforms.

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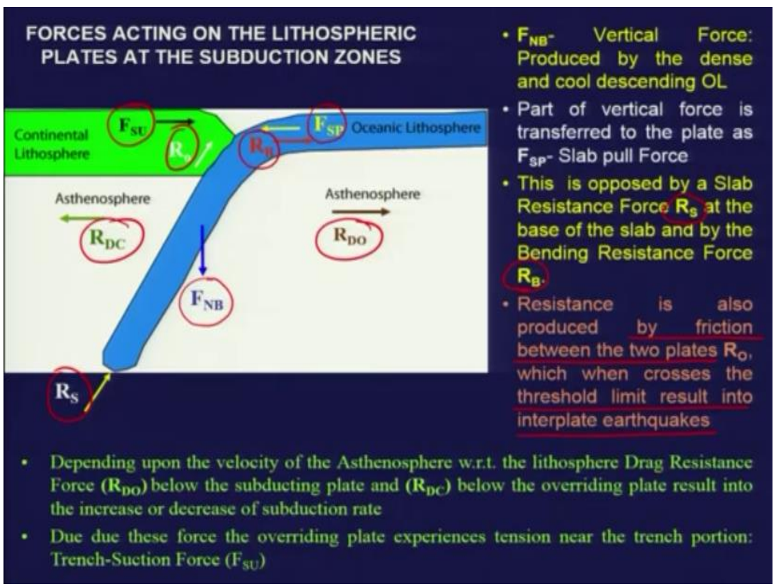

So before we get into the main topic, these are two important part, which was left out. So I would like to cover this. That is related to your subduction zones and what we look at the plate boundaries, because extensional environment, we will be also able to see because of this subduction between the two plates. So this one is like two aspects, which remained. So before getting into the detail of extension tectonic environment, let us discuss about the different type of forces, which are acting on the lithosphere along the subduction zones.

So we have already discussed about the two different types of subduction zones, that is Mariana subduction zone and the Chilean subduction zone and what we see here is that we have the configuration irrespective of what type of subduction zone, we have, we will just generally discuss about what are the forces acting in the subduction zone. So we have the continental lithosphere, which is lighter as compared to the oceanic one and the oceanic one will subduct below and both of them are floating over the asthenosphere.

So we have number of forces which have been given here, you have vertical forces and then few of them are the slab related forces and then you have the resistive forces, which is acting when the slab has been pushed down and so on. So let us see what are these forces, which have been classified here and how they are affecting the overall deformation. So FNB is your the vertical force produced by the dense and cooling descending oceanic lithosphere.

Then you have part of the vertical forces for the vertical force is transferred to the slab and that has been termed as slab pull force and that is over here. So this is because of the drag which is taking place along the subducting plate and this force is slab force, slab pull force will be effective in this region and then this force is usually seen that has been opposed or by the resistive, slab resistive force RS at the base of the slab and by bending the resistance force RB.

So this will be affected or opposed by the slab resisting force at the base of the subducting plate and by the bending resistance force at this portion that is your RB. So FSP that is your slab pull force will be affected by this two forces, that is your RB and RS. So slab resisting force and bending resistance force, which has been seen here or experienced here. Then the resistance is also produced by the friction between 2 slabs or the 2 plates and that has been termed as RO.

So resistance will be produced here between and so you can you can compare this that the portion that remains in contact between the 2 plates and that of course is marked as the plate boundary, but in case of the Chilean trench and the Mariana trench, this will vary. So when this crosses the threshold limit, this will result into the interpolate earthquake. So depending upon the velocity of the asthenosphere with respect to the lithosphere track resistance force that is your drag resistant forces RDO.

RDO is here this one again. Below the subducting plate and RDC is below your overriding plate. It results into increase or decrease in subduction rate. So these 2 will definitely affect the velocity of the plates. Due to these forces, the overriding plate experiences tension near the trench portion and that is termed as trench suction force okay. So you will see that over here that is the trench suction force and particularly in this region.

So the idea behind this is that the forces which are acting or either they are opposing the subducting plate and the overriding plate, they will result into the different pattern of deformation at different point of time.

