**Earthquake Geology: A tool for Seismic Hazard Assessment**
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**Lecture – 39**
**Compressional Tectonic Environments and Related Landforms (Part - V)**

Welcome back, so in the previous lecture we mainly discussed about the distribution of earthquakes in the Himalayas and now, I will give this lecture is pretty basically related to what type of deformation we see mostly in the fold and thrust belts.

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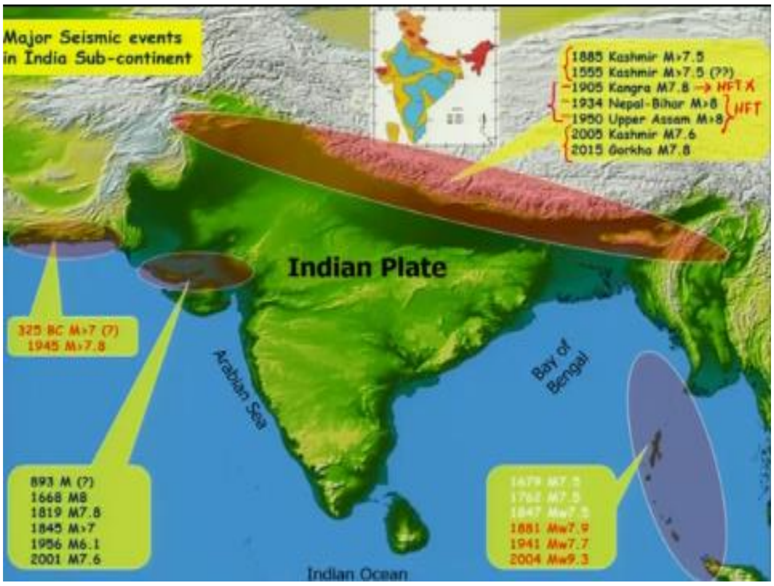


So as we were talking about that we have a few earthquakes which are listed here either we have, we found them from the historical literature or the recent earthquakes which have occurred in the 20th century. We had a couple of them 1905, 1934, and 1950 and so on and the recent ones in the 21st century we had 2005 and 2015. Now based on the earthquakes which are listed even for the Andaman region or from the Kutch and Makran zone.

The area that is what we have the Indian part has been categorized or we have at least 4 major seismic zones.

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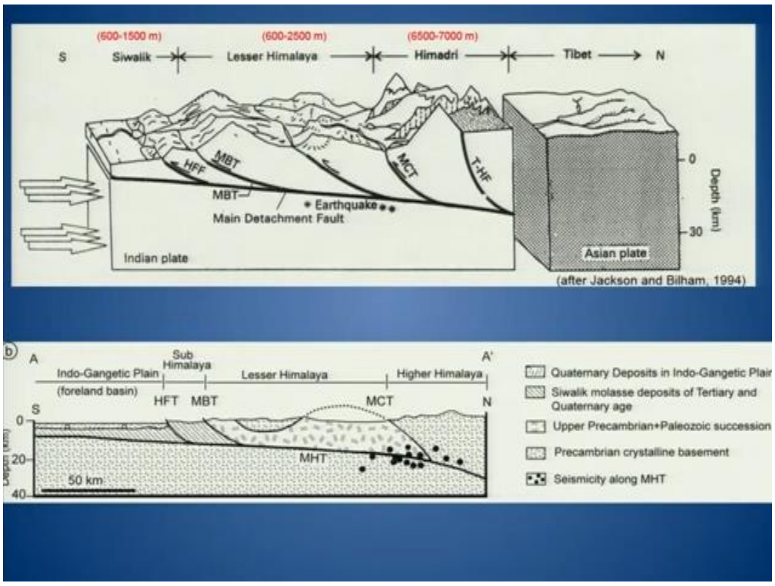


Now if you look at the deformation pattern in Himalayas then what we have this partly, we have discussed before also that we have a detachment or we also call this as decollement and we have the implicated thrust fault system, which are resulting into the deformation and the topography of Himalaya. So mostly what has been identified based on the seismicity also that most of the earthquakes they occurred between MBT and MCT and the frontal part is locked.

And this has also been identified based on the GPS studies, now if you take the overall deformation pattern then what we did was we performed by a very as small experiment using sandbox and we tried to understand that how and this fault system may must have evolved over the time and what are the best sections we can see during the experiment?

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So this is a short movie which we have clicked and done in our lab, so if you look at the deformation mainly in the collision zone then this experiment will help you in understanding the overall deformation pattern. So what we did was we performed a very simple experiment considering that we have very soft deposits so we kept the sand and finer self layers here with we put on the horizontal manner.

On a very horizontal we are not taking into consideration the inclined ramp, but so we just used the flat surface and created some thick, thickness putting different grain size of like sand silt and all that and with different colours, so that we can look at the development of the topography and also the pattern of deformation on either side and we used a very fine screw here which we drive with handle and attached with this a wooden plank.

So we tied this and so keep on moving within constant speed and then we saw them that the different types of faults and the faulting which occur during the process. So you can if you can watch this carefully then you will be able to understand that what exactly happens in the collision zone. So consider that this is your plate from the Eurasian side and this is your Indo-Gangetic plain or Indian plate and what type of deformation you will see.

And how the folded range will come up, so now if you see this one this is the part where we are moving this screw and with a very constant speed and then you can see here the development of the fold and the manifestation on the surface that is your topography. So this different layer helped us when viewing the pattern of deformation. So this we consider that the material is not homogeneous.

It is with the different grain size and loose material which is getting crumpled and you see the topography is slowly getting developed, so initially it will keep folding and then what we found was that there were beautiful folds low-angle faults which developed along with the folds. So now we can see slight displacement which is coming up here and the contact between the two portions that is this wooden plank and the first like this contact between the sand and the wooden plank is getting almost vertical.

