Earthquake Geology: A tool for Seismic Hazard Assessment
Prof. Javed N Malik
Department of Earth Sciences
Indian Institute of Technology, Kanpur

Lecture – 41
Compressional Tectonic Environments and Related Landforms (Part-VII)

Welcome back, so in the previous lectures we discussed the geomorphology of the active regions and mainly, we looked at the tectonic geomorphic features or the markers on the surface and I was showing the example from Central Himalaya that is Kumaun himalaya where we were able to see some paleo wind gaps or uplifted paleo channels of Dabka and Baur River and let us go further.

What we identified from the trench and how we did? And how we proceeded for the trench after identifying appropriate locations? And this part, I have already discussed in the previous lecture, the best location to dig the trenches, to identify the youngest landform which is displaced and at the same time we also look at that if those areas are not been disturbed by any human activity. Even if the area is quite eroded, then you will not be able to pick up the sharp signature on the satellite data.

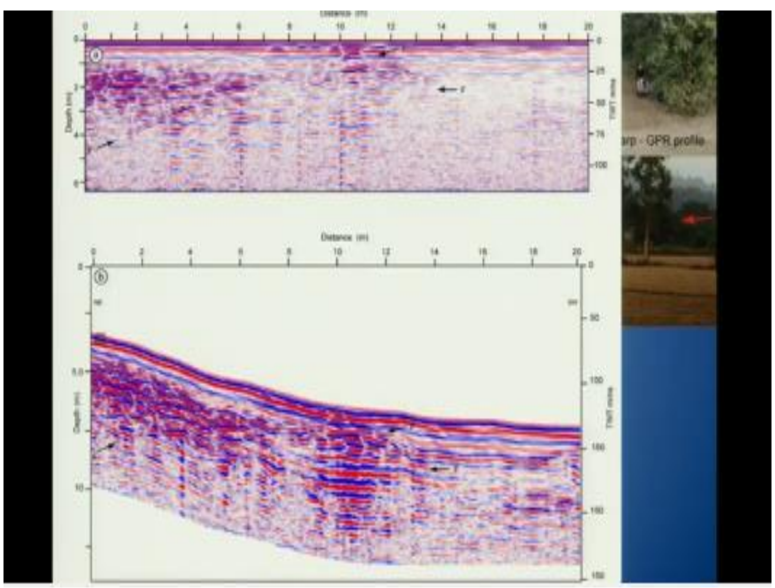
Hence you will avoid those locations but once you have identified after doing detailed field work. But the appropriate site is good in terms of excavating the site and all that then you can proceed further and for mapping.

(Refer Slide Time: 01:45)

So now, if we look at the field photograph of the location here, then what we see is that we clearly make out there are two scarps. The front, one is the younger scrap and then you have the older fault scarp at the backdrop, here and the front side is your Indo-Gangetic Plain. So we identified this scrap which was the youngest scrap and after having a detailed survey walking down along this scarp, we identified appropriate sites for digging.

And this was, of course because in the forest area, so we were also concerned about that, we are not going to cut trees and all that. So we identified the appropriate area and before getting into the trenching part, we did a GPR survey which helped us in fixing up our trench boundaries.

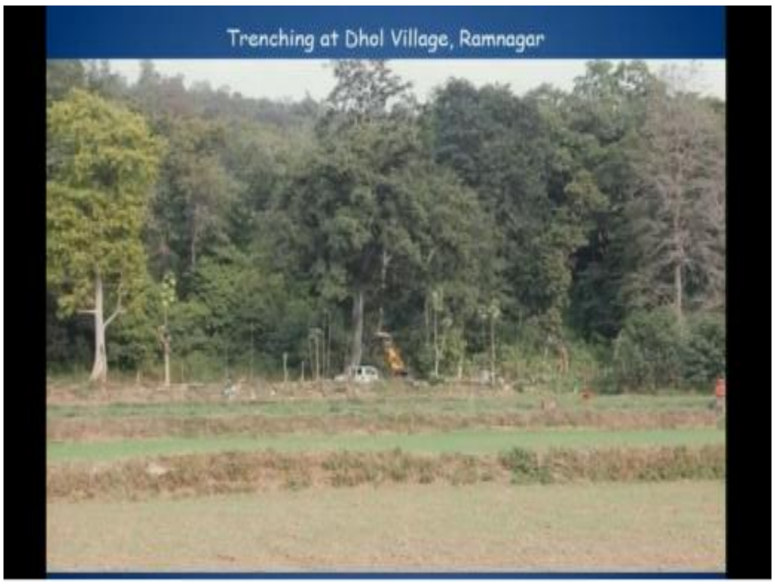
(Refer Slide Time: 02:41)



