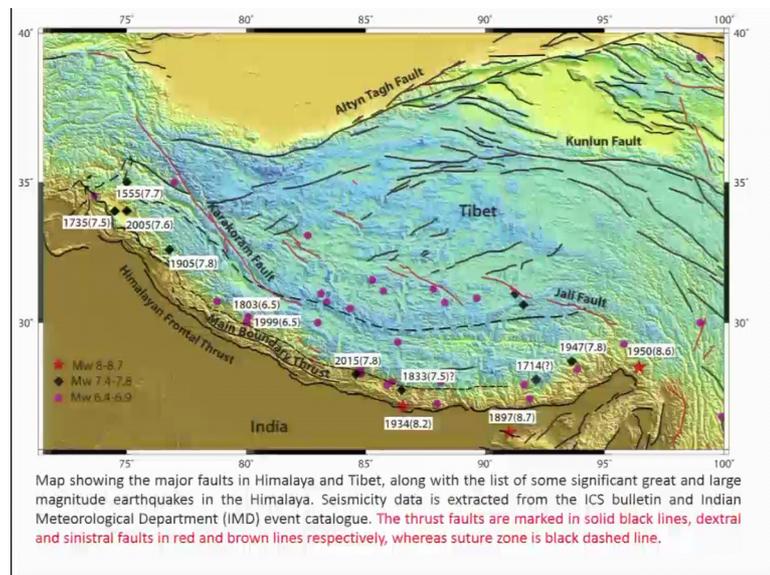


**Natural Hazards**  
**Prof. Javed N Malik**  
**Department of Earth Sciences**  
**Indian Institute of Technology, Kanpur**

**Lecture – 17**  
**Earthquake and related hazard Part II (North West & Central Himalaya)**

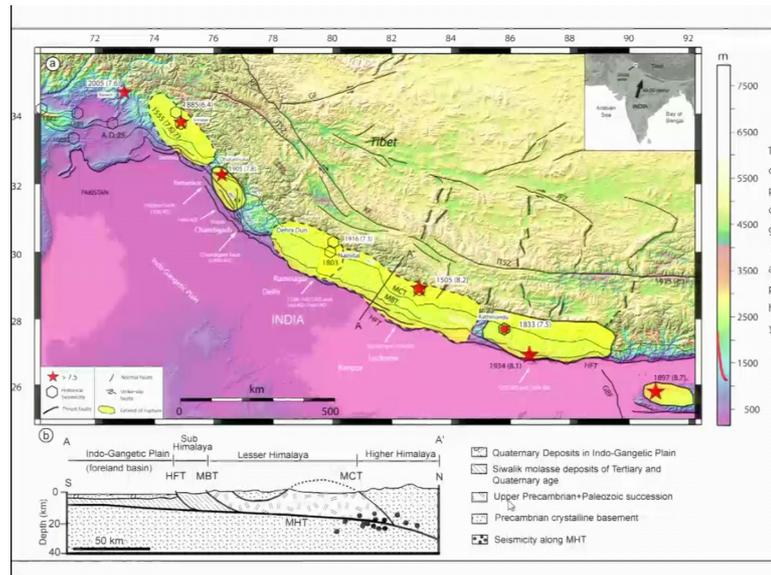
So, welcome back.

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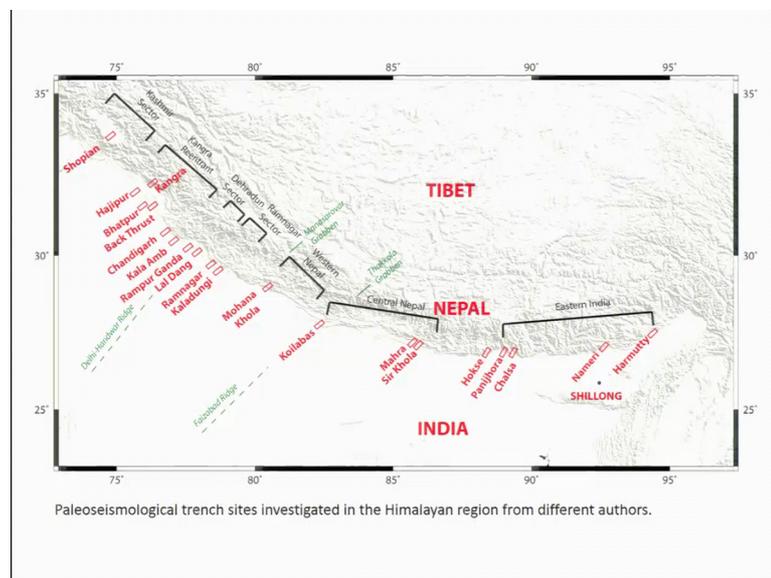
So, in this lecture, I will very briefly talk about, but maybe I will go in detail and talk about the earthquakes which has been triggered in along the Himalayan front during the historical past and recent. So, as we I discussed in the previous class that we have very old earthquakes which have been triggered in Himalaya over here. Still other than this we have another map, which shows about that the earthquakes goes back into the history I can just try to bring that slide here and talk.

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So, if you look at this we have the earthquakes which have been triggered in recorded in AD 25 and then further old events and along with that we have the recent events also which were triggered in Nepal that is 19, 2015 earthquake.

