Earthquake Geology: A Tool for Seismic Hazard Assessment
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Lecture - 30
Lab & Field Techniques in Active Fault Mapping and Paleoseismic Studies (Part – V)

So welcome back. So in last lecture, we discussed mostly about the geophysical techniques and all that and which can help us in locating the and the subsurface deformation, near subsurface deformation and that helps us in identifying the potential site for trenching and that means to carry out the paleoseismic studies.

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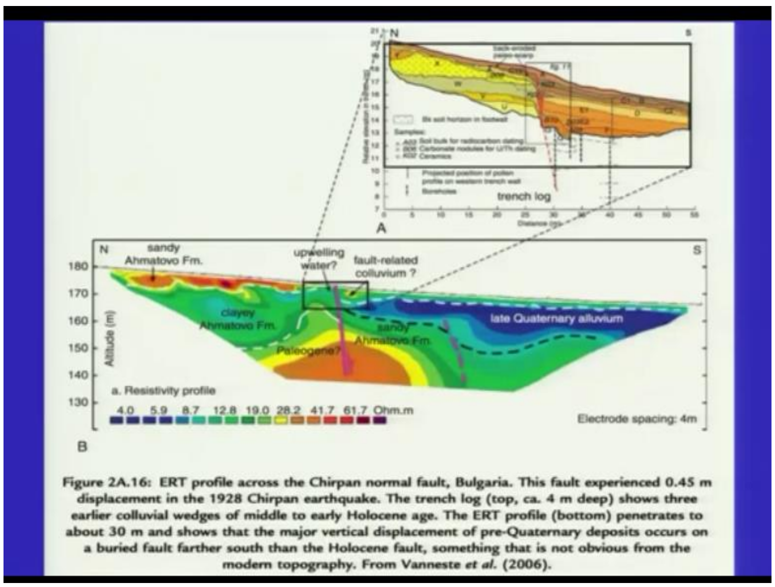

Figure 2A.16: ERT profile across the Chirpan normal fault, Bulgaria. This fault experienced 0.45 m displacement in the 1928 Chirpan earthquake. The trench log (top, ca. 4 m deep) shows three earlier colluvial wedges of middle to early Holocene age. The ERT profile (bottom) penetrates to about 30 m and shows that the major vertical displacement of pre-Quaternary deposits occurs on a buried fault farther south than the Holocene fault, something that is not obvious from the modern topography. From Vanneste *et al.* (2006).

Now as I emphasized in previous lecture also that with the help of geophysical technique, you would not be able to categorize the fault, whether it is an active fault or not, but atleast you will be able to identify the deformation in the recent sediments and atleast to some extent you will be able to tell that where very exactly the fault exists and to be more precise will be able to identify atleast the pattern of deformation and geometry of fault.

So various techniques have been discussed in the last lecture, starting from seismic refraction, other geophysical methods like resistivity survey and a few more are left out, which we have is particularly on the GPR.

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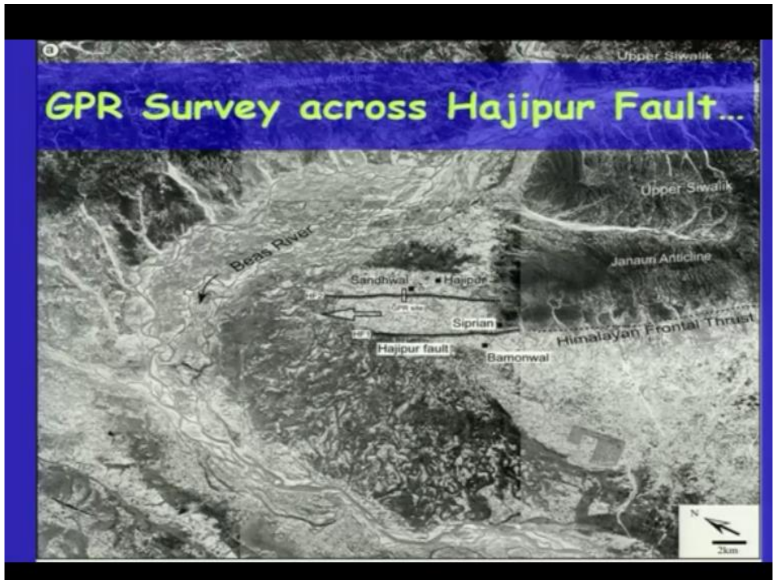

So this is the area where we identified the active fault trace using high resolution satellite photos and before getting into the part of the paleoseismology fitted GPR survey to locate the fault trace and the location of the fault subsurface.

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So this is the fault scarp, which I am showing exactly is somewhere over here that is on the left bank of the Beas River, where the Beas River debuts into the Ingo-Gangetic plane in Northwest Himalaya and Punjab region. So again the like it was really good experience we had in this region. People did not allow us to dig the trench, because there was a water pipeline, which was running somewhere in this portion.

But the even the villagers were not very much aware that where exactly or precisely the pipe lies and if while digging because in for paleoseismic studies, we will open up the trench here. So we will dig the area to look the dissection and the displaced layers before getting the details of the events and all that. So then we explained them that we have a technique by which we can identify the location of the pipe as well as the area where we would like to go for trenching.

So we did 3D and 2D GPR mapping of this region, which was like across the scarp. So usually we open up the trench to see the section across this scarp, as I have shown you what we did in the collection of the topographic profile and all that. So this were the location of our trench after GPR, but I would like to show that what we observed in GPR and in what way it helped us in restricting ourselves to a particular area without damaging the subsurface utility.

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