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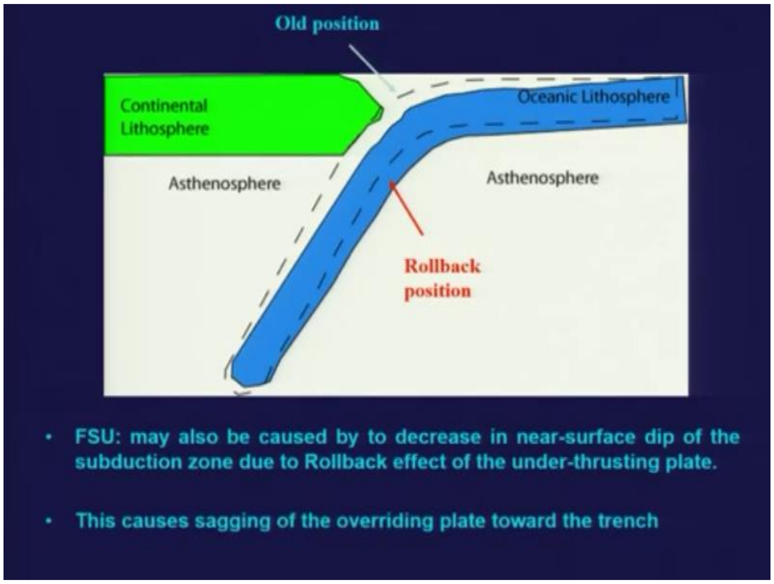

Now coming to the next one, we have gained another example of this, which suggest that you have the similar figure we are considering. So we have another that is control back position. So if this is the plate which was subducting along this line here, this is the old position of the plate, let us roll back because it has sunk in the asthenosphere okay. So FSU may also caused by the decrease in near surface depth of the subduction zone due to roll back effect and under thrusting plate.

So this will happen over here and this causes sagging of the overriding plate towards the trench. Now with this understanding, let us look at into the detail of the extension tectonic environment.

So I would like that you please keep in mind know the discussion which we had here and basically what we are talking about the trench suction force. Now trench suction force may be effective when there is a rollback in this region.

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So coming to the area of extensional tectonic environment, in general if we take then we briefly, very briefly we discussed about one example and that was here mid-oceanic ridge or mid-Atlantic ridge and the surface expression of the extensional tectonic environment was that we discussed was from African plate and the mid-oceanic ridge coming right up to the surface, which is exposed. Usually the mid-oceanic ridges are exposed in ocean.

They are not seen on the surface, but some portion of that has been seen in Iceland. So sea floor spreading centers are usually we term that as constructive plate boundaries, where we have the two plates which are moving away from one another and the areas they are considered to be the area of extension and then another region where you will find the extension is the hotspots, then back up basins behind the island arcs, then you have behind continental-continental collision.

So you will see extension. So here for this particular, you can refer the collision zone that is Himalaya and the extension is taking place behind the Himalaya that is north of Himalaya in Tibetan side, we see the extension. Then we have the rift system and this was the example which we saw from the African plate, where you are having East African extension which is going on and we also saw one small movie or the clippings of the news where the recent huge crack or the wide crack was evident, because of the extension, which is going on in that region.

Then you have for the another area of extension is near the subduction zone and the previous two slides if you consider, then that will also contribute towards the extension of the plate, which is roll back plate as well as the overriding plate, because of the overall deformation is of course the compressional, but some portion of the plate will experience extension. So near the subjection because of the various forces which are acting on the plate, it will result into the extension of tectonic environment.

So these are few which have been listed, broadly most we will see the extension in such environments, sea floor spreading, hotspot, back arc, behind continental-continental, collision zone along rift system and near subduction zone.

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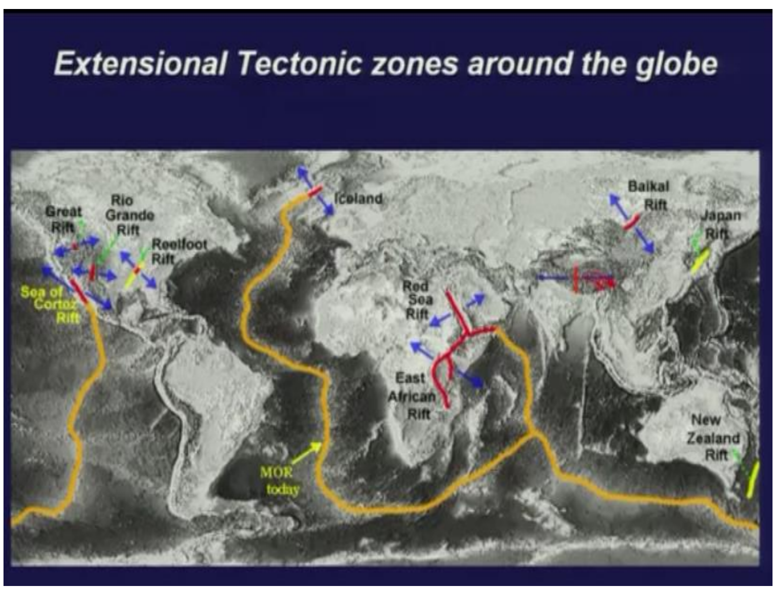

Now extensional tectonic environment around the globe if you see the distribution, then we have which has been shown here by blue arrows. So we have this what I was talking about that this comes, that is the here mid-oceanic ridge, which has been one of the longest one and it definitely is the area where we termed this as a constructive plate boundary and this is exposed on the surface in Iceland okay and then we have the East African Rift system, which is on the continent.