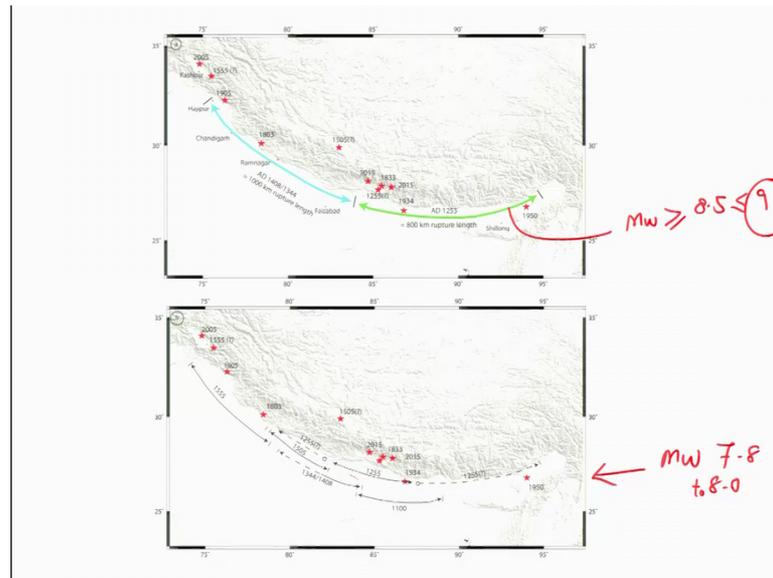
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Now, what is basically happening here is that we have the frontal range of almost like more than two 2000 kilometers and those locations which are shown in boxes here shows the geological investigations, which have been taken up to identify the signatures of the paleo earthquakes.

So, pretty good number of a trenches were been dug across the false curves in Himalaya and what we found was not there is an overlap in ages because we tried to find out the ages of the layers different layers which are the space layers and try to understand that what when was the event when during in the historic past or maybe before that also. So, these are the locations which have been listed here the location of the trenches.

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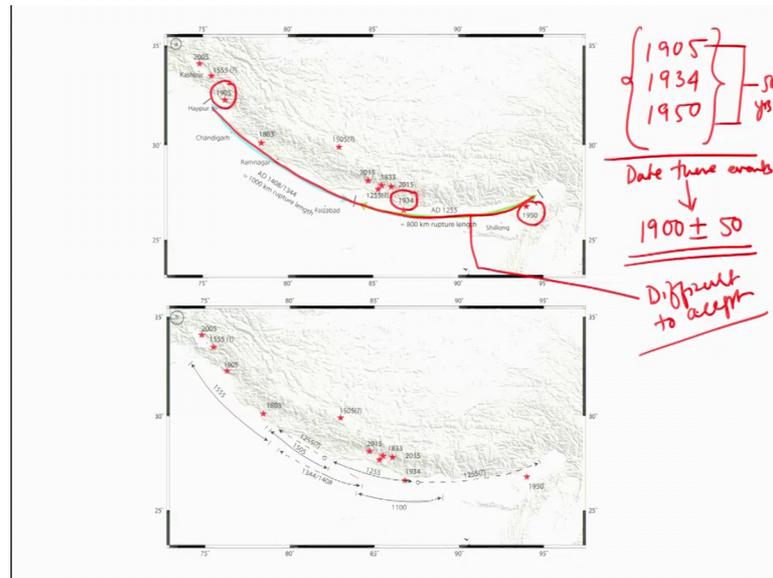


And, then what we when we observed and inferred was that there could be in two scenario. If we consider all the trenches and the overlay overlapping ages then we end up saying that whole front got ruptured in two major events one was during 1200 to 1300 AD and another was around 1400 to 1300 AD within rupture of almost like 1000 kilometers or 800 kilometers. So, then we have released the complete strain which was available with us.

The other scenario is that even with the overlapping ages we can have multiple earthquakes that could have marginally ruptured the different segments. In that case, you will have an earthquake multiple earthquake for example, in 1555, then 1505, 1255, 1344 or 1400, 1100 and so on. There is an equation that because the ages, which have been found along this range in trenches or during the geological investigations probably suggest that this whole area was ruptured in 1255 AD earthquake. So, we can so, in that case what we are doing that we are saying that this may be an earthquake of magnitude



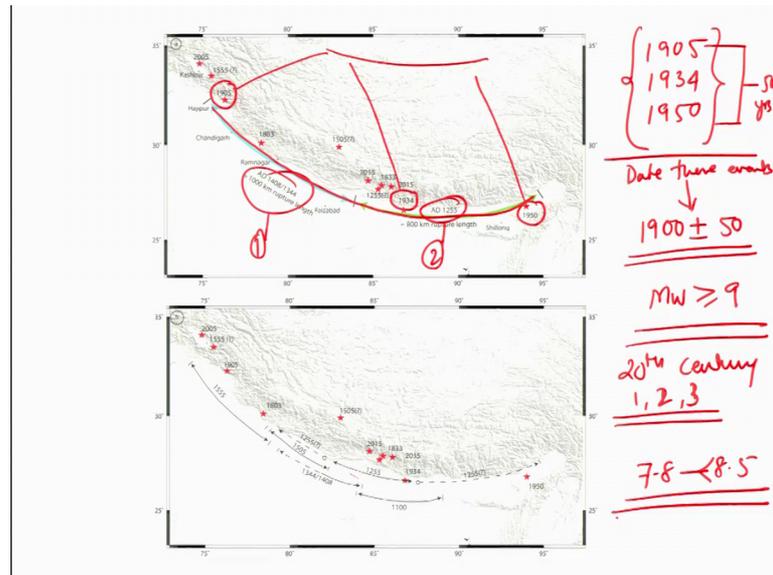
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Now, going back to this part and what I would like to emphasize is that if you look at the earthquakes which are triggered in twentieth century. So, one is this one, another is this one and third is this one. So, we have 1905, we have 1934 and we have 1950, these are the three earthquakes which we are having. Now, the difference between these two earthquakes is hardly 50 years.

Now, after 100 years suppose we date these events what we are going to see is that we can say that all events occurred in a range of around 1900 plus minus 50 or so, it is just I am roughly talking about then in that that case I will be able to rupture this whole front which is bit difficult to accept.