So this was the GPR profile, this is not I would say that this is a raw profile, what we took this not processed at all. But this is not for further, we added the topographic corrections to this, as well as the slight processing part. So after processing, we clearly see the low angle fault cutting and the deposits young deposits and since we until we are unable to open we will not be able to say that this is young deposits.

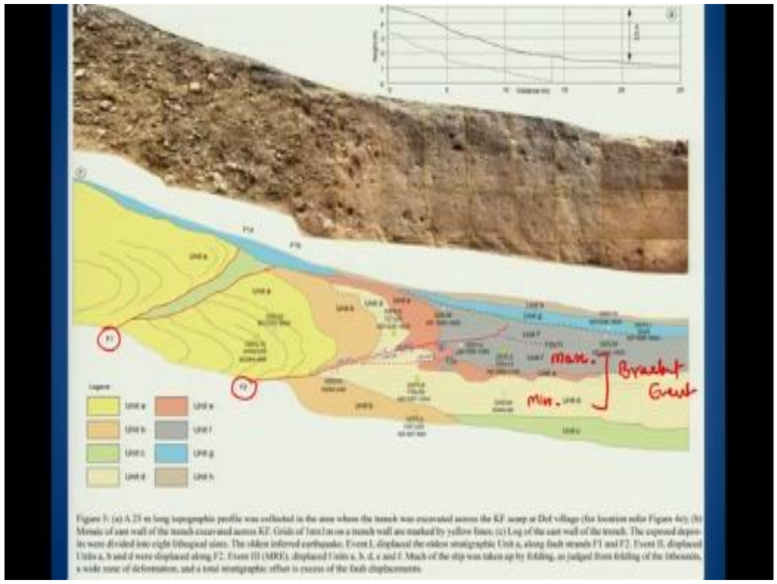
But of course, looking at the topography here that was at least confirmed that this scarp is as developed by displacing the young deposits in these areas. We are confident enough that, whatever we are seeing is the near surface stratigraphy and has to be in young deposits.

(Refer Slide Time: 03:37)



So, finally we started opening the trench and what we did cleaning in that part of everything, I have and what we will do after cleaning the trenches? We will grid the trench and all that, so I will just straight away move to the trench log, what we how we interpreted; the trench in this area.

(Refer Slide Time: 03:58)



So, this is a photo mosaic of the trench, which was escalated across this curve here and which goes almost like about 10 to 15 meters and this is the topographic profile we have and the trench portion has been marked by the dotted box here and after mosaicking the photographs you can prepare a detailed sketch, but this be we did as I have discussed right in the beginning, that we did the sketching of the trench precisely using the grid in the field on a graph sheet.

And we demarcating at different units in the field itself because that will help you in identifying the fault strengths, as well as the contact between the different units here. You can clearly match a few more units which are showing prominent contacts. For example, this contact is very prominent here and it is quite clear that we can see this structure within the gravel which is folded along the low angle fault here.

So, after having detailed cleaning and all that and after the demarcating the boundaries between the different units. We mark the fault which goes right up to this point here. And of course, a few doubtful areas which could be the portion or the erosional contact we have been marked by this one thing is very sure, that at places, we were able to see very typical norcheres which we have developed within the sediments.