So this we can mark this, that this probably is indicating the suture zone and you can see small kinks which are coming up and there is a slight displacement which has been taken up by this portion. So you are having the higher topography on the left and then gentle topography getting developed now on the South, so on the right and similarly if you look at this force, now the new fold is developing here far into the.

So if you consider this as an Indo-Gangetic plane and then what you see is then on the southern side we have another topography which is coming up slowly. So this older faults will accumulate more slip as compared to what we see in the frontal part here, and you can see the topography has developed here so I would suggest not you can look at this video carefully which will explain you how the topography is developed and what exactly we see in section.

So this is a typical of what I was explaining when one of the slide in previous lecture the bulldozing effect. So you are just pushing at this plate is just climbing up over the Indian plate and the deposits are just like push if you are using a bulldozer and just pushing the deposits for the material. So in section you will see such folds which will develop and the topography will be like that actually.

So you will see the topography which is developing something like that. So the next one if you carefully look at the previous fold which was developed here and now the another one is taken up by this one. So this again explains the younging of sequence typically seen in fold and thrust belt. Now if you look at like further what we were trying to explain you in the previous slide that we took all horizontal and then we had sediments and then we push this block.

So in this video what we see is that we have the folds which have been developed here earlier and they are slightly having higher depths as compared to what we see here. So this is what you will keep getting when you are having the plate like in the Eurasian Plate climbing over the Indian plate and this we can put as a short often and decollement or the flat surface or detachment which is having the indicated fault system getting connected at the base.

So if you look at the neck the further this video then you will understand that how the initially the deformation was along this one then it was with propagated further, so if you consider this as an Indo-Gangetic plain and this you have this of Himalayas and this you have the so called we can say lesser Himalaya and this is higher Himalayas. So if we further keep deforming this then what we will see is a similar process that we will have the deformation which will be seen here.

So this will show the younging up, so for example if you look at this one then this one is your I will just put exactly on the top of that so this is your HFT this will be your MBT and this is your MCT main central thrust and this will be your suture zone and the topography which you see here is something like it goes like that and then you have before the topography now next will be like you will have the deformation which will be taken up over here actually.

So if you compare this, those faults here they are with the steeper depth but this one is a very low angle. Now we will see in the next coming like further that this will become almost like flat here or it will show the bending moment in this portion. So this is moving and the displacement has been consumed as well as along this one and along this one here. The time will come that this block the older one will stabilize.

And the deformation will be passed on to the next zone of the deformation in the frontal part that is towards the foreland side. So now you can see that this is getting bended here and the older faults are getting with the greater depth, so this is slowly moved further, so this is a typical of what I was explaining of bulldozing effect. So the Eurasian Plate is overriding in a form of a bulldozing bulldozer which is putting the material crumpled material on the Indian plate.

And the deformation what we see here is the similarly what you see in the Himalayas. Now slowly if you see this part is now getting deformed, so the new slip is can taken up by this portion here. So you see some bending is taking place in the different layers and then the deformation is the tip of the deformation is over somewhere here actually. So now we can see that when the deformation has been taken up.

So this, what we were trying to identify that when exactly the new thrust is getting developed at what distance from the previous one actually. So that what we tried that the distance between the older one and the younger thrust and then from this older one to the younger one the next one, what was the distance so this distance we measured it was almost similar that was over 10 centimetre.

So this also can be taken into consideration if you want to do some typical calculations, that if you have the cross thickness of the crust or the thickness of the sediments and if you are deforming with the same rate then in what way the deformation is been taken up by differential faults. So this is the old fault now the new young fault is been developed here. So this is how you can do a very simple experiment to understand the ongoing deformation in Himalayas.

So this is one of the best way to understand that the pattern of deformation when thrust and fold belt all I would say that this is the best example to understand in the collision zone.

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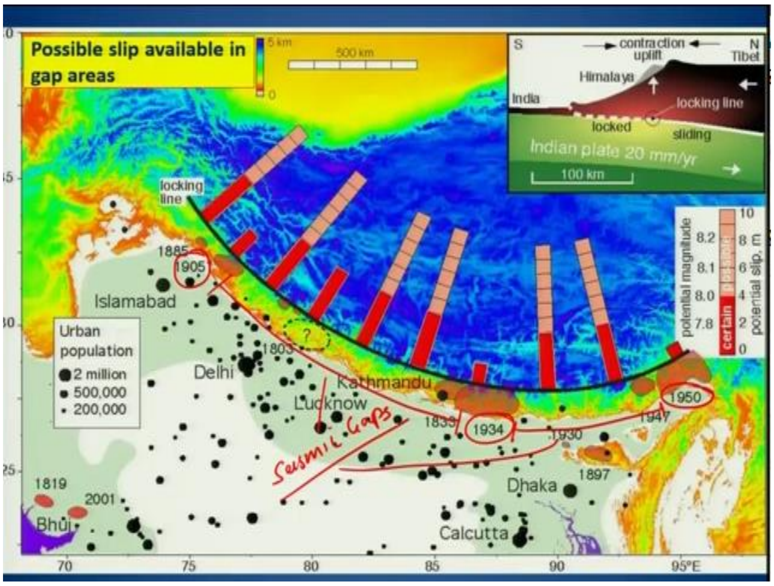


So coming back to the part of the seismicity, this was long way back like this paper was published and in this it was been discussed that the major earthquakes which have been triggered during 21st, 20th century that is for example; 1905, 1934 and 1950. They were responsible because they were all the large magnitude earthquakes and they were responsible for releasing this slip which was available along the Himalayan Front.

And mostly it was been suggested that all 3 earthquakes had their slip along the frontal part. Now the based on this and the historical data for example what has been shown here 1803 earthquake 1885 and one more which was there in 1555 here and few more in 1505 and all that but anyway, if we just consider this 3 events here 1905, 1934 and 1950, then this portion is not having enough slip to trigger earthquake in near future.