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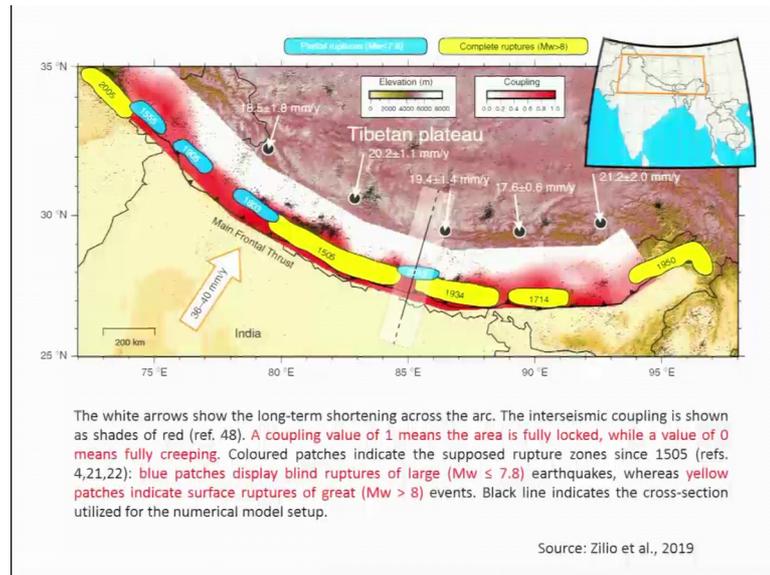


Now, if you rupture this full front then you need a magnitude rather than equal to 9, but this was not true which we experienced in twentieth century there were three earthquakes which occurred at different point of time in rupture different portion. Similarly, based on this exercise which we did we have tried to infer and we are of opinion that there were three or more than three earthquakes in this region which were responsible for rupturing the complete trend and not only the two events which were responsible in rupturing the complete trend that were in past, like this I am talking about that these two events, that is 1200 AD and 1400 AD event; this was not the only two.

But, if you want to infer come taking into account the overlapping edges then you can say that there were only two events this was one and this was another one which completely ruptured the whole front. Similarly, if you want to take this three earthquakes here then also you can say that this whole front was ruptured that is again not correct.

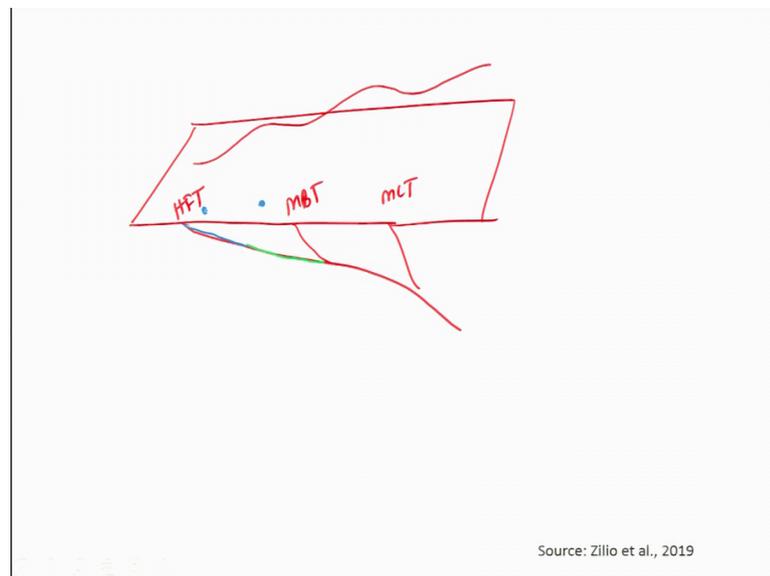
So, considering all the scenarios and the best fit scenarios we are of opinion that Himalayan frontal thrust or the Himalayan region can host earthquakes with magnitude around 7.8 to 8.5 and, but not more than that or even less than 8.5 that is what we would like to emphasize here. Because this paper we have already published which we will try to make the link available to you so that you can refer it.

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Now, another scenario which comes up is that where these earthquakes were triggered? Whether these earthquakes were triggered along the front or they were triggered in the hinterland side.

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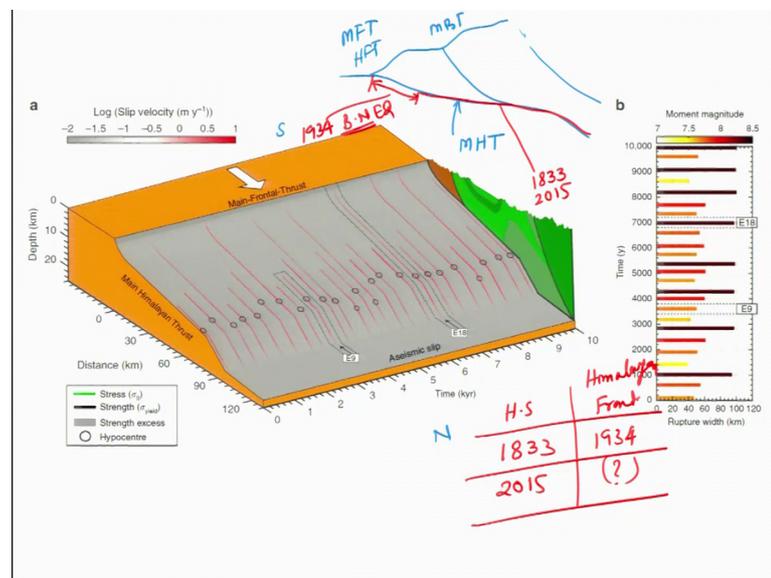


So, when I say they along the front or the hinterland side then I would like to just put in sketch here that we have the Himalaya this is see like here lesser Himalaya then you go up higher Himalayas and all that, and then in section if you want to see and what you are able to look at is and that this is the section here. So, we have the MCT then we have

MBT and then we have the Himalayan frontal thrust; so, MCT, MBT and Himalayan frontal thrust.