So to how the portion of this plate is moving away from each other and resulting in the deformation of cracks. So the time will come, this whole ocean will be separate island and then we have this portion, of course is again an extension here, this is extension and this portion we discussed in the beginning and plate tectonics that this is indicative of the triple junction. We have extension which is going on.

This is the collision zone here and that side of the collision zone we have the extension, which is going on and if you remember I was showing one slide with the GPS vectors, where this portion is extruding in this direction and that is resulting into the extension, because this plate is moving like this and this is moving in other direction. Then we have a very prominent one, Baikal Rift and then rift in Japan and then you have rift in New Zealand and so on.

And you have great rift Rio Grande Rift here and so on okay. So we have the distribution of the extensional tectonic zones around the world.

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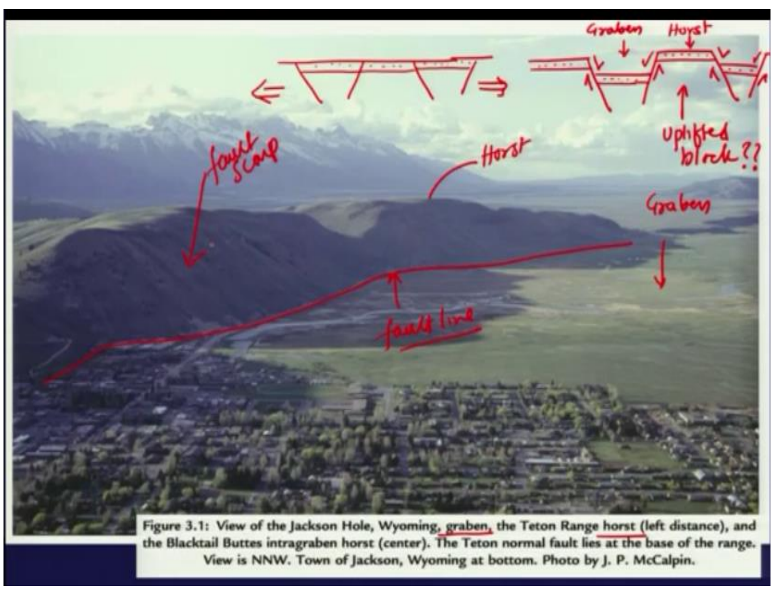

So as I have been telling that usually the fault scarps or the extensional tectonic environment, you will see that very similar boundary or the topography, as you can see in the case of the reverse or the thrust faulting environment and usually along with the normal faulting or in the extensional tectonic environment. Then usually you will see a formation of a basin. So what we call this as a graben. So this is a graben. So usually what we say that you have the faults here.

So multiple faults, you are having here and then if they are moving normally, then you see that somewhere like what is going down here okay. So you have this block has moved down; this has moved down; this has moved down and this has moved down. So you have the blocks which has gone down. So if you consider this line here, so what we see here is that we have this have been termed the area which has gone down, we term this as graben.

And the area which has remained up with respect to the down faulted blocks, we term this as in horst. So this is basically because of the extension. So along with the fault scarps, what you will see is this is all graben. So depression, which will be seen and that so you have the graben and the horst. So you can see this part as what has been termed as lift distance as your horst and this is your graben. Usually you will find a horst and grabens are formed side by side.

Now some geologists, they believe that this block that is a horst block is an uplifted block, but this one question mark here, because usually the area has just been pulled apart and this has moved down, but this has remained as it is. So this has never been moved with respect to this one. So but since this has moved down, it appears that this block has moved up like this. Anyway then, let us move ahead so. We have like this is fault scrap here.

So this one is your fault scarp and fault trace run somewhere like this at the base here. So this is your fault line.

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Another picture of the same area, we have the horst here and then you have the graben, which is sitting over here.

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Example from the East African Rift Valley, this portion that we were showing the movie from the news that explained that there is an extensional crack, which has developed. So this portion is one of the active rift valley where two blocks of the plates are moving away from each other and this is located over here. So this is your African plate and the rift valley is located exactly over here. That is your East African Rift Valley and this is the aerial photograph of that.