And this could be a result of bulldozing effect and the displacement along the default strength. So in this trench, we were able to pick up two fall strains F1 and F2 were the major one and since, what we saw is that the F2 has displaced more younger units. Hence we concluded that the F2 was the fault strength, along which the most recent event took place and was stratigraphically, if we maybe reconstruct the stratigraphy of the sediments, which are deformed of course then unit A is the older one and unit H is the youngest one.

So this is a topographic surface. What all we did in this was that we also measured the displacement amount of displacement between different units and that also helped us in understanding what we see there. For example, we are seeing here in this play, the displacement of unit B is almost like 170 centimeters.

This, we have taken into consideration the outer boundary, this one here and this point here, meant almost like 170 centimeter and then further we have marked the contact that is we have considered the either the upper bounding surface or the lower bounding surface of this respective unit. So here what we are looking at the lower bounding surface of unit D. For example, to see this displacement then we took this part and then this one here, which shows the displacement of almost like one this is the tip we have considered and this one is here.

So this gave us a displacement of 110 centimeter and then, more than like 35, 40 and 25. Now, with marking this all displacement along with that, we also measured in the field the tip angle of the fault strength here. Both the fault strength dependence will be measured and then the samples were have been collected keeping in mind and the hanging wall and the footwall and then again, when the events were fixed.

For example, which were the, because this shows the maximum displacement of course, then this becomes the unit which was displaced at least for more than two events and this one is showing the maximum displacement which we were not able to figure it out, because we do not have the same unit on the footwall side. Anyway, then what we also interpreted here that this unit c did not get displaced along this strand, so this is sitting away from the deformed area and on the footwall.

So let us see what all the ages which we have found here will tell us in terms of bracketing the events, now the best way is that we usually take the, suppose this is the unit here and the ages which have also been calibrated ages and calendar years we have given here in AD and BC often, so we have the OSL ages, we have carbon ages over here. Now, we will take if we have, this is the event horizon and this was displaced at the time of the earthquake.

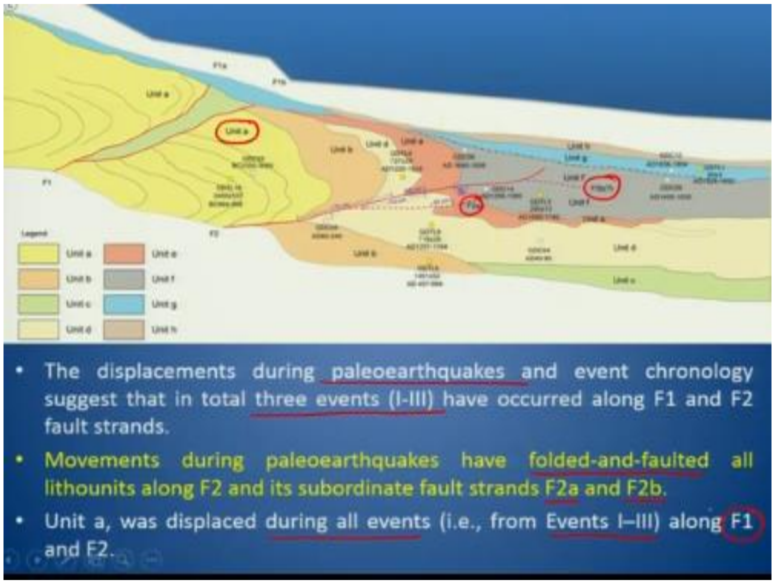
Then what we will take the minimum age of this unit. That is little, the last depositional age of this unit we will take or if we are having the charcoal. Then we will take the youngest age of this particular unit and then the oldest of this unit. Because this is scraping the minimum and maximum of this and that will allow us to bracket the event. Now, for example this age of this unit, that is unit D, what we have is AD 40 to 80.

And then you are having 1200 to 1300 and then you are having 1200 to 1300 here. So we can consider one of the ages from this because this will become the older age, but this is the young comparatively younger age and this is more younger. So we will take this age as the minimum age of this particular unit d and similarly, if you have the age of unit e in our case, we were unable to find any effective sample from this.

