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

Lecture - 26
Lab and Field Techniques in Active Fault Mapping and Paleoseismic Studies (Part – I)

So welcome back. So now we will start discussing about the field techniques and the lab techniques what we need to do for mapping active faults and further how we will be doing the excavation of trenches to identify different events preserved in sediment succession.

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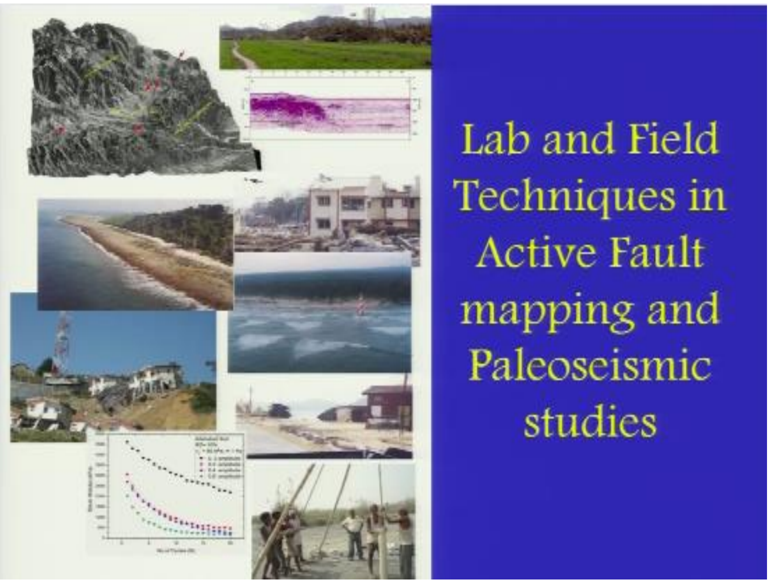

So lab and field techniques in active faults mapping and paleoseismic studies. So we basically what has been shown here that we use satellite data interpretation and then go into the field, try to identify the features, those are the fault scarps and also we do some geophysical techniques to identify the near surface deformation to some extent, but we would not be able to go to grip with that because we usually use the GPR and all that, but of course you can go at the deeper depth using seismic reflections and all that.

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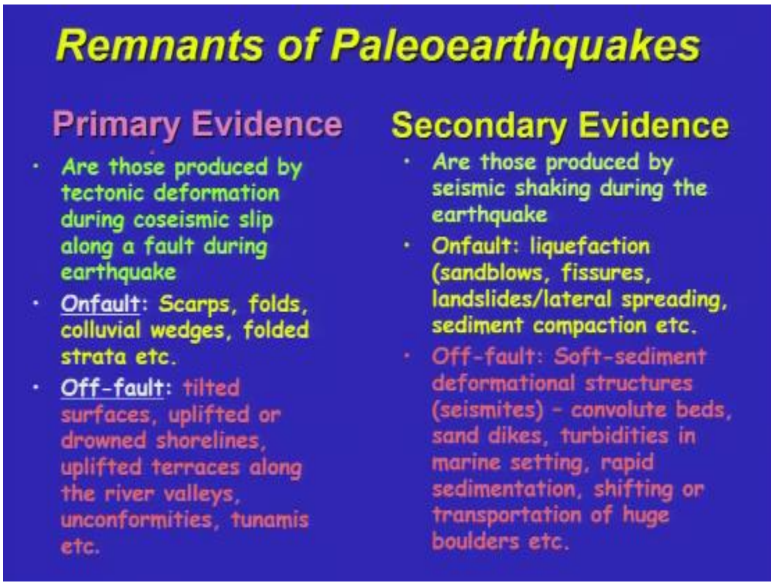

So let us look at what are the different parameters and different techniques we are going to use to identify the remnants of paleoearthquakes mainly. So as we have discussed about the primary and secondary structures we have now the primary and secondary evidence of the paleoearthquakes. So primary evidence are those produced by tectonic deformation during coseismic slip.

So coseismic is at the time of deformation and slip along the fault during earthquakes and the features which usually we will come across are fault scarps, folds, colluvial wedges, folded strata etcetera and this is on-fault. So this is near the fault and off-fault which you will see is the tilted surfaces, uplifted and drowned shorelines, uplifted terraces along the river valleys and unconformities and also you will see off-fault the secondary evidence is the tsunami.