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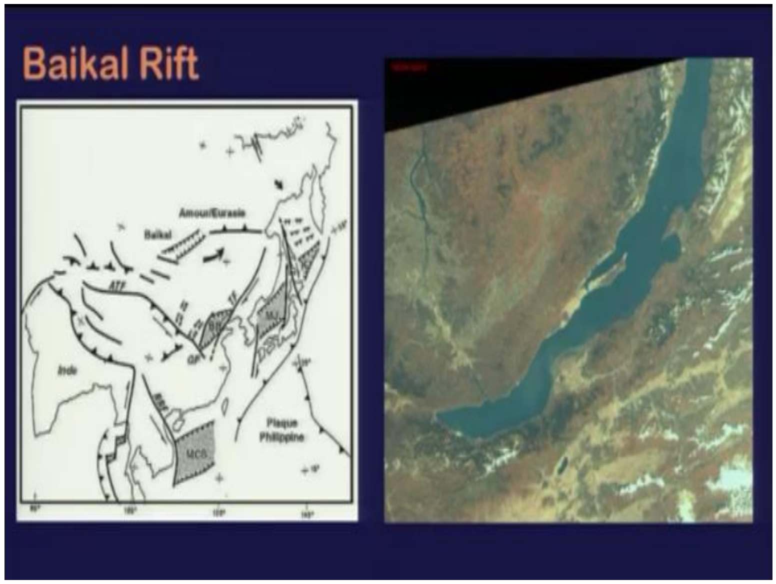

Then Baikal Rift, you have further in the Eurasian site over here and this rift is well evident by the Baikal lake.

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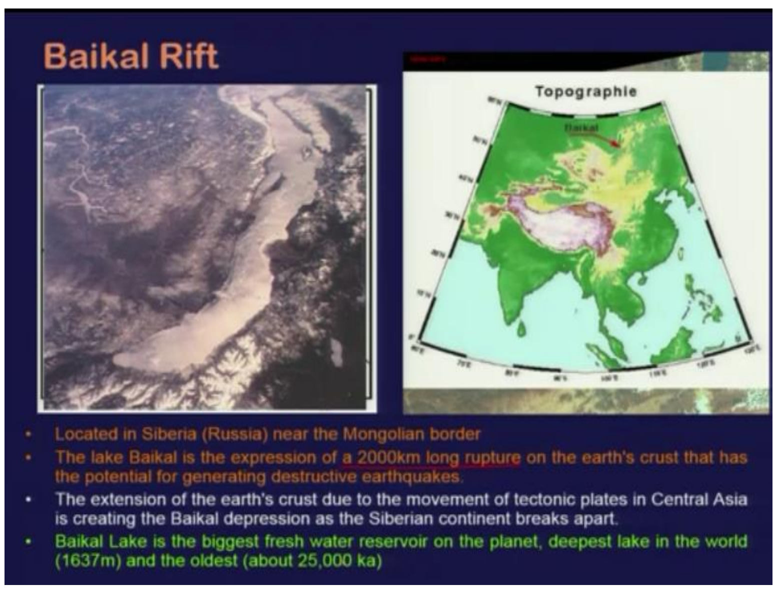

So you have it is located in Siberia, Russia near the Mongolian border. The lake Baikal is the expression of 2000 kilometer long rupture on earth crust that has the potential for triggering destructive earthquake. The extension of the earth crust due to the movement of tectonic plates in the Central Asia is creating the Baikal depression as the Siberian continental break apart okay. So as I told that the Baikal Lake is the biggest freshwater reservoir on planet deepest in world. It is around 1600 meters and the oldest as old as 25,000 ka.

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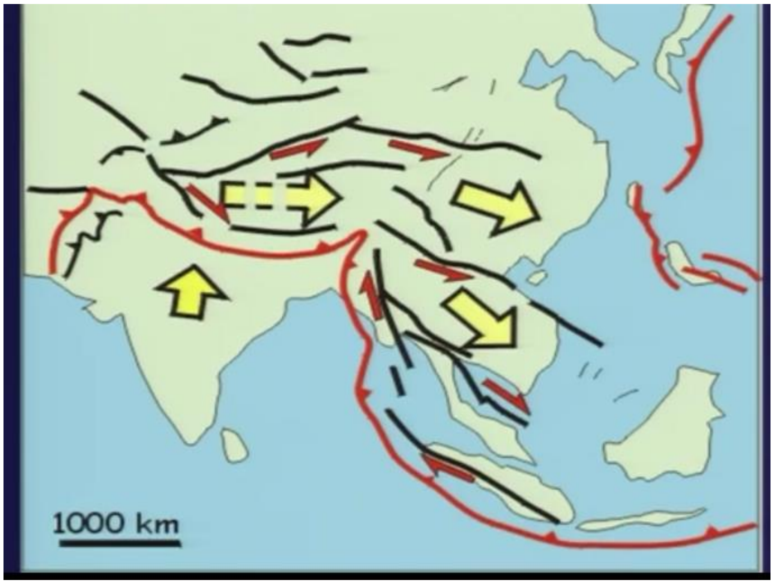

Then, another extensional tectonic environment can be seen just behind the collision zone between the Indian and the Eurasian plate where the portion of the Tibetan plate is extruding towards Southeast. So this is going east and towards southeast.