So what we did, we consider the age of the immediate overline layer, that is your unit f, so the minimum age of a unit f, because that what we are we want to say that, this was the scraping unit and this was deposited after the event. So that younger age of this one, we will take and sorry the oldest age because the younger age will be on the upper side. So we will take the older age of this one.

So the minimum age of this and maximum age of the overlying unit we will take and that will allow us to bracket the event. Now let us see further, how we have interpreted this trench in particular.

(Refer Slide Time: 11:51)



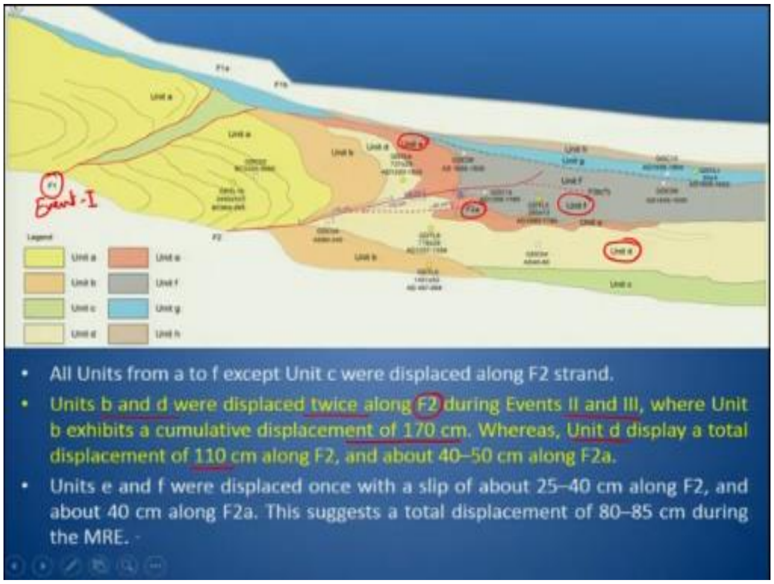
So based on the interpretation, using all the cross-cutting relationships along the fault and different fault trends and the ages we interpreted that at least 3 events have occurred along and we were able to identify at least three events along the Kaladhungi fault, that is an imbricated fault of HFT. So we say that the displacements during paleoearthquakes and the event chronology suggest that the total 3 events have occurred along F1 and F2 strands.

So at least 3 events have occurred along with F1 and F2 strength and out of these 3events, 2 events have occurred along F2 and one event which was the older, one along F1. So most moments, during the paleoearthquakes have folded and faulted all the 3 units. Along F2 and it is subordinate falls which were F2 a and F2 b so you have F2a here and F2b is this one, so what we see is that it has just not displaced the units very sharply.

But it has also resulted into a major folding here, so this was again and very important like observation, which we were able to identify from the trench a lot. I will explain this, so this is a typical of what we were looking at the sandbox model that if you are having a low angle fault which is bending close to the surface, then you will have the fault propagation folding along the tip of the fault, so this was a typical folding we see.

Now, the unit a, which is the oldest one was displaced during all events. So that means it got displaced along F1 as well as it got displaced along F2, so there is a stratigraphy, it is the oldest one, so it was displaced along during all events right from event1 to event 2, event 3 along F2 and F1.

(Refer Slide Time: 14:41)