But this can be also considered as a primary one because this helps us in understanding that what type of earthquake it resulted into the tsunami mainly in the subduction zone regions. So secondary evidence are those produced by seismic shaking during earthquake. So these are all what includes on-fault you will see liquefaction, sandblows mainly fissures developed on the surfaces.

So this I will talk in detail about the sandblows, but the fissures which I have shown in couple of slides when we are talking about 1995 Kobe earthquake and then landslide, lateral spreading, sediment compaction etcetera. Off-fault here we will see softer sediment deformation, seismites. So you can also have liquefaction on-fault as well as off-fault then such deformation evidence of the deformational structures on soft sediments.

Mainly the alluvium then those are termed as seismites. So what you have you have the convolute beds, sand dikes, turbidities in the areas where you are having the water bodies mainly in the marine setting, the rapid sedimentation because of the ground shaking, shifting or transportation of huge boulders.

This you will be able to see when you are having along the slope of any region or you will also see the transportation of huge boulders which are related to tsunamis. So we will keep in mind when we are talking about the on-fault and off-fault evidence and whether they are secondary or primary signatures.

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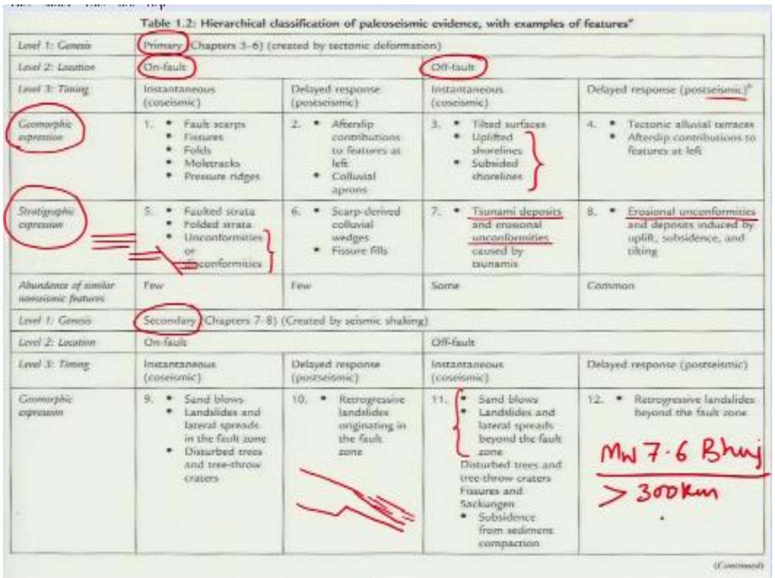
Table 1.2: Hierarchical classification of paleoseismic evidence, with examples of features*

Level 1: Genesis	Primary (Chapters 3–6) (created by tectonic deformation)			
Level 2: Location	On-fault		Off-fault	
Level 3: Timing	Instantaneous (coseismic)	Delayed response (postseismic)	Instantaneous (coseismic)	Delayed response (postseismic)*
Geomorphic expression	1. • Fault scarps • Fissures • Folds • Moletracks • Pressure ridges	2. • Afterslip contributions to features at left • Colluvial aprons	3. • Tilted surfaces • Uplifted shorelines • Subsided shorelines	4. • Tectonic alluvial terraces • Afterslip contributions to features at left
Stratigraphic expression	5. • Faulted strata • Folded strata • Unconformities or disconformities	6. • Scarp-derived colluvial wedges • Fissure fills	7. • Tsunami deposits and erosional unconformities caused by tsunamis	8. • Erosional unconformities and deposits induced by uplift, subsidence, and tilting
Abundance of similar nonseismic features	Few	Few	Some	Common
Level 1: Genesis	Secondary (Chapters 7–8) (Created by seismic shaking)			
Level 2: Location	On-fault		Off-fault	
Level 3: Timing	Instantaneous (coseismic)	Delayed response (postseismic)	Instantaneous (coseismic)	Delayed response (postseismic)
Geomorphic expression	9. • Sand blows • Landslides and lateral spreads in the fault zone • Disturbed trees and tree-throw craters	10. • Retrogressive landslides originating in the fault zone	11. • Sand blows • Landslides and lateral spreads beyond the fault zone Disturbed trees and tree-throw craters Fissures and Sackungen • Subsidence from sediment compaction	12. • Retrogressive landslides beyond the fault zone