So, question which is coming up is that whether this part was ruptured I will use different pin so that you can easily make out. So, whether this portion got ruptured or this portion is getting ruptured, ok. So, out of this like whether the earthquake was triggered here or it was along this one this is an important part and this what has been explained and or tried to understand either east to the recent earthquake of Gorkha, 2015. So, what it was been found that? This earthquake was triggered in the down the portion. It did not reach right up to the Himalayan front.

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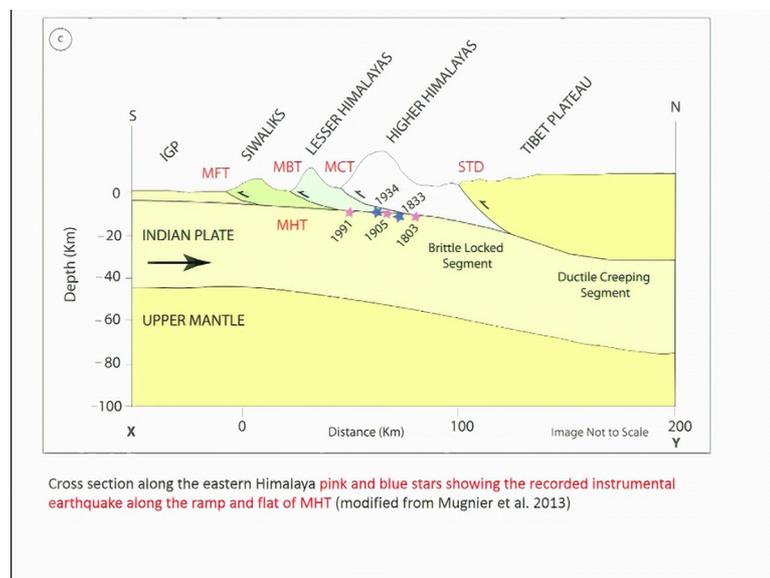
So, this is the section from this we are looking to this a south and this is the north side. So, it did not rupture the front. So, if I take the section here then you will be able to see something like this. This is the Himalayan front and then we go up. So, this goes like that. So, you are having MBT somewhere here and then you will get MCT we are sitting here ok. So, this is HFT or you can say main frontal thrust this will be your detachment main detachment of the Himalayan main Himalayan thrust, this was detachment or the calm and this is your MBT.

So, the question now is then what has happened what was experienced was that this did not come right up to the surface? It ruptured somewhere over here actually. So, still this portion is likely to rupture and this is what people are inferring or the research groups are

referring them this will rupture in near future. So, this part which got ruptured was very much similar to the earthquake which was triggered in 19 1833 and then what we had and was in 2015. This portion was ruptured and they believed that this was ruptured in 1934 this is in Bihar-Nepal earthquake.

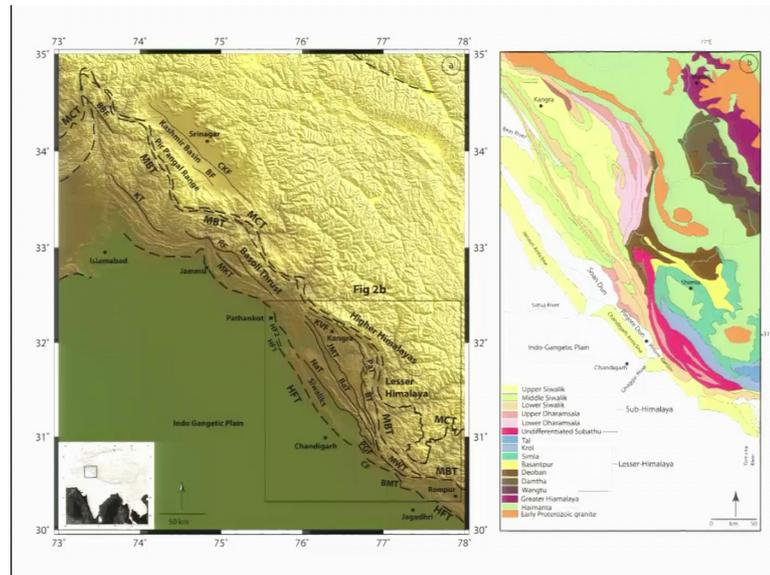
So, if the cycle what we see is correct at 1833 was in hinterland side and 1934 was along the front then hinterland side we had another one 2015. So, next we can expect and the frontal part. So, this is what we have like many groups are talking about and we can expect the another event the major one similar to 1934 along the Himalayan front in near future.

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So, these are the scenarios which have been given like that the rupture initiates far behind the Himalayan front along MHT and then the deformation propagates towards the south.