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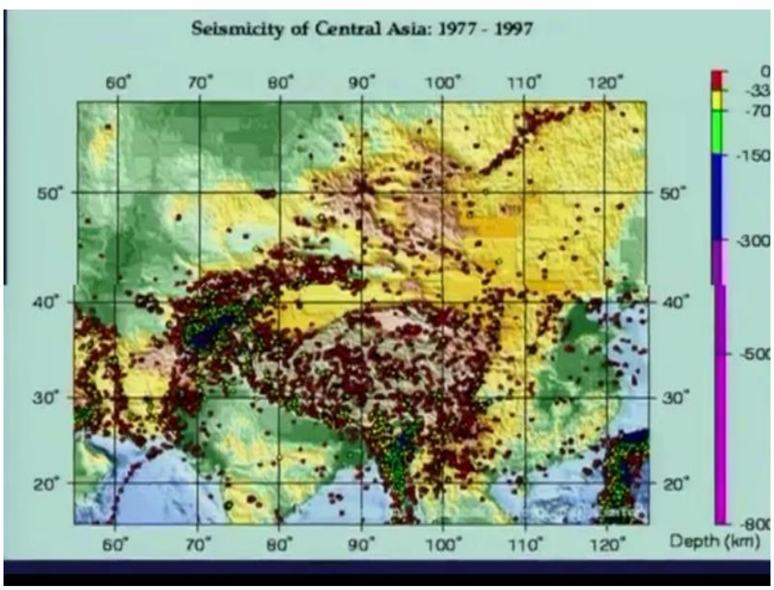

Then the seismicity in the Central Asian area, say if you look at that the extensional tectonic environment are also capable of triggering large magnitude earthquakes in this region. So this is your collision zone and the extension, which is taking place as you have seen in the previous slide, this one which is occurring here. So this whole area is showing a prominent alignment or the occurrence of the earthquakes large magnitude earthquakes in this region.

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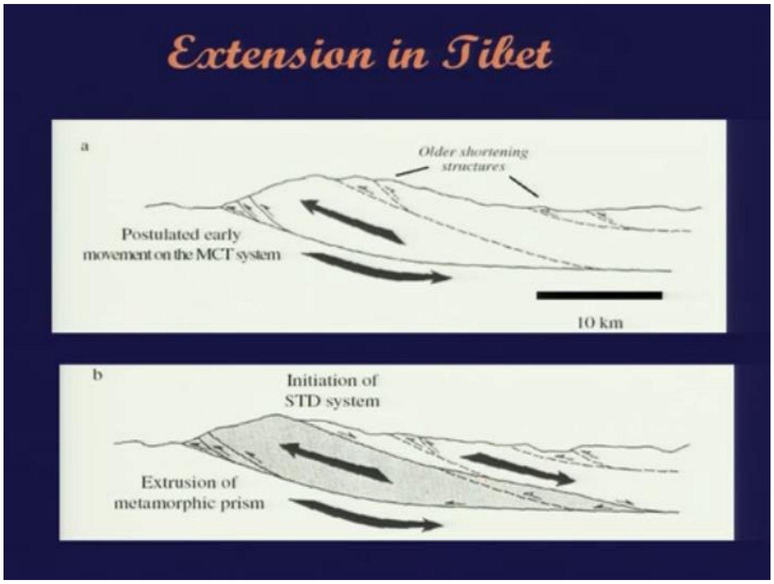

Extension in Tibet, so what has been considered that this extension probably is because of the sliding back. So you have the under thrusting plate here boundary and the overriding plate and after this plate or the deformed material of the overriding plate has achieved the enough altitude or the elevation, they will slide back and that is what is happening along the Tibetan faults that you are having the this whole portion has been sliding back and that is resulting into the extension okay.

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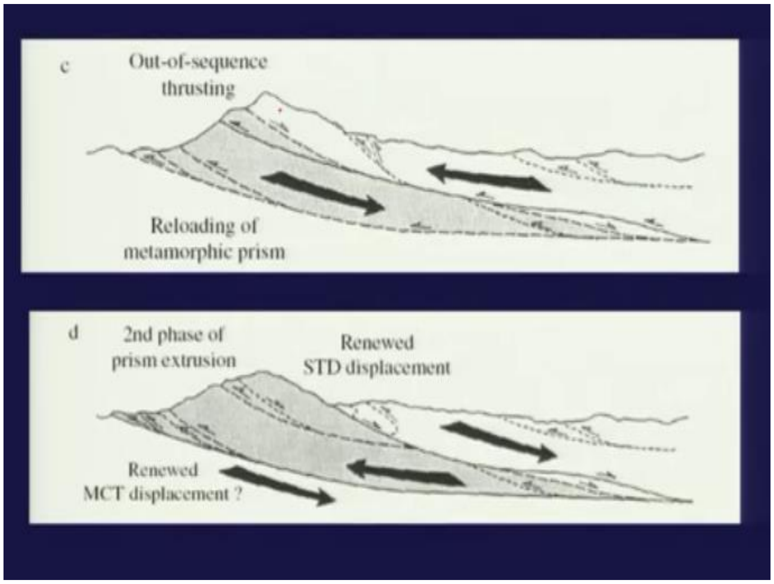

So another one, we have like out of sequence thrusting that can also been accompanied because of the rollback or we can say the back rolling of the elevated portion.