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So in detail if you look at the hierarchical classification of paleoseismic evidence. So we have one genesis then we have location, timing and what will be the geomorphic expression and what you will see the stratigraphy. So for us what we are doing is mainly we are talking about the geomorphology that is the expression on the surface and the signatures which are preserved in the stratigraphy sequence.

So and further we have abundance of similar non seismic features and you have again the same we are talking about that what are those non seismic features and those are. So this you are talking about the primary and briefly I have shown you in the first slide and then you are having the secondary on-fault as well as off-fault. So coming to this on-fault instantaneous coseismic then you have fault scarps, fissures, folds, moletracks, pressure ridges etcetera.

That will be your geomorphic expression whereas in case of your stratigraphy 1 you will have folded strata. So displacement will be evident when you are looking at in the section and in the sediment succession and folded strata you will have unconformities or discontinuity. So this part is your cross cutting relationships between the different layers then coming to the coseismic that is your delayed after the seismic event.

Then afterslip contributes to feature at left so they are like afterslip features and then you are having colluvial aprons. So this is related to the erosion which will modify the faults scarps or fissures or folds or moletrack then the stratigraphic expression will be your scarp derived colluvial wedge, fissure fills etcetera. This will be after the so whatever the fissures which have been formed, which will be covered by the sedimentation.

And that what you see is the delayed response and coming to the off-fault. So these are the signatures that is you are having primary and on-fault whereas this one is your off-fault and again what you see is the off-fault instantaneous during the coseismic. So now what we are looking here is that we are near the fault and we are moving away from the fault. So what are the signatures you will see during the earthquake or when the earthquake is occurring.

Then you are close to the fault and away from the fault. So away from the fault you will see tilted surfaces, uplift shoreline, subsided shorelines etcetera. So this will be in the coastal region of course you will also see, but in close to the on-fault you will come across the uplifted terraces and all that and then delayed response very much similar to what we were looking at the on-fault.

This is what we will see off-fault will be tectonic alluvial terraces because delayed response will result into the erosion and incision of the channels which will result into deformation of terraces. So this will be a long term after the event after the seismic event that is coseismic one. Afterslip contribution to the features at the left. So you are having the modification of similar features which have been formed will be modified because of the delayed response.

That is your due to erosion and to some extent you may come across the elastic rebound phenomena. Then coming to the stratigraphy one you will have off-fault then you will have tsunami deposits of course the tsunami deposits to some extent we consider that as a primary signature, but since it is in secondary phenomena associated with the earthquake we see we may consider this as in tsunami deposits as a off-fault.

Because you will find the tsunami deposits away from the displacement of the fault into subduction zones. So tsunami deposits and erosion unconformity is caused by tsunami you will see because the tsunami waves are very powerful and will result into the very sharp unconformity with respect to the underlying sediment succession. Then delayed response you will again have the erosional unconformity and deposition induce by uplift subsidence or due to tilting of the surfaces.

So erosional unconformity will be the basic signature which you can identify and this could be related to the delayed response of the dispose seismic activity. Then coming to the non seismic one. So we will have very few signatures here, very few some we will see and very common in the delayed response then coming to further here we have the secondary those are created by seismic shaking.

So mainly we are talking about the secondary features and this we were talking about the primary one. So on-fault secondary features again because of the coseismic that is during the earthquake you will see those are related to your strong ground shaking. So you will have sandblows. So this is in liquefaction, you will have landslides in the hilly terrain because of strong ground shaking, lateral spreading.

Because of loss of (()) (10:37) in the fault zone, disturbed trees and tree thrown craters. So you will be basically looking at the uprooted trees in such cases during the coseismic and these all are your on-fault secondary and then you have delayed response. Retrogressive landslides originated in the fault zone so you will have this could be because the material which is sitting on the slope will definitely because of the strong ground shaking will lose out their shear strength and result into the delayed response to the seismic events.