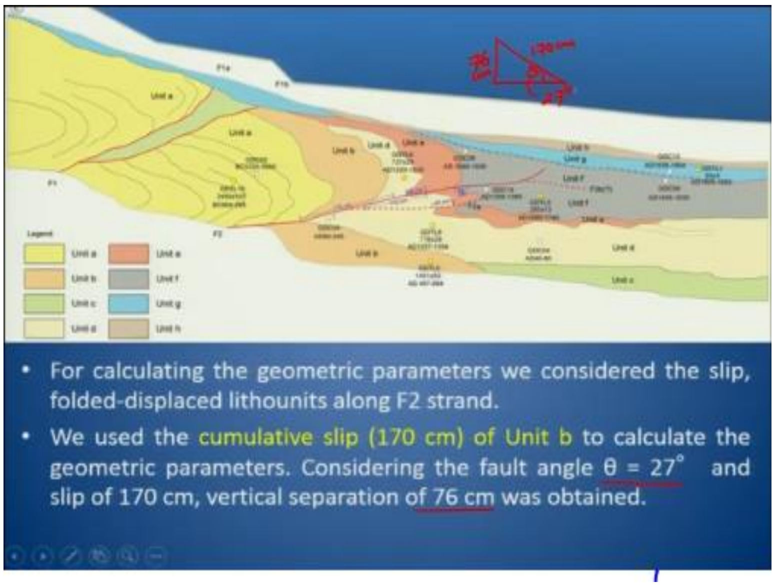
Now all units from a to f, expect c were displaced because c as I explained that c was lying far away. And the footwall from far away, from the deform zone and the footwall area hence it was not affected. Now, unit b and d, so if we take unit b and d, so you have unit b and unit d as this one were displaced twice and that was along F2, during event 2 and 3 because if event 1 was along F1.

Now we are talking about event 2 and 3, so these 2 units were displaced twice and they show a cumulative displacement of 170 centimeter this is what it comes to here 170 centimeter, so they were displaced twice whereas unit d displayed a total displacement of about 110 centimeter along F2. So this what we saw as that it is displaced 110 here and there the rest has been consumed along the F2a.

So this around 40 centimeter has been consumed so this becomes more or less similar to what we see here. So around 40 to 50 centimeter along F2a and this was for unit d. So unit e and f were displaced once with the slip of about 25 to 40 centimeters this has been shown here, so e and f and this is also good it is displace and this during this event, this unit f was also displaced and this one the unit e and f were displaced along F2 and about 40 centimeter along.

So event e was displaced about 40 centimeter very much similar to this along F2a, so this was displaced along F2a here and then 25 to 40 centimeter, which we see here along F2. Now this, since there is no displacement, which has been taken up by the capping unit e, so we say that this was the most younger event or we can say the most recent event MRE.

(Refer Slide Time: 17:36)

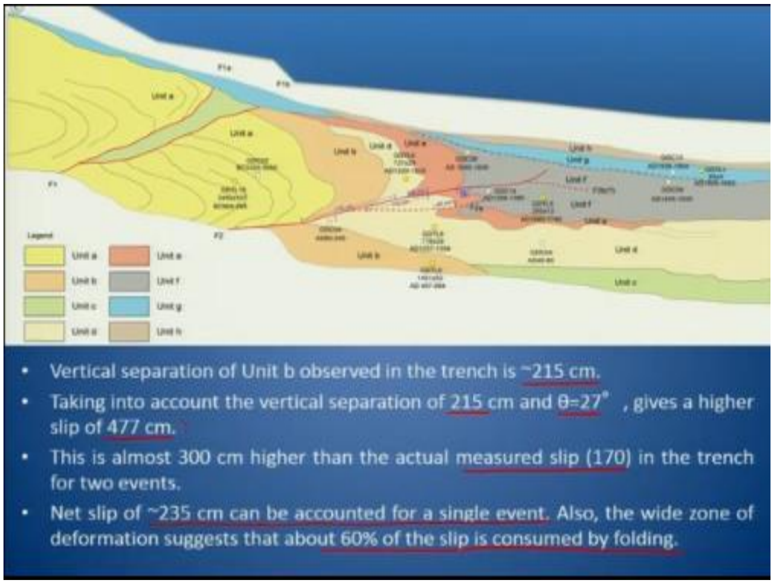


So for calculating the geometrical parameters, what we did was that we considered the slip one, folded and displaced the three units, along F2. So you wanted to go back into the deformation pattern and reconstruct how the deformation exactly took place. So, we use the cumulative slip of 170 centimeters of unit b to calculate the geometric parameters. So we used a very simple trigonometry here like for considering you have the fault angle here.