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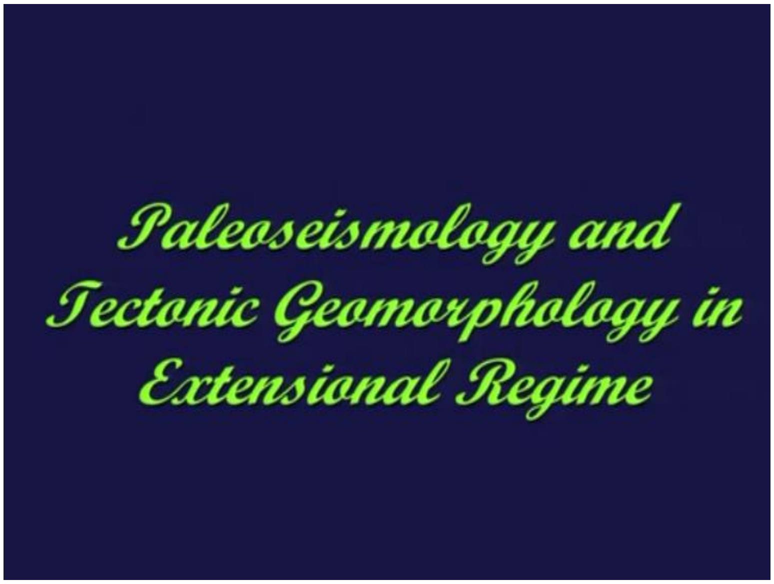

So paleoseismic and tectonic geomorphology in extension tectonic environment, so I will try to see in this part, that what are the surface expression in the extensional tectonic environment and mainly we are talking about the normal faulting.

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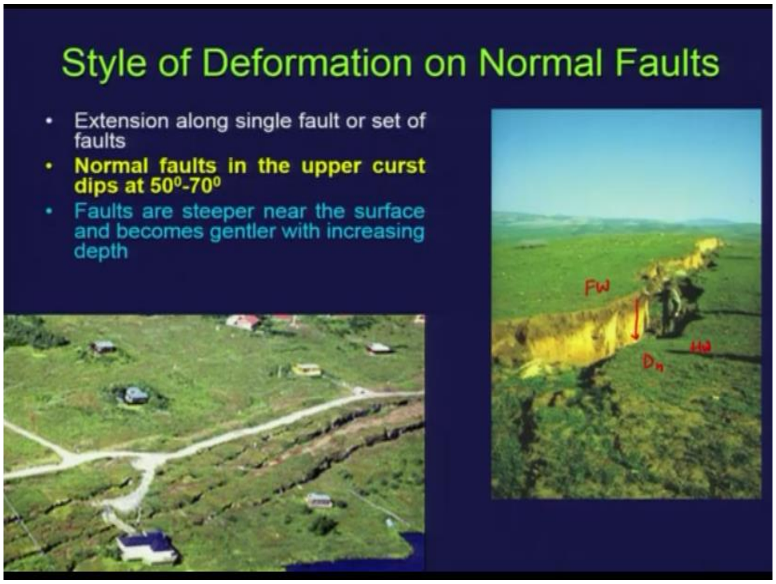

So style of deformation on normal faults, so extension along single fault or you will see that the deformation and set of faults and not on the single fault. So normal faults in the upper crust dips, which ranges from 50 to 70 degrees fault are steeper near the surface and becomes gentler with increasing depth. So you will see that most of the faulting in extensional tectonic environment and that is normal faults will be seen either in a single fault rupture or you will see multiple inner fault zone or sets of fault.

So close up of that, you can see that those are the normal faults and further the ground photograph of this what you see is that a very sharp boundary between the two blocks. So this has moved down and this has remained stationary. So this is your footwall and this is your hanging wall. So the movement has occurred along this plane.

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- Scarp of the 1954 Mw 7.2 Fairview Peak, Nevada, earthquake. Scarp height was >3.3 m in the mid-1985; when this photo was taken. A small amount of colluvium shed from this semi-consolidated Quaternary gravel deposit in the 30 years since scarp formation. Photo by J. P. McCalpin (1985).