And you will have the landslides which are originated in the faulted region that is on-fault signatures. Off-fault again coming to the instantaneous you will have sandblows, landslides, lateral spread beyond. So depending on what was the magnitude of an earthquake this features you will come across. For example I was talking in one of my lecture that Mw 7.6 Bhuj earthquake the secondary effect was observed like about 300 kilometers from the epicentral area.

So again you have uprooted trees, fissures and like (()) (12:12). This is part of the very much similar to the landslide, but usually what we see is that if you are having this sloping surface then the landslide will occur here okay, but this one usually what has been seen is something like this. So this portion has been slip down and because of this is secondary features and such features are been termed as (()) (12:40).

And then you have subsidence from the sediment compaction this will be again the delayed coseismic, but you will have off-fault and then delayed response is again the landslide beyond the fault zone area. So there are many common features which you will find in different type of deformation and hence they are been kept as common, but as we learn more about that we have fault scarps mainly in the thrust environment.

But we will see along with the fault scarp we will see lateral displacement of the landforms including the streams or the channels or river channel in case of the strike slip one and of course the moletracks will also be seen in the strike slip and pressure (()) (13:32) and in all cases you will see the displaced strata or faulted that is faulted, folder in case of the compressional tectonic environment and strike slip tectonic environment.

And in all the environments like three environment which we are talking strike slip, normal and that is extensional and compressional we will see unconformities or discontinuities between the strata. So basically discontinuities what we are looking at is that we have the horizontal surfaces and if they are faulted for example then this will mark the discontinuity between the strata.

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Table 1.2: Hierarchical classification of paleoseismic evidence, with examples of features[a] (Cont'd)

Stratigraphic expression	13. • Sand dikes and sills Soft-sediment deformation Landslide toe thrusts	14. • Sediments deposited from retrogressive landslides	15. • Sand dikes • Filled craters • Soft-sediment deformation structures • Turbidites	16. • Erosion or deposition (change in sedimentation rates) in response to retrogressive landslides or surface features such as fissures, lateral spreads, or sand blows, or other forms of landscape disturbance
Abundance of similar nonseismic features	Some	Very common	Some	Very common

[a] This classification scheme yields 16 types of paleoseismic features, as numbered consecutively in the categories "Geomorphic expression" and "Stratigraphic expression."
[b] Does not include delayed response movement on other faults due to stress changes induced by initial faulting.

Further, the stratigraphic signature in case of your non seismic features you will have sand dikes then you will have sills soft-sediment deformation and landslide toe of the thrust then you have sediment deposited from the toe (()) (14:33) landslide and further if you move away that is on off-fault then you have sand dikes, filled craters, soft sediment deformation, turbidities and all that.

And delayed features you will have the so this is coseismic and these are the delayed coseismic. So erosion and deposition change in the sedimentation rate because the deformation will trigger because the land level has changed so this will trigger either into erosion or deposition in the area depending on what type of movement whether it is an uplift or it is you are having subsidence.

Then the gradation and degradation of the sediments will response to the tectonic events and we will landslides or surface features such as fissure, lateral spreads and (()) (15:26). So these are all the post seismic signatures you will come across in a stratigraphic expressions. Now in areas where we clearly see the on-fault deformation that is in coseismic features if we are able to see coseismic deformation features.

Then we will be able to easily pick up this one and we will be able to mark the active faults and all that, but regional scale if you look at then we will have to look at that what was the effect of that deformation on a larger scale which is away from the fault and if suppose we are having the blind earthquake on a blind fault then we may not have come across the features which have been listed here.

In that case we usually take into consideration the secondary features which will help us in identifying the tectonic event. So in most of the areas where we have like even away from the fault and we look at that whether the area was been affected by any earthquake during any earthquake by liquefaction. So lab and field technique in active fault in paleoseismic studies.