And the area which is sitting between these earthquakes one is this one another one is this they mark seismic gaps. This means that no such earthquake has occurred in this area, hence, this area is vulnerable to next large earthquake because the slip is available in this region where a slip has been released in this portion here as well as slip is available. So these areas are marked as seismic zone.

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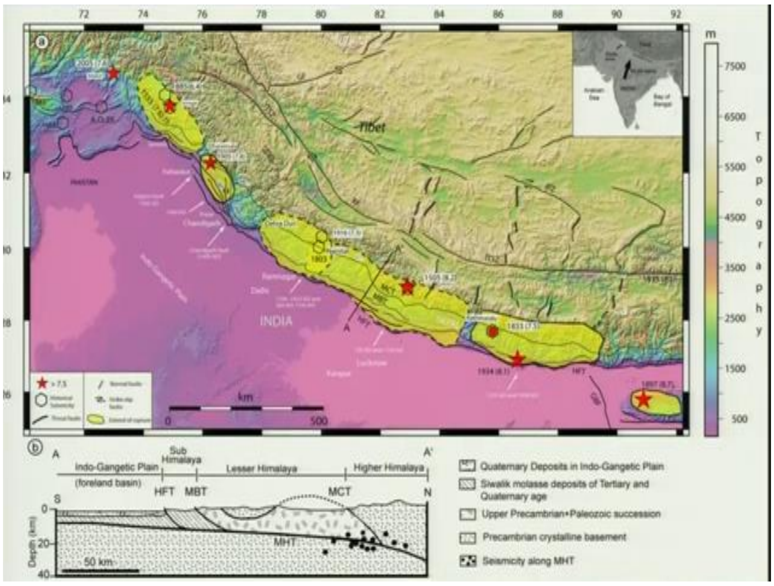


Now taking into consideration more events from this region there is an historical record of 1505 earthquake many more from Nepal part which I have not discussing right now here and then we had this along with 1505 another earthquake which was been listed in the historical record is 1803. So a lot many Paleoseismic studies, these are the few examples which have been given here but I will discuss more in detail when I am taking up and separate lecture on this one.

So I will discuss that part in the next coming lecture one of the coming lecture that what all paleoseismic studies have been done and I will give a brief lecture on that part.

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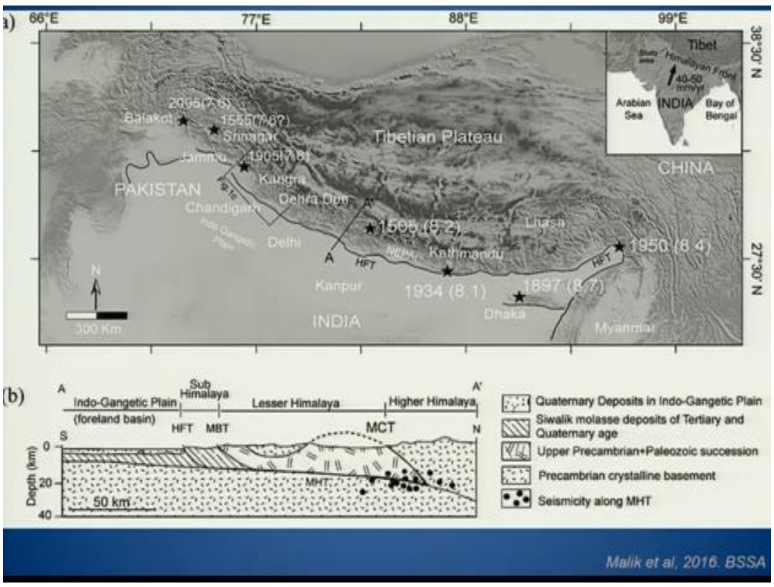


So this is from again the Kangra region, we did some studies and that also if possible I will discuss in the next one.

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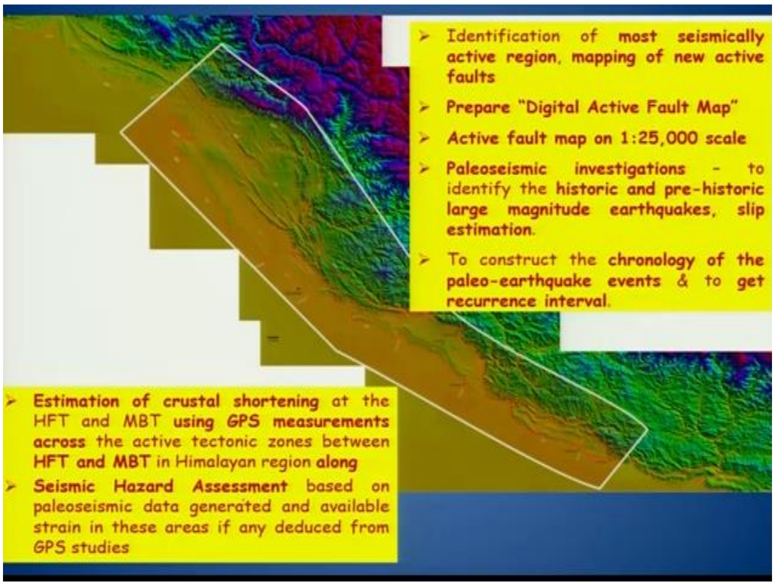


But if you move ahead and see that what we have that we have the all the Himalayan Front which is almost running 2900 kilometres and if we just look, take the part from the central Himalaya that is west of Nepal and tried going into the Jammu and Kashmir part but this portion is covering up to Jammu. We have multiple fault lines which have been marked here and so we are doing one project.

In which it is a national project under the umbrella of Ministry of earth science and the aim behind or the objective behind this project is to come up with distribution of active fault map and also we do the Paleoseismic studies and along with that we use the high resolution GPS data to understand the ongoing crustal deformation. So this information which will be produced through this project will be extremely helpful for the better seismic hazard assessment.