Another example of the normal fault and this was in 1954 Nevada earthquake with magnitude 7.2. So the scarp height was greater than 3.3 meter in mid of 1985, when this photo was taken. A small amount of clue will shed from this semi-consolidated cottony gravel in the period of 30 years since the scarp formation. So what you see is this scree material here and that is your colluvial material, which has been deposited, because of the erosion up along the scarp.

So in coming lectures, we will also discuss that what is the importance of this colluvial, which has been produced or shred from the fault scarp. So this is not very old fault. It is 1954 scarp and then what we see the scree material is in just in the period of 30 years.

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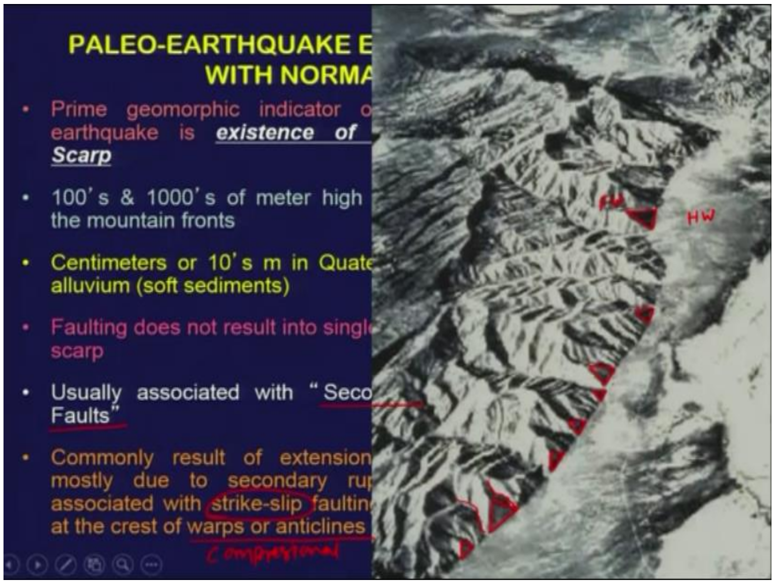

Then paleo-earthquake evidence associated with normal faults, so on the regional scale, you can see a very sharp boundary between the plane areas and over the hills or the mountains, which marks the normal faulting environment. So prime geomorphic indicator of old earthquake is existence of the fault scarp. So this, we usually considered for all the environments. So for any signature of, like the indicator of any earthquake, paleo-earthquake, then we consider there has to be an existence of the fault scarp.

But nevertheless, we also discussed in one lecture that we may have the displacement or the earthquake on blind fault. In that case, you may not be able to see the fault scarp on the surface, but this we consider that the geomorphic expression are the indicator of any earthquake. That will be the primary indicator, will be the existence of the fault scarp on the surface. So 100s or 1000s of meter high along the mountain fronts, this we are talking about the fault scarps.

So it may range in the size which can be more than 1000 meters or around 100 meters or less than that also. Centimeter or 10s of meter in quaternary alluvium and in one lecture, we also discussed that the fault scarps may be even less than a half a meter. So that also should be taken into consideration. So that is mainly in the younger deposits. Faulting does not result into single fault scarp. It may have multiple one and along with that we will also see the secondary faults.

So for example, this I am just drawing in case of you, if you take the fold okay, then the associated faulting, you may see had the crust part and that will be your extension faults and those will be considered as secondary faults and one example, we also looked at, in the Great Rann of Kutch, where we saw the secondary faulting in the young sediments. So they are commonly result of the extension and mostly due to the secondary rupture.

So normal faults usually you will find that the result of the extension or because of the secondary rupture associated with the strikes the faulting and at the crust of the warp of the anticline, which I was showing with this sketch. As I told that the extension tectonic environment irrespective of the tectonic regime, you will find that normal faults will be associated with warping, when we are seeing the warp and anticlines and then we are talking about the compression tectonic environment and this is your strike-slip faulting environment.

So basically, if you demarcate this boundary here, which is typical of normal fault and vary with very sharp face here along the mountain front and these are typical of the normal faulting environment. So this part is the hanging wall and this is your footwall and what you see, we will come to this part later in tectonic geomorphology. These are all triangular facets. So I will just remove now and then you can see, what I was putting her or triangular shape.

And they are confined between two drainages everywhere, you will be able to see the drainage here. So these are the typical indicators of normal folding. Nevertheless, we have also seen similar features, because this is tectonic retrieval or features which are because of the erosion, which are also seen in some locations along the thrust faults also in Himalayas.