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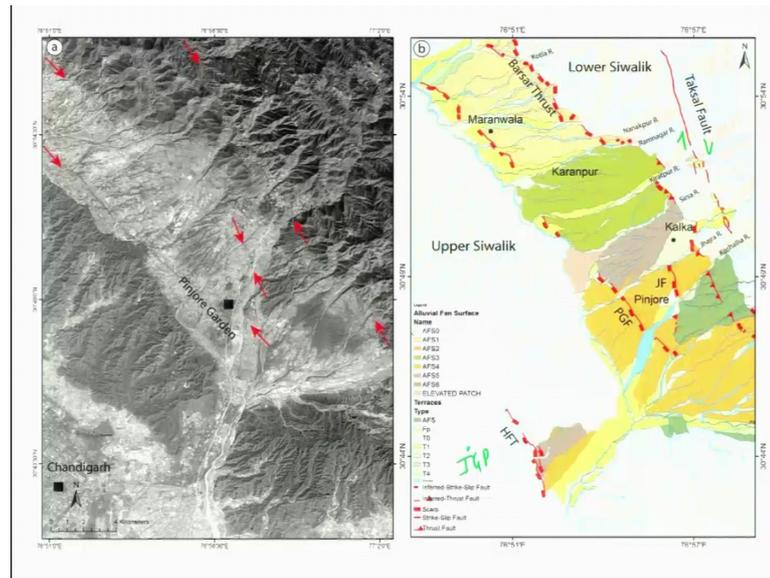


Now, why I will just quickly show you some results which we have done and what type of studies we are doing to understand the past earthquakes and what are the signatures we see on the surface. This is from Himalaya the case study; as well as I will talk about some very important modification of landscape or this sculpturing of landscape took place from Great Rann of Kutch, western India.

So, this area falls close to Chandigarh where we have an very prominent Himalayan frontal thrust fault line and then along with that we have another indicated fall system which have been seen between MBT and HFT; MBT is your main boundary thrust. So, this area is we say Chandigarh and Pinjore Doon there is in this area which has been shown here is the intermountain valley between the two hill ranges this is Siwaliks and this is this is lesser Himalayas which we see.

So, there is an valley between that. So, the study which we took we conducted in this area is from this region.

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So, we have marked based on our interpretations on satellite data several fault lines. Chandigarh is sitting somewhere over here that is in the Indo-Gangetic plain and then the frontal part starts from this place. So, we have a number of faults. This is the part of the HFT named as Chandigarh fault and just move ahead towards the northwest-northeast you will find there is another fault which is running and crossing the Doon Valley; Pinjore Doon valley and we have named this as an Pinjore Garden Fault. Then there is an oblique fault here Jhajra Fault we have another one which is Barsar thrust and then we are having another fault named as Taksal Fault. Now, this Taksal Fault is your right lateral strike slip.

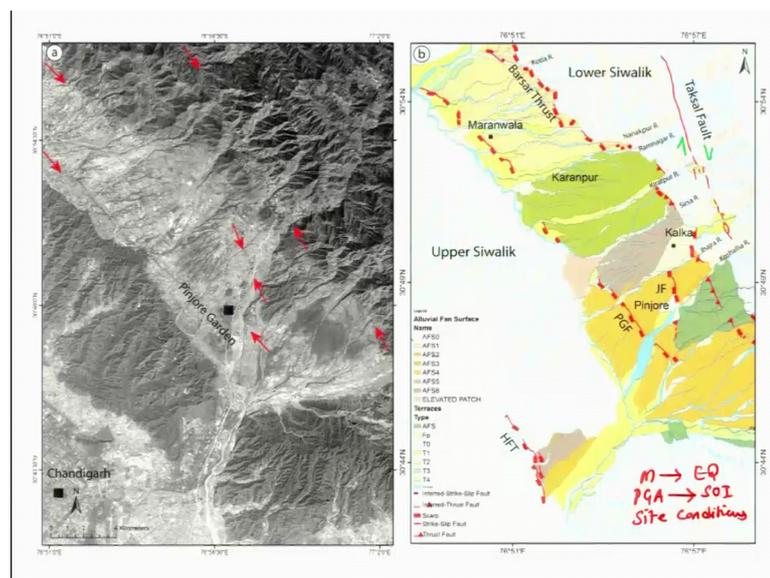
So, based on the topography of the active faults we classify these active faults and different types for example, whether they are thrust faults or they are normal faults or they are strike slip faults. So, mostly the faults which you see here at this Himalayan frontal thrust is in thrust type.

So, it is very typical in the compression tectonic environment this is also thrust, but this one is flight oblique which shows both component thrust and reverse thrust and strike slip component. This is pure thrust and this is we are having right lateral strike slip. So, we have very beautiful off set of streams and offset of land forms which were been identified and based on this the mechanism of the faulting that is which type of faulting it is we have decided.

Now, my only point here which is like very important one that if you take the scale this is hardly 30 to 40 kilometers or maybe less than that and within that distance we are having almost 1 2 3 4 and 5 faults which are sitting and all fives are at factor fault. So, the hazard posed by this faults because this faults are capable of triggering large magnitude earthquake that what our research says. So, any earthquake hosted by this faults if magnitude is greater than 7, definitely the region which are sitting in the Indo-Gangetic plain in the nearby area or in the vicinity of this faults are definitely going to be affected.

So, from hazard point of view now a seismic hazard assessment need to consider this faults and what is the history of earthquakes on this fault that is also another important point which we need to consider.

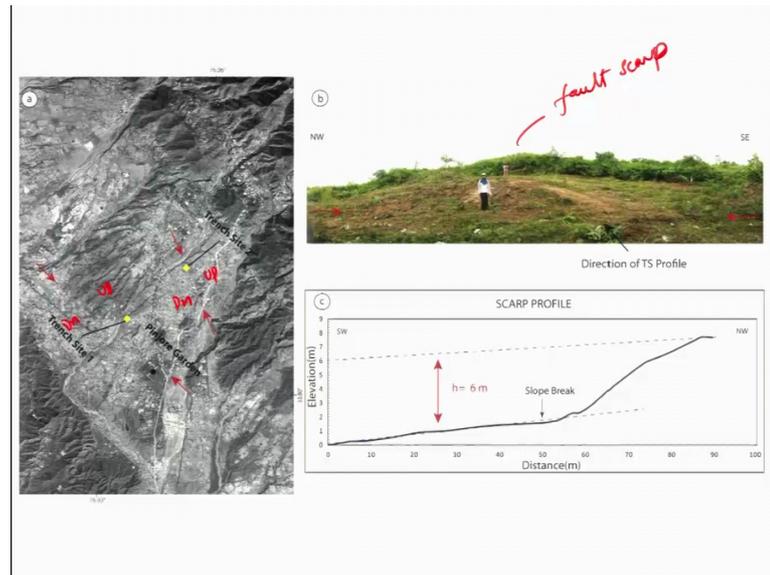
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Now, in one of my class I was talking about the need most important part which we should deal with will be one as the magnitude of the earthquake; then second is that what will be the expected peak ground acceleration at the site of interest. So, this is this is very important because it will vary from place to place that is ground acceleration will not be the same at all locations because it depends highly on the on the site conditions.