So this whole area we are trying to cover and we are planning to come up with digital active fault map from this area. So this is the one of the main aim to come up with in digital active fault map and the scale which we would like to put based like the maps at 1:25000 scale, and also the aim is to investigate the different faults and try to reconstruct the history of the ancient events and also estimate the magnitude associated with those earthquakes and this slip also.

And finally reconstruct the chronology of the Paleo earthquake events and also if possible get the recurrence interval between that. So we are also putting the permanent GPS stations across this area, to identify the areas which are deforming more as compared to one another that is the area along the active faults and this is very much similar to what I have shown in the beginning.

That we have multiple fault line and it is very much similar to what it has been seen along the San areas fault system. We want to have to go for the seismic hazard assessment this information will be extremely vital.

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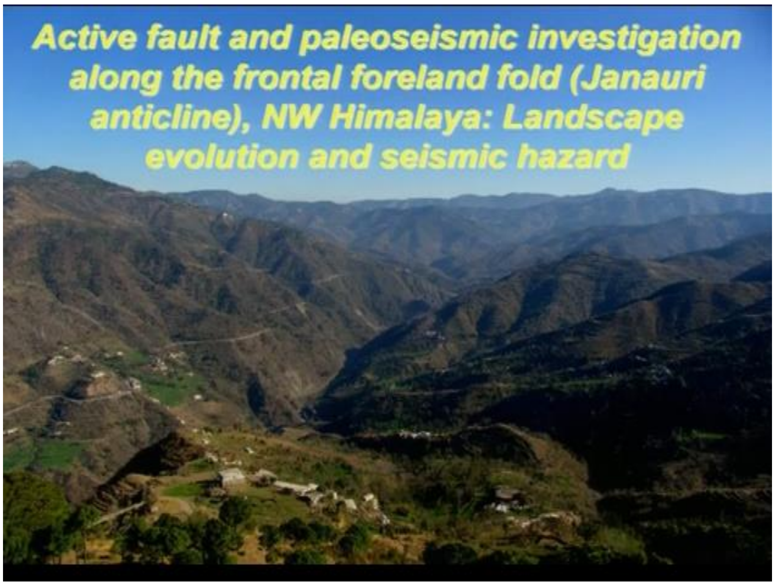


So active fault and Paleoseismic investigation along the frontal foreland fold, so in this actually I what I would like to do is I will discuss few examples of like surface morphology how we can take into consideration? And how we can understand the landscape change over the time because of the ongoing deformation? And that can also help us not only to have the better seismic hazard assessment but also to understand the Paleo landscape change over the time.

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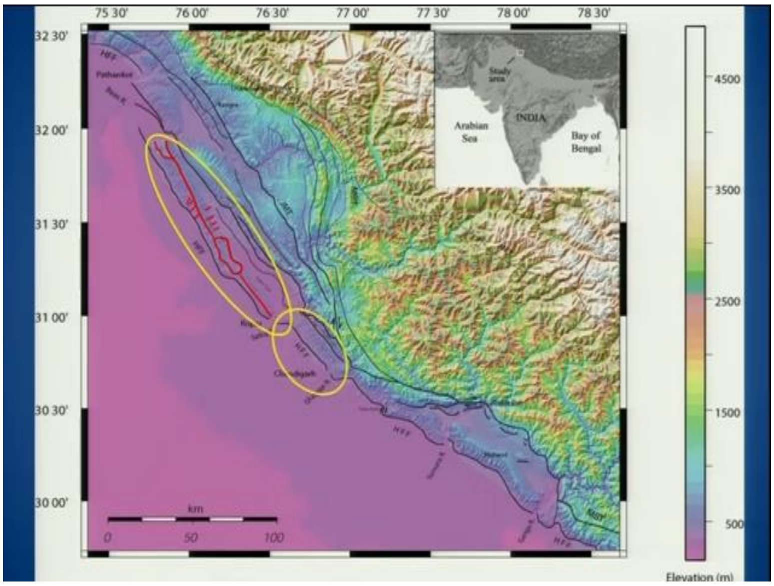


So taking into consideration this portion which is known as Janauri anticline and for your reference if you look at then we are sitting somewhere here in the northwest in the western portion of the Himalaya. So we have the Janauri anticline and the frontal folds, we have Chandigarh anticline and then Mohan anticline over here and so on. Now how this, folds were developed actually over the time.

Of course one can say that you have the deposits and then if you keep compressing this and you will have the formation of the folds and all that. As we have seen in the one of the slide or the short movies of the sandbox model. But in nature what we see is not slightly complex phenomena. So if you look at this topography here then what we have that we have drainage divide here in the crust of the fold here.

At this I will just put the line here, that will be helpful, so we have the drainage divide here like that here and then even in this one. So these streams are flowing on either side like this but this portion is comparatively flat, so what does this indicate and this one also here.

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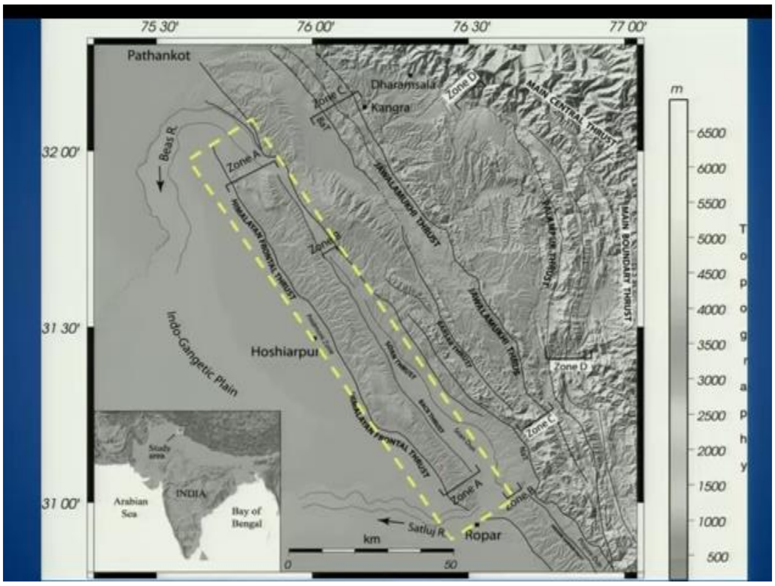


So we took up this and did some geomorphological studies which helped us in understanding that how exactly this whole fold system of almost 100 kilometre Janauri anticline was developed.