And then simply we are using in the trigonometry in that sense and then the angle which we took was around 25 at an average angle of this one and this you will get by when you measure the tip angle in the field, so this we consider 27 degrees and the total slip of 170 centimeter, vertical separation which gave within simple trigonometry around 76. So this was this we considered and we obtained using the angle.

And the slip we got 76 centimeter of vertical displacement, that is your this one and slip, you are taking here like 170 centimeter here and theta you are taking around 27 degrees.

(Refer Slide Time: 19:05)

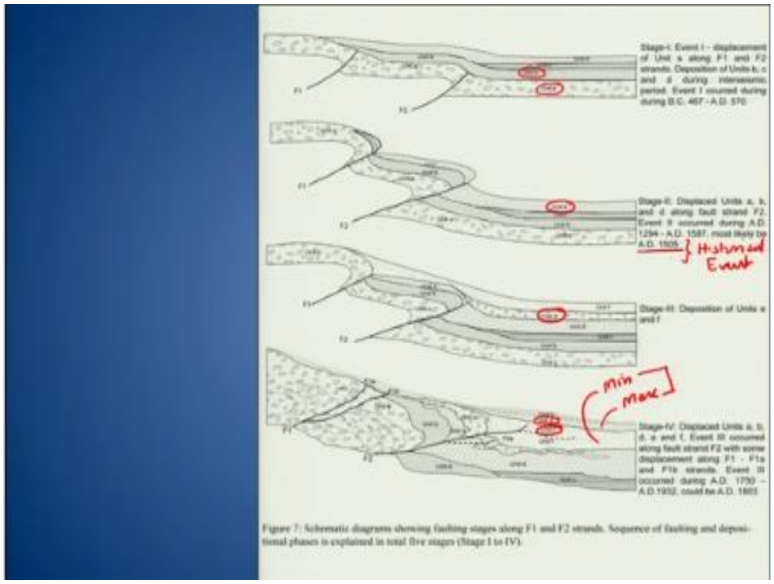


So the vertical separation of the unit b to be observed in the trench was 215 centimeter. Taking into account the vertical separation of 215 centimeter and the theta 27 degrees, gives a higher slip of almost 477 centimeter but actually the slip, what we obtained, was 170 centimeters. So this is almost 300 centimeters higher than the actual slip, what that we measured in the trench that was 170 centimeter for 2 events.

Because this is showing in cumulative slip, this 170 is your cumulative slip. So that the next slip of 235 centimeter, approximately can be accounted for a single event, because if we take this as a the 2 event slip then for single event this will be around 235, also the wide zone of deformation, suggests that 60% of slip is consumed in folding, because we are unable to see this slip in trench, but we if you just take the cumulative slip then it is 170 whereas the cumulative slip.

If we talk in terms of this slip using the vertical separation. Then we should have seen this slip of this much 477, so almost like 60% of the slip is been consumed by folding. So this is very important, when we talk about the slip rate or we talk about the magnitude and all that appear, so in actually the slip would have been or would have occurred much much larger than what we have mentioned in the trench so the rest of the slip was consumed along by folding.

(Refer Slide Time: 21:40)



So, with this you can recalculate and go back into the history and talk about the different events and how many events and what was the slip during a single event and if you are unable to fix up the slip he will have to look for the other explanation, as the explanation we looked for that the 60% was being consumed by folding and not everything was seen as a part of the slip then further with the help of ages and you can fix up the events and go for literal deformation sketches which we have prepared here.

So what we say that the event 1 took place and displace, unit a along F1 and F2 and that was the event and did that what bracketing we have done so it was during BC 467 and AD 570. So now considering all the parameters, here which we have discussed that you have the cumulative displacement, if you take the average angle of the fault and the ages you can reconstruct the events chronology.

And this was been done using OxCal, the calibrated ages, which you see here and the bracketing, you got from the OxCal but I will just explain that, how we have reconstructed the history here and then we will come to the bracketing part in the next slide. So what we have we inferred that event 1, it displaced unit a along F2, F1 and F2 strands, so was here and then there was a phase of deposition which deposited unit b, c and d.