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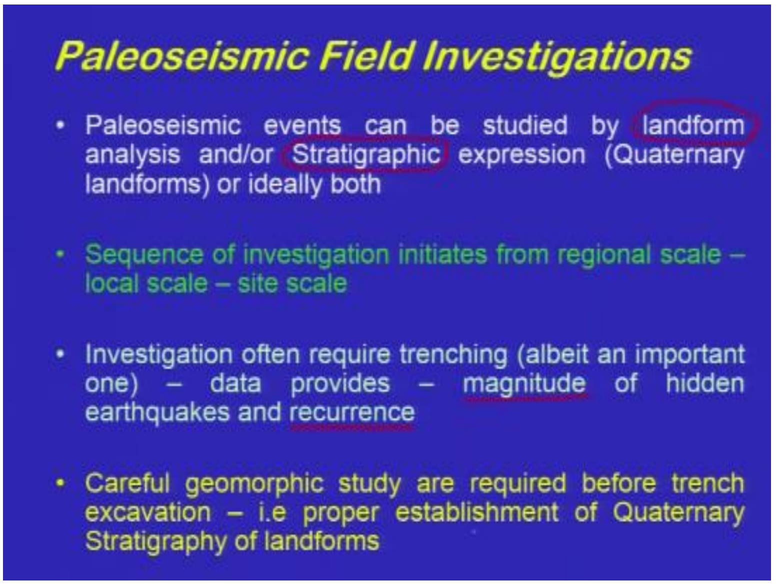

So paleoseismic field investigation what we usually do is that we paleoseismic events can be studied by landforms. landform analysis or stratigraphic expression. So these are the two most important parameters which we are going to emphasize for identifying the tectonic deformation. Now in case for example if you are looking at on the earth surface that is continent then we will be able to identify both that is your in stratigraphy as well as on the surface that is landforms.

But in case of the subduction zone earthquake we would not be able to see the faults or the deformation which has occurred along the trench area, but near to the coastal regions we will be able to pick up both the land level change as well as the sediment record. So mostly we try to look at both in most of the cases so it is essential to look at the stratigraphy as well as the expressions which are preserved in landforms.

Sequence of investigation initiates from regional scale, local scale and side scale this we have already talked about that we looked at either you can say the global one then coming to the regional and the local or site specific scale you need to do investigation often requires trenching (()) (18:41) an important one data provides magnitude of hidden earthquakes and reoccurrence.

So this is important for the seismic hazard assessment that we need to have the magnitude of earthquake and the recurrence at what will be the next when will be next event and what will be magnitude. Careful geomorphic studies are required before trench excavation that is proper establishment of quarternary stratigraphy of the landforms. So as we have been talking right from the beginning that if you are having an active fault.

Then it has moved number of times and multiple earthquakes have occurred on that particular fault that means that the landscape has preserved the past earthquake events and whenever there is an earthquake that does not mean that the no landforms in future will form. So new landforms will come up. So we would like to do in this exercise is we need to reconstruct first the total geomorphic that is landform stratigraphy in terms of which landforms are older and which are younger.

And that will also tell you that if the older landforms along with the younger ones are displaced then we can easily or we can quickly make a decision that this fault has remain active since past where the older landforms are also displaced whereas the younger landforms are also displaced of course the amount of displacement on surface as well as in this stratigraphic section will not be the same.

Because the older one will show cumulative displacement whereas the younger one will show the most recent event when they got displaced. So you will need to establish the quarternary stratigraphy of the landforms as what we do in case of the sediment stratigraphy.

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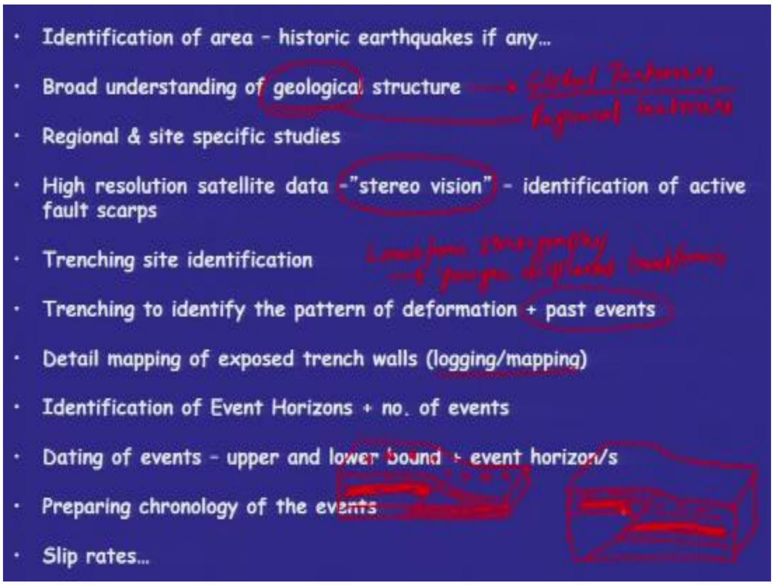