So, these are very important points which we will discuss when we are talking about the ground deformation and ground effect a different topic, but it is related to the seismic hazard.

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So, after identification what we do I will just quickly browse through couple of slides. We take the detail we undertake detail mapping of the landforms which we have identified from the satellite data. So, this is the high resolution satellite image carto set image and the resolution is almost at about 2 to 2.5 meters and we what we do is that we use this image which is also corrected and this image has in stereo vision and made with the stereo vision capability. So, that we see the terrain in 3-dimension that helps us in identifying the deformation which is preserved on the on the surface and young landforms are been displaced.

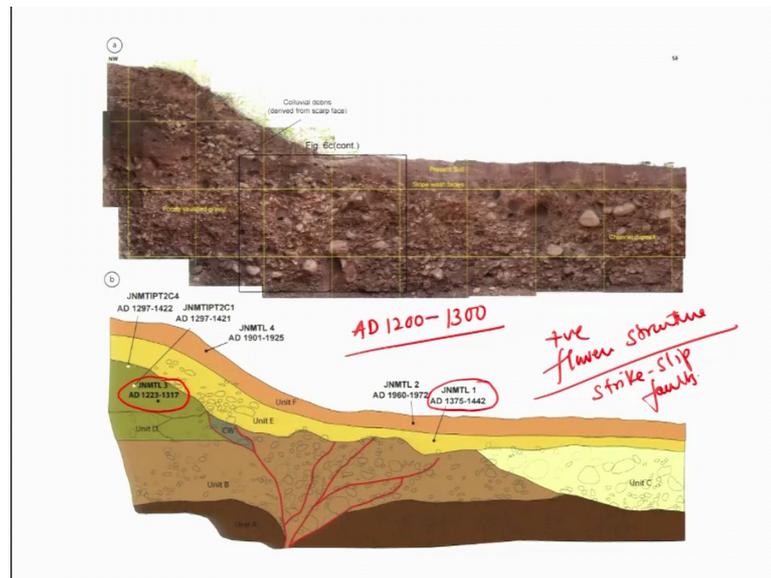
Now, for example, which I have we have put the arrows here he will you will not be able to differentiate easily whether this side is gone up or this side is down, but since we have looked this image in 3-dimension or 3D prospective view we know that this side is up this is down and relatively to this fault line this side is up and this is down.

So, we know this very clearly and we understand that what are these sharp features which we have picked up. So, the portion the photograph which has been shown here is taken from this place here and this curve which we say faults curve this faults curve is along the Pinjore Garden Fault.

So, what we do after the detail mapping we take an profile topographic profile either you can use very high resolution like GPS-RTK you can do real time kinematic or you can take with the total station also. This information is available because when we have the

ages of this surface then we can easily talk about that how much what was the rate of offset of this surface within in time. Then that you can we can that can help us in understanding that what is the frequency of earthquakes which have been hosted on this particular fault in past.

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Even we can talk about to some extent the future prediction. So, this is one of the trench which we have dug over here on the Jhajra Faults and this showed us a very clear cut branching pattern and what we typically say as in positive flower structure. This positive flower structure is commonly seen in strike slip faults the positive flower structure means if we are having this as these are all popped up, ok.

So, this has gone up this is this has gone up like that. So, this is this a very typical positive flower structure with developed because of the right lateral movement and also the reverse component which has been seen. Now, what we do is a very simple way we try to identify or judge the events. So, we see the cross cutting relationship of the faults and where the fault or the deformation is getting terminated that will be ever capping unit. So, for example, if you have to date this event that is the faulting which displays this gravel, but was finally, capped so, there was no deformation on top of this. So, this layer was not disturbed.

So, at least you can say that if you are having the edge these are the edges carbon 14 as well as OSL edges optically stimulated luminescence we collect quad samples or the san

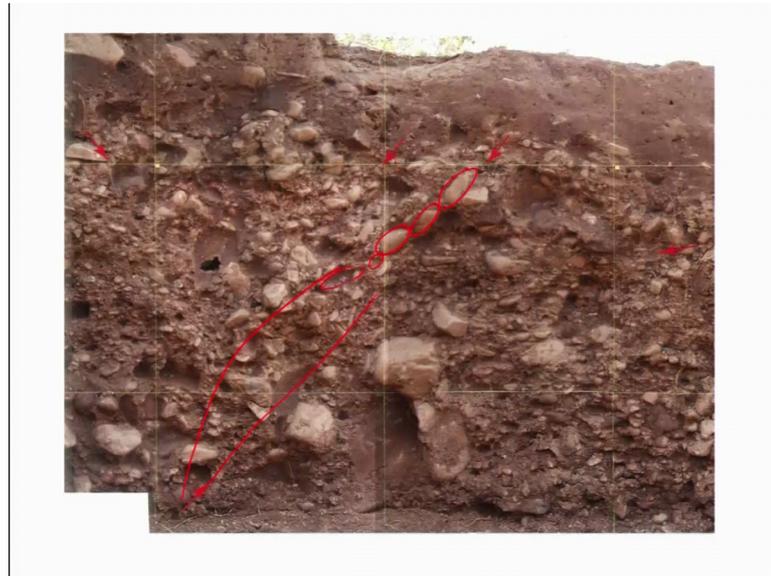
samples which are not exposed to the sunlight then we process that completely in our lab. So, based on the energy or the dose which was a key which got accumulated over the time in the buried quads that is exposed and stimulated artificially or with the help of what we say optically stimulated luminescence and then the energy released is measured and then we do that ok.