And after this there was an event which again displaced F1 and F2 and they displaced all the units, which were deposited along with the older one that is your unit a, and then there was a phase of deposition.

That is your unit f, which kept the unit e and f were deposited after the event which took place and this was the event horizon, so this and after the deposition of unit f there was an final earthquake that is your more and most recent earthquake. So now in this one you can at least talk about the event 1 took place after the deposition of unit a and before the deposition of unit b and in this case the event, 2^{nd} event took place after the deposition of unit d.

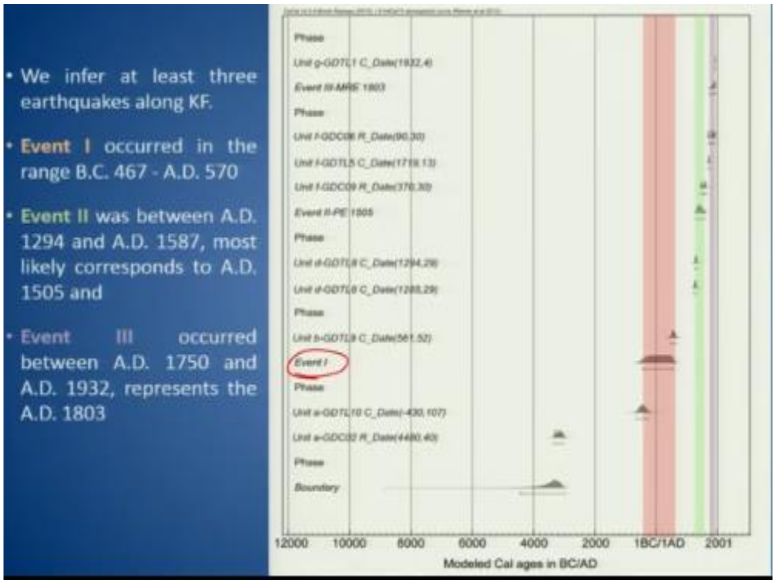
And before the deposition of unit a and finally what we see, here is that the event 3 was after the deposition of unit f and before the position of unit g. So if you are having the age and that is the older age of this one the oldest or the maximum age we can say of the capping unit and the minimum age of the event horizon then you will be able to bracket the event.

So what we inferred that the event, the second event, event 2, was bracketed between AD 1294 and AD 1587 and most likely we correlated this event with 1505 and this is well recorded event in historical data, similarly our youngest age which we caught, we bracketed this event and that was between 1750 and 1932 AD and if we correlated this event with 1803 but there are, like other groups who have worked and they said that probably there was no such event, which was recorded in their trench.

Possibly, they were not able to pick up this because the deposition of the units, will vary from place to place and we may not be able to see the same events, in a single trench. So ideally what we do is that we open multiple trenches enclosed by and try to understand that if there is the same event in some time not having the same event picked up from both the trenches. So this is because of the variation in the deformation of depositional patterns that the sedimentary phases will not be the same, all along this curve.

And they may vary and some places, if this units are eroded then you will not be able to pick up the events nevertheless at least, we were very confident about this event that this has occurred along this fault and this is one of the largest earthquakes which has occurred in this region during historical times.

(Refer Slide Time: 27:29)



So this is what we use the OxCal and we calibrated, all our ages and we tried to mark the brackets, the different events which we based on the ages, which we got from different units. So this, what we say that event 1 here was so we infer at least three earthquakes along Kaladhungi fault event 1, which occurred so based on this we were able to bracket the event here, so we say that the event was bracketed between these 2 ages.

So we have the 467 and 570, which is coming from the OxCal model and then we have the event 2 was between this here, we have the white range which is between this and this, so we have like this 1294 and 1587, which probably corresponds to 1505 earthquakes in this region event 3, which I told that this is the debatable event and but what we saw in our trench, we have correlated with 1803 and this was the youngest most recent event in this region.

So I will stop here and we will continue in the next lecture talking more on the strike-slip fault, thank you so much.