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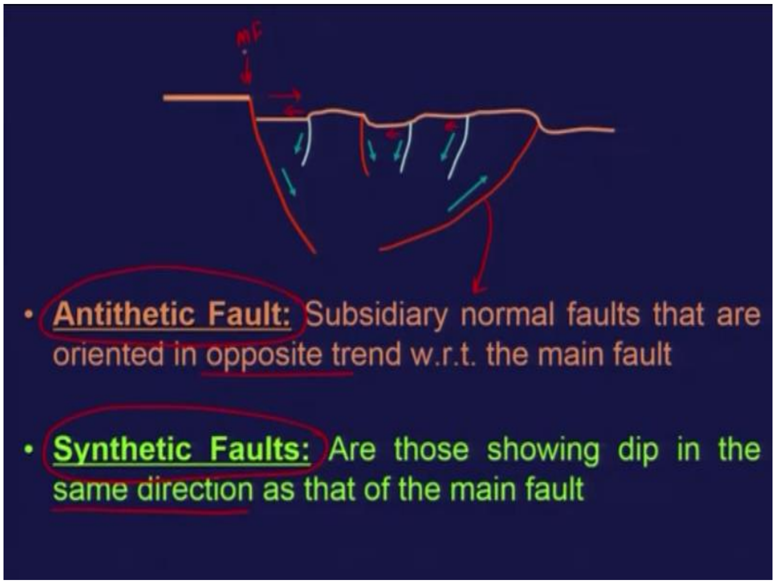

So if you look at this part here, what we have? We have the secondary faulting along with the main normal faulting. So what we call this as an antithetic fault and so subsidiary normal faults that are oriented in opposite trend with respect to the main fault. So if you consider this as an main fault, then we have the other faults, which are dipping in up there in opposite direction and another set of faults, which we have.

They are termed as synthetic faults and that shows the dip in the same direction as that of the main fault. So in this we have, this is one the main fault. So we have these are dipping opposite. There are dipping in the same direction. So they are dipping in this direction and those are dipping opposite to that. So the opposite one are termed as antithetic fault and in the same direction, they are termed as synthetic faults. So main antithetic fault is this one, you have okay and this is your the main normal fault.

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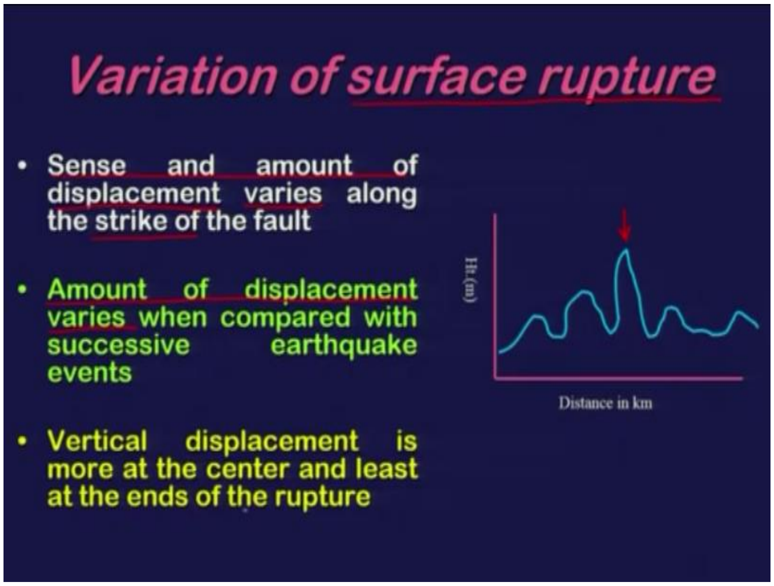

So variation in surface rupture, since an amount of displacement varies along the strike of the fault, now this part which we are discussing will remain same or similar things we will observe in other faulting environment also that is the sense and amount of displacement, it will not be the same all along the strike of default. So if you draw it, so for example the fault line, this is on the plane view. So the one is, it will never be the straight line.

What usually we expect and this we usually do, when we are marking the lineaments, but the strike keep changing as it has been shown here and sometimes you may see the fault traces like this okay, very curved nature on the plane view. So wherever there is a change in the strike, suppose you are having the deformation sigma 1 like this okay, so I am just removing this straight line here.

So if you are having this one, the relationship here of your sigma 1 is different than what you see over here. So this portion and this portion will show a different pattern of deformation, the sense and amount will vary along the strike. Then second part is also along with that you have the amount of displacement varies, when compared with the successive earthquake and events in this we discussed in the beginning that the displacement never remains the same during each earthquake or successive earthquake.

It will vary. So sense of movement, amount, sense and amount of displacement will vary and then second the amount of displacement will not be the same during the different earthquakes okay and this we are talking along the strike and this we are talking on fault during individual earthquakes and third one is your vertical displacement is more at the center and it reduces or it is least at the end of the rupture.

So for example, if you have an rupture, which has been given here in distance and kilometer and the displacement which is coming right up to the surface and what you see is, this will be that you will have maximum here and you will have least or it reduces on the either side of the rupture. So with this I end here and will continue in the next lecture.