So, that is in completely indifferent topic, I am not going to talk about that here, but at the important point is that these are the edges which we are getting from OSL for example, are the depositional edge that is the time at which the sand grain or the sand or the sediments got deposited and buried. So, this is these are the edges which we are having from OSL the edges with the C-number here which we have letter are all are charcoal edges. So, we do aim is accelerator mass spectrometry dating that that sample edges we are having.

Now, what we see is that since this is the capping unit then we try to look at the oldest edge of this unit which is close to for example, the and the contact between the unit B and then unit E. So, if you get that we will pick up for example, if you take this one age of the capping unit which is the probably the oldest one or here and then minimum edge of this one somewhere here, ok. So, we got what we got was the age here that is of this unit which was because this unit was also disturbed, but it was not this default did not rupture or fracture this unit; that is unit E.

So, we took the age of a this unit D. So, hence we can bracket the event that we can say that this earthquake which ruptured or deformed sediments occurred somewhere between AD 1223 and AD 1375 or we can say 1442. So, this will be the age bracket we can say that this becomes an event of like AD 1200 to 1300 AD event. So, they said these are the ways which we have tried to incur incorporate in our data.

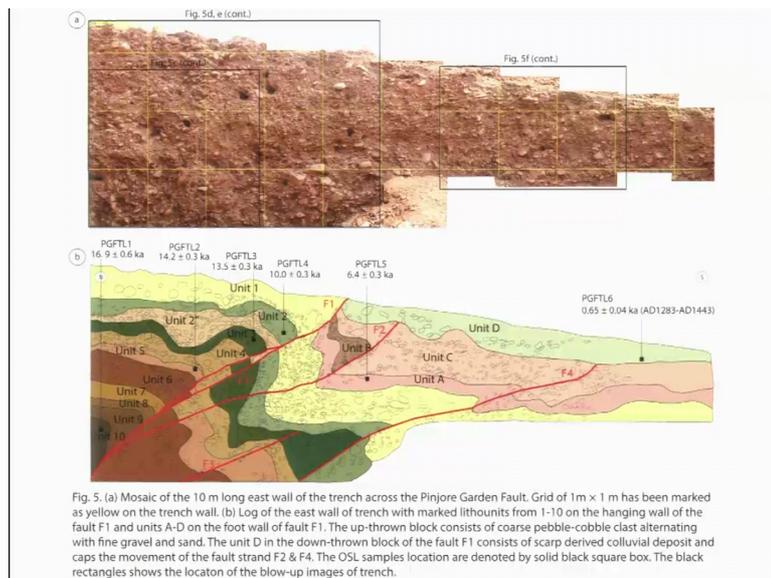
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And, then the features which were been shown in the previous slide we try to map the displacements in the exposed trenches as shown by the arrows this is what we call the sheer fabric.

So, we have we are having most of the other gravels which are elongated over here along the high fault. So, fault runs somewhere over here like this and then like this also, ok.

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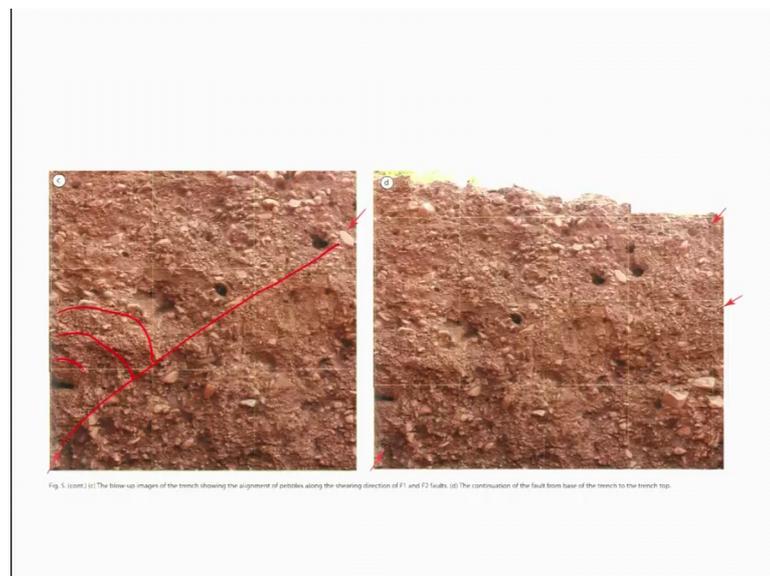


So, basically what we do is that this is another that is the same figure, but the different location which we dug the trench across this. So, we have we open up the another trench

here to look at the different upon machine pattern as well as the events which have occurred. As I explained in the previous trench the sections which were excavated across the fall scrap that was from Jhajra Fault this is from Pinjore across the Pinjore Garden Fault.