So first step what we do is the identification of the area and then any particular area so we are moving from regional or global to regional and to site specific one. So if we have to take into consideration the local site or the site at the local scale of our interest then first of all the first step we will do is that we will look for the historical data if any of that area.

And then we will have the broad understanding of geological structure. So we will also consider here the global tectonics. So here what we have discussed about the (()) (21:52) tectonic and all that. So we will take into consideration that in that and then we will look at the geological structure so we are talking about the regional tectonics. So this will help us in understanding that what type of deformation one can expect based on the global tectonics.

Then regional and site specific studies we will take and we will do detail geomorphic mapping using high resolution satellite data and this what I was emphasizing in the previous lecture and if you are having the stereovision photograph then this will help us in identification of active faults scarps because this will help you in viewing the whole area in three dimension.

So in this exercise we will give a lecture on this and how you will prepare the (()) (22:51) and try to see the satellite photos in 3 dimensions and the terrain you can even use that data to generate the digital elevation model and after doing the detail studies that is identification of active faults scarp and field mapping then we will go for trenching identification of trenching site and this when we are doing this that is the identification of the trenching site.

We will take into consideration the landform stratigraphy because we will not like to excavate the older landforms. So we will look for the younger displaced landforms. So for this we need to have the landform stratigraphy of quarternary landforms and the youngest displaced landform will be the target for the trench site. So you should remember so trenching to identify the pattern of deformation of and past earthquake.

So what type of deformation has been seen of course based on this understanding the global and regional and the geological structures and the landforms to some extent you will be able to understand that what will be the pattern of deformation either it is in reverse fault or thrust fault or strike slip fault, but along with this the trenching will help you in identifying the signatures of the past earthquake.

So now we are getting into the stratigraphy here. So this what we were talking about the landforms and all that is your geomorphology then further detail mapping of expose trench walls so we will do logging and mapping of detail and this will help us in identifying the cross cutting relationship between the sediment layers and that will help us in identifying the number of events.

Identification of event horizons plus the number of events this we will do we will be able to do when we are doing detail logging of the exposed trench walls. Dating of events upper and lower bound we will try to collect and then that will help us in identifying the event when exactly it took place. Prepare a chronology of the events. So this finally will help us indentifying the slip rates also.

So just about the event horizon if I have to just explain here I will just put that. Suppose you are having and preexisting fault scarp for example you have identified. So this is the top most surface which remained exposed before any particular event. So suppose this is your you are having this layer over here and then the rest of the layers were displaced. So you have this unit was displaced.

And this was been kept by this now during the next earthquake suppose for example if you are taking the next earthquake if you are having the displacement then you have the displacement of this unit. For example I am just putting in sketch here and this also is displaced. So what you have is this is your event horizon during the next earthquake. So this is your during this earth that is the next earthquake in this one then this will become your event horizon.

So how many times this units have been displaced that basis you will talk about this slip rate and the number of events basically and finally you can talk about the slip rate also that what was the amount of slip or you can talk in terms of the average slip during one single event.

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So using high resolution satellite photo and this are what we say that this is one of the best photographs which are available at least for the Indian terrain. These are the photographs which have been taken by corona satellite photo way back in 1960s and we have this will the stereovision. So with this I will stop here and we will continue in the next lecture and talk more in detail about the satellite photo interpretation and associated landforms.

So I will show you some examples based on the photo interpretations and what we have done in field and what all mapping tools we will use for collecting the data. Thank you so much.