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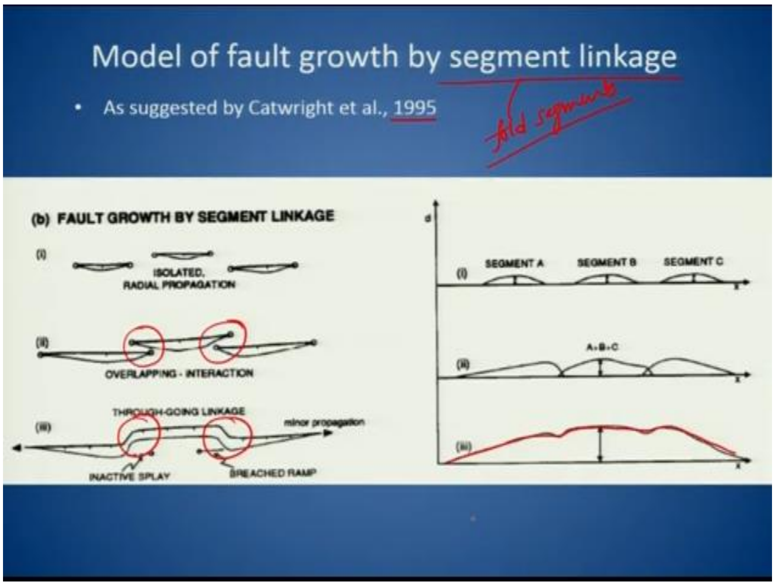


So there is a model which has been commonly used and we call this as an model of fault growth by segment linkage. Now this segment linkage is related to your fold segments. So this was when given by Catwright in 1995 and few more models will been given. What has been suggested that the fault growth by segment linkage? So any earthquake or the displacement, which because displacement is definitely going to result into the ground shaking and that process is your earthquake.

So it will start at the nuclei and then keep the deformation will be acquired like a depth also as well as on surface also along the strike. So it will keep developing, it accumulating the displacement like vertically as well as horizontally and this segments different fold segments will keep growing over the time and they will be radially propagating. So over the time the edge of the segments the tip of the segments will come closer to one another.

And they will interact and they will merge with or overlap with one another resulting into the formation of one single fold which has been shown here, so this is what we call the linkage segments. So links segment here and finally what you see is the large hole topography.

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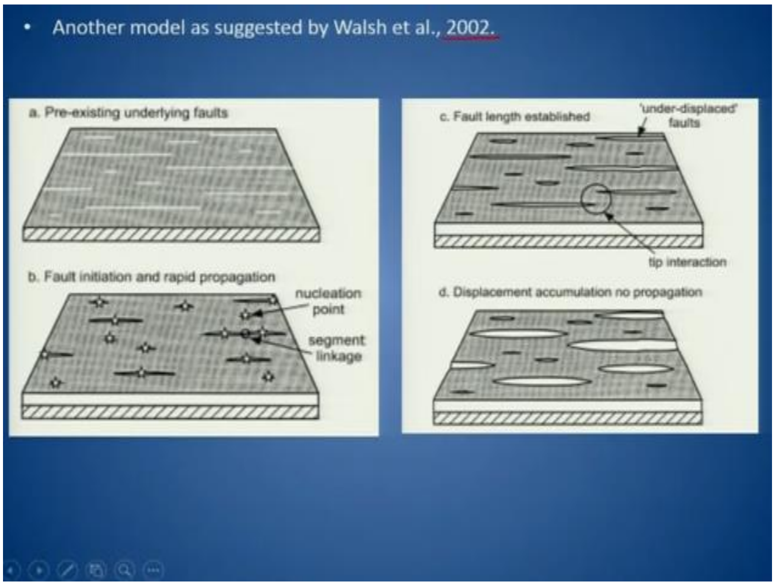


Similarly based on this we also looked at the topography here when Janauri anticline but before going to that let us see another model which was been proposed by Walsh in 2002, which also suggests they similar. So he suggested that the deformation will start at a nucleation point here and then in the folds will keep growing radially or we can say laterally and then the time will come the if they are coming closer to one another they will get linked and this is your segment linkage.

So if they come closer to one another then they will get linked and that how we will see our formation of the largest fold range but this problem is because of the linkage of smaller segments and this was also been shown here. So slowly other steps will interact and then you will have the larger fold which are developed.

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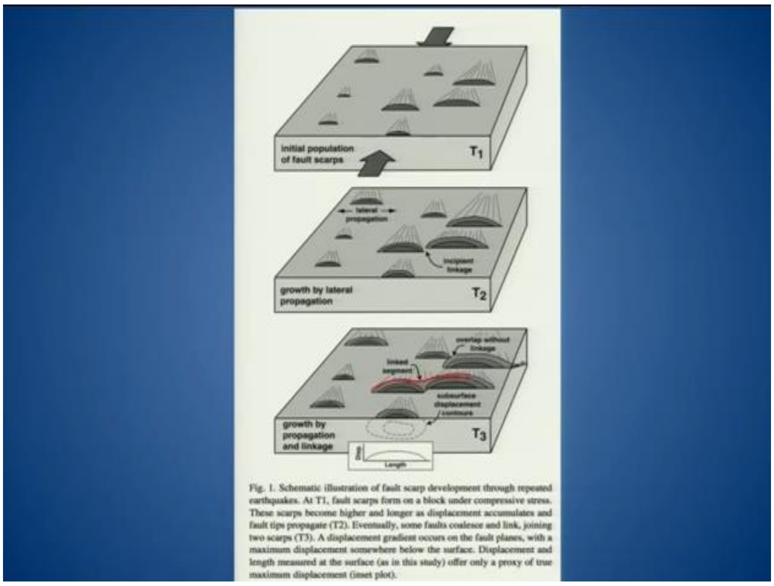


So this is another example given by Davis which also explains the similar one. So you will initially start developing the fold and it will keep growing and the time will come it will interact and this will form a major fault system which has a linkage segment here.

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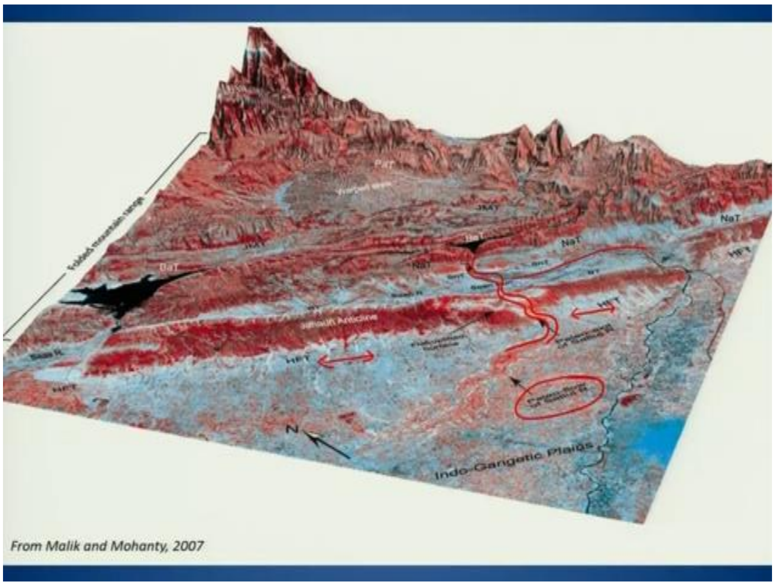


So with this concept we looked at the overall topography of the Janauri anticline and what we found was that this the edge of this fold that is this smaller segment and this one the larger segment they interacted somewhere over here and how we interpreted this that how they this topography was evolved and how it affected the local drainage also in that region. So local drainage if you look at here then the that it has and one of the major river system which is flowing in this area that is your Sutlej.

So what we suggested is that the before because the fold was growing on like that both the fold segments and this area was available to Sutlej which flowed through this area like this. So this we were able to pick up the Paleo Sutlej channel. So the Sutlej is used to flow through this before this whole segment got blocked and when this interlinking segment that is what we call the flat uplifted surface there is the link segment of this to fold segments.

So this blocked the river and force the river to flow through this region and so this is your presently river and this marks the Paleo exit of Sutlej. So if you go on the surface is exactly flat as what we see in the Indo-Gangetic plain.

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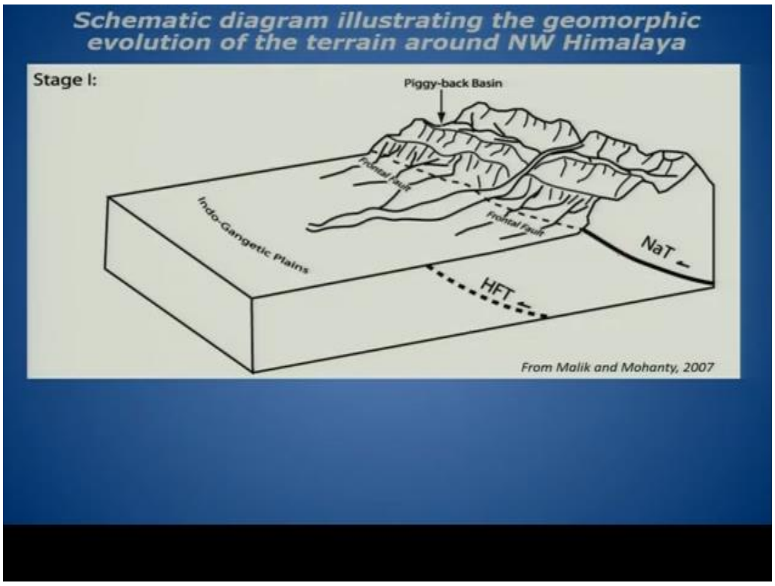


So we came up with an schematic diagram which explains that, we did not have the frontal fault that is your HFT before and we had Nahant thrust that is one of the fault system

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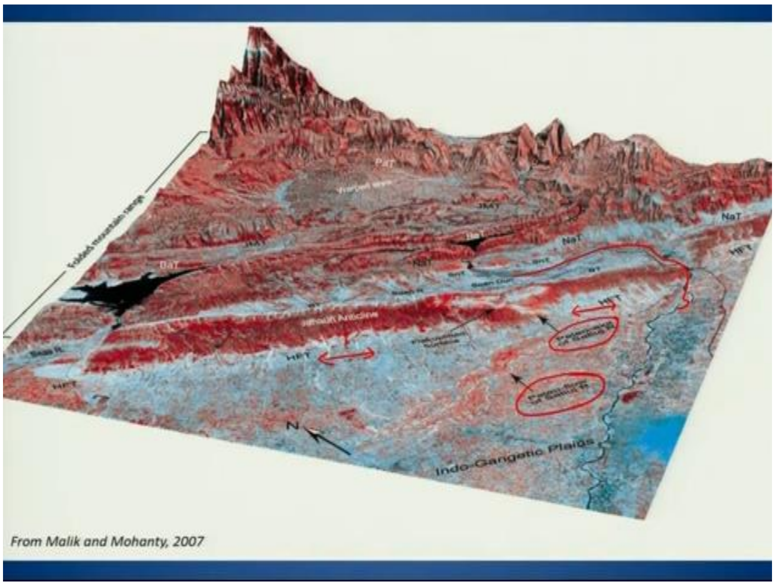


Which is sitting here so this is the Nahant thrust, NaT. So we had all flat areas similar to what we see now today with respect to this fold. So this fold did not exit earlier. So we had the streams or the channel river channel coming and debauching into the then-existing Arabian then existing Indo-Gangetic plain in this region.

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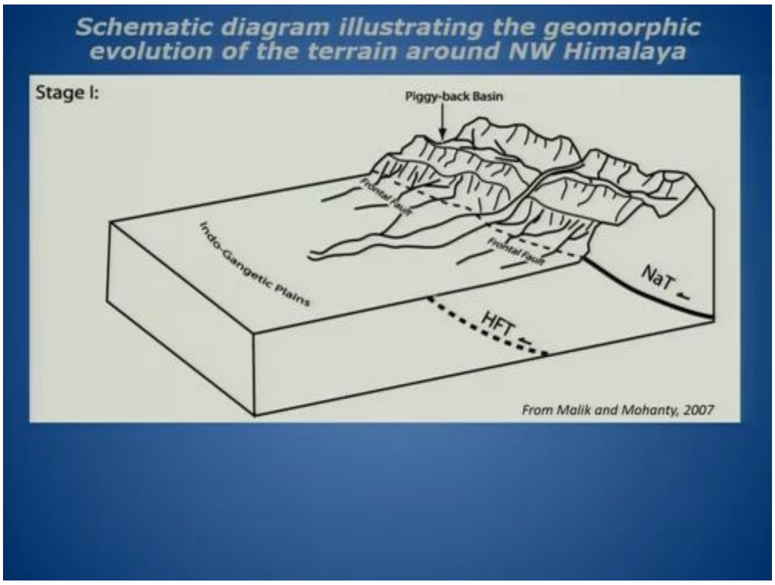


So similarly what we were looking in the sandbox model that the younger faults will keep developing in the frontal part. So we have the Indo-Gangetic plain here, so no deformation has been seen or has been taken up by HFT and slowly, so initially the channel flowed directly onto the Indo-Gangetic plain.

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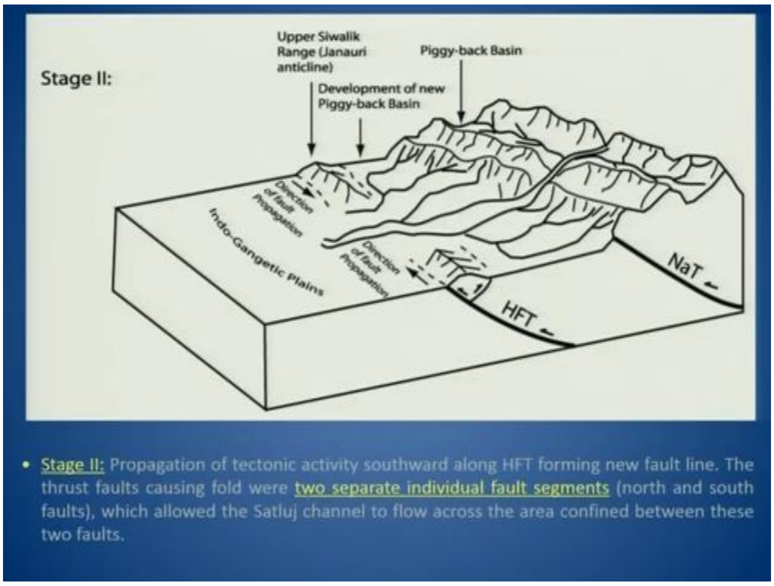


But slowly the deformation was been taken up by the frontal fault that is your HFT. And the fold started growing on either side, so direction of the fold propagation has been shown here by these two arrows so this segment folds, fold segments started growing on either side. So rate radially and still the gap was available which allowed the Sutlej to flow through this area.

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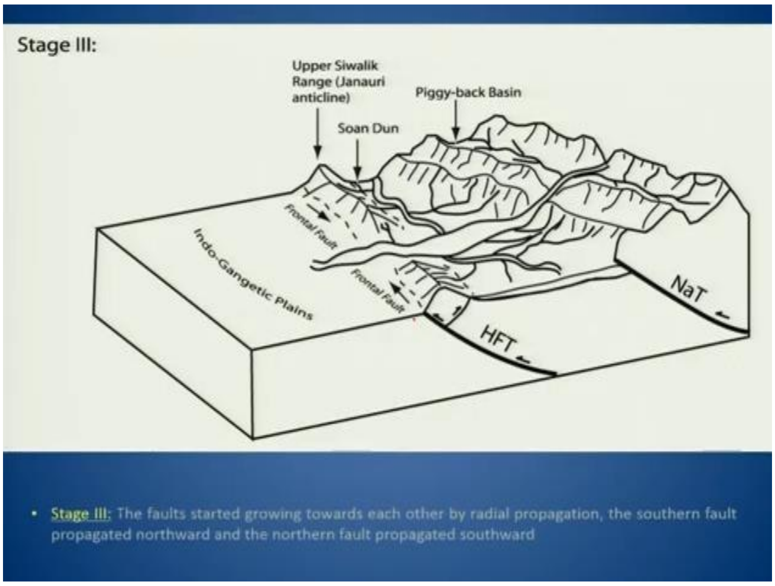


And then this was still it came closer to one another and what we see is;

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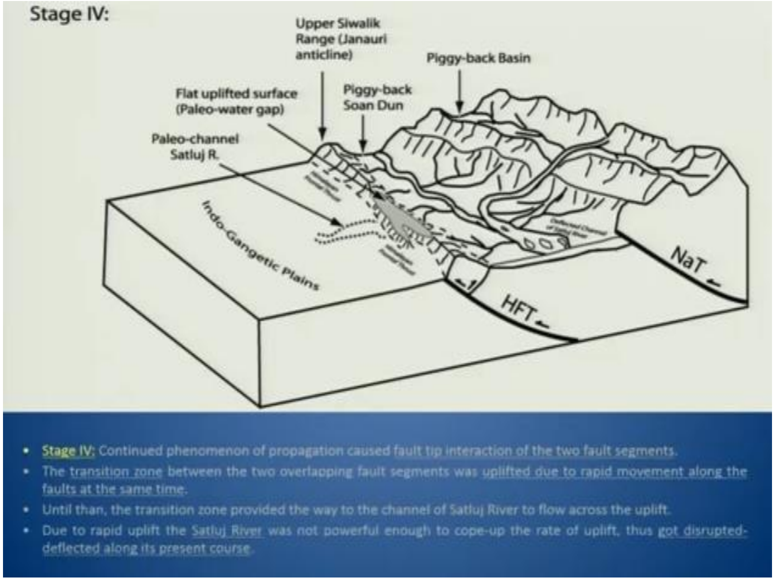


Final closure of this so this, the Sutlej which use to flows through this. The area was blocked because of the interaction of the two segments of the folds here and Sutlej was forced to flow along the strike of the fold on the back limb side, and this exactly what we see in the present topography.

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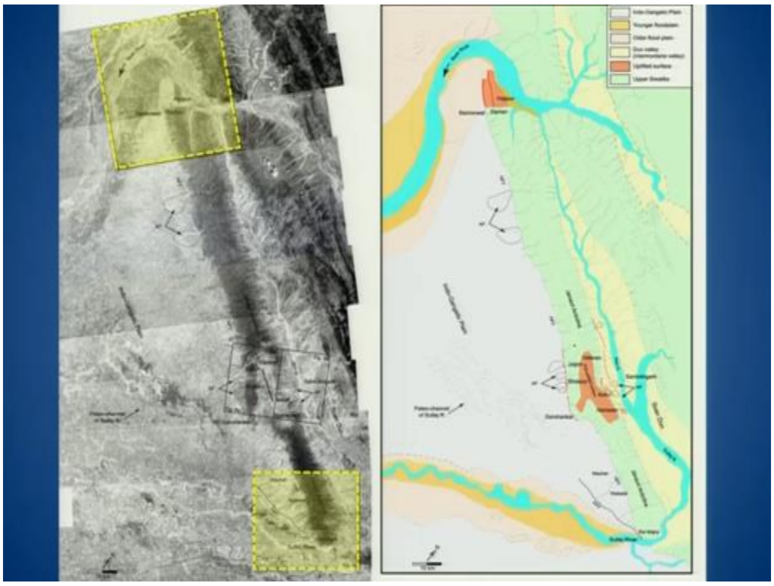

So this is the area which I was showing through the Sutlej used to flow through this one, this way is marked as in paleo channel here but now the Sutlej flows like that, similar example can be seen and for the Beas River also. So this part also behaved in the same way and this is the tip of the fold because the fold is not growing further this side now it has started growing on either side.

So these are the two ends of the larger fault system that is your Janauri anticline. Initially you had 2 segments. Segment 1 here and segment 2 here and they got merged at this point here.

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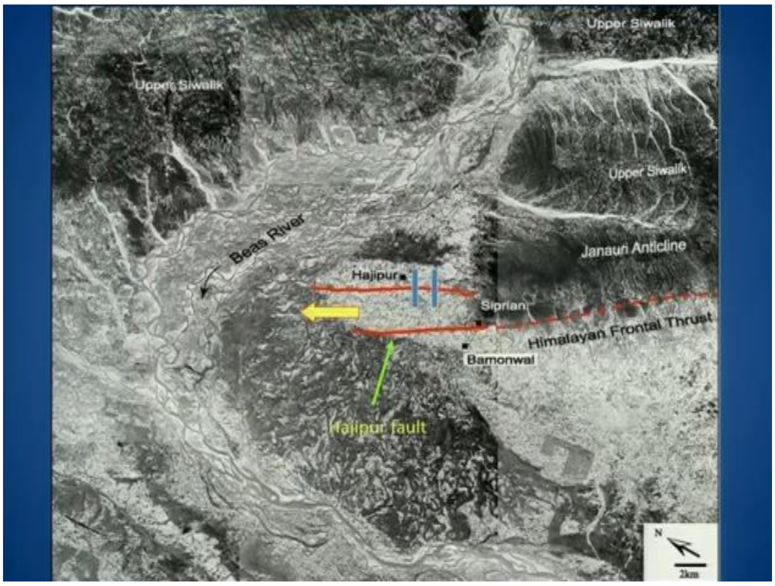


Now coming to this part here if you look at then what we see is that the Sutlej the Beas channel is taking a huge turn here and get into the Indo-Gangetic plain and this is because of the growing of this nose of the anticline. So earlier it used to flow through this one and then slowly it shifted. So whenever there is an earthquake the displacement is been taken up by the 2 faults here and they will propagate in this direction.

And they will push this channel further towards north-west, now this is important to understand the before we get into the Paleoseismic path, that what is the tectonic geomorphology tells us about the landscape evolution. So we also keep doing this type of studies so that we understand that how exactly that overall landscape got evolved, actually the young landscape in this region.

So this is the Himalayan frontal thrust the active fault trace. We were able to of course there a there were a few more signatures here but this was the most prominent one which we marked and this is the another fault which is again the part of the active fault here, and the major fault system Himalayan frontal thrust. So this is we have termed this as in Hajipur fault, so this keep on moving on this side and we will have the deformation pattern further pushing or the deformation pattern typical to the what we were looking at the propagation of the fault

And next earthquake and the displacement on this fault will push, Beas further towards North-west. So let us look at that what we did in terms of the Paleoseismology. I will talk this in the next lecture I will stop here. Thank you so much.