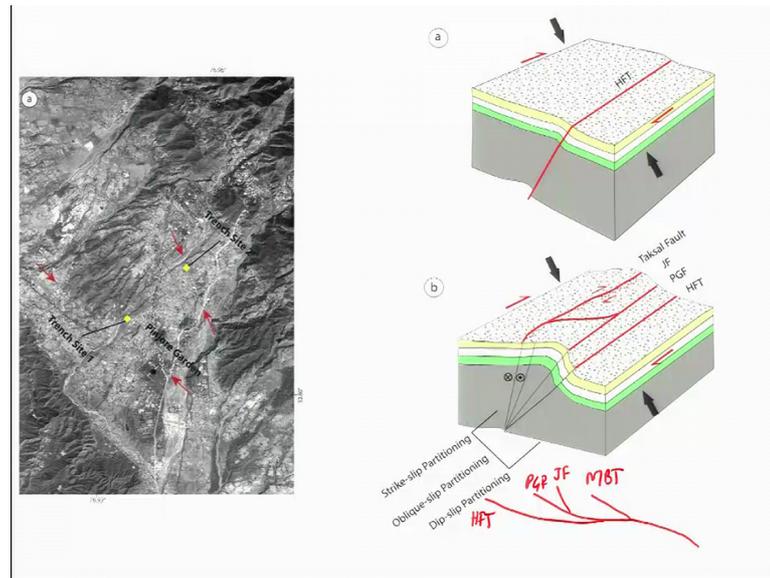
So, we have we identified like we say that fine because this is the top most unit or the unit which on there is no capping here because we were unable to find the capping on this and the most recent event took place along this faults where the younger unit that was also this displaced. So, we bracketed the event because there was some problems related to the in the top unit, but anyways in short what we are interested here to identify the deformation pattern and try to bracket the events.

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So, this is again similar shared fabric which has been shown here and you have the deformation pattern which has been like enfolding we see here like this there is a fault plain and the folding is taking place over like that.

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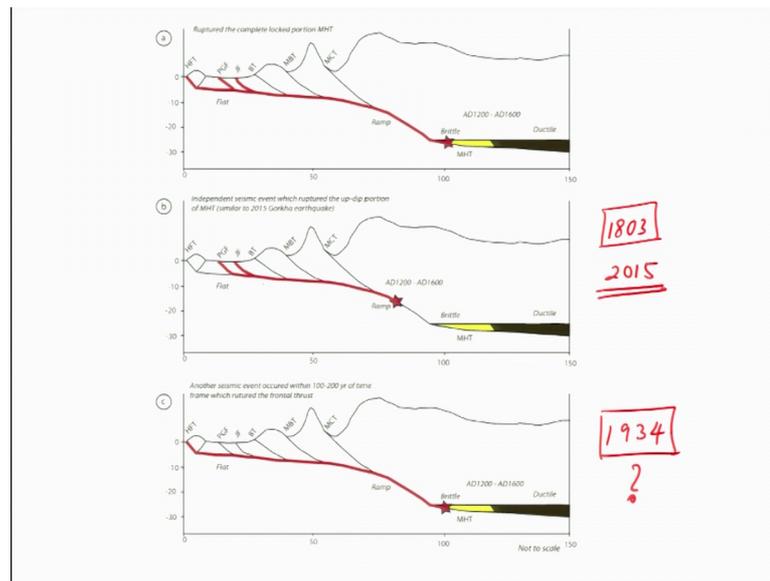
Now, this is the model which we have proposed, but of course, the most important part why I am showing this model is that these are all out of sequence events, which we have identified on Pinjore Garden and Jhajra Fault they are all out of sequence. So, this the sequential pattern which has been suggested is that that the from the hinterlands side you will have the deformation here, then this will propagate over here and then in the frontal part.

So, this is like for example, what we say the HFT, then this is your another we can say Pinjore Garden Fault and then one is here another one which is coming here is Jhajra Fault and then we are having I want to say MBT. So, if we say sequence faulting and sequence deformation then what we should have got is that first earthquake would have occurred here then it was next to here and third here. But, this was not true in the case what we identified on this faults probably this where the events which we talked about the out of sequence, but one very surprising thing which we noticed was. So, this was where our understanding that what we see here.

But, the dates or the ages which we got what we found was that all this fault the edges of the events which we bracketed are falling in the same domain of the time range. So, HFT we did not do, but previous we have done one trench on that and that says suggest about 1300 to 1400 AD event. Here also it was more or less similar it was here it was a more or similar.

So, there was an big confusion, which was created that all those faults probably moved together in one go or there were different events in the same the time range or either we use 100 years time region out one or 50 years time range. So, that is another scenario which we have suggested. But, basic the topography which we have been picked up we have picked upon from the Pinjore Garden Fault clearly suggests that there is an oblique slip partitioning which is taking place and the case of and slip partitioning over here.

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So, these are the scenarios which we have suggested that is quite possible that in scenario 1, what we suggest is that they there was not deformation or the earthquake which occurred close to the brittle ductile boundary along the ramp and ruptured right up to the surface even displaced the displacement was been consumed by the Pinjore Garden and Jhajra Fault. In second scenario, what we suggest is that there was another event because if you if you trigger an event here and bring the rupture bond close to the frontal part then you need in very large magnitude earthquake.

But, here if it is on the on the ramp side then taken up by the flat structure then probably these two fault move together and one earthquake or there is an there is an scenario that there was a major earthquake which separately moved this HFT, ok. So, these are the three scenarios which we have projected that either all the rupture the complete log segment that is this because this is an log segment what we have we are looking at, it ruptured right up to the surface breaking all the faults. Then independent seismic events

which ruptured the update portion of the image see this is the update portion of the image B, similar to Gorkha earthquake.

And, another scenario was the seismic event which took place after the event which occurred here on Pinjore Garden and Jhajra Fault resulted into the rupture here and this is the scenario which we were talking in the previous slide similar like 1934 and this was similar like 2015 and then before that there was 1803, ok. So, this two have already done with. So, this have a this as occurs when other is could be expected here.

So, I will stop here and I will continue in the next picture with more examples from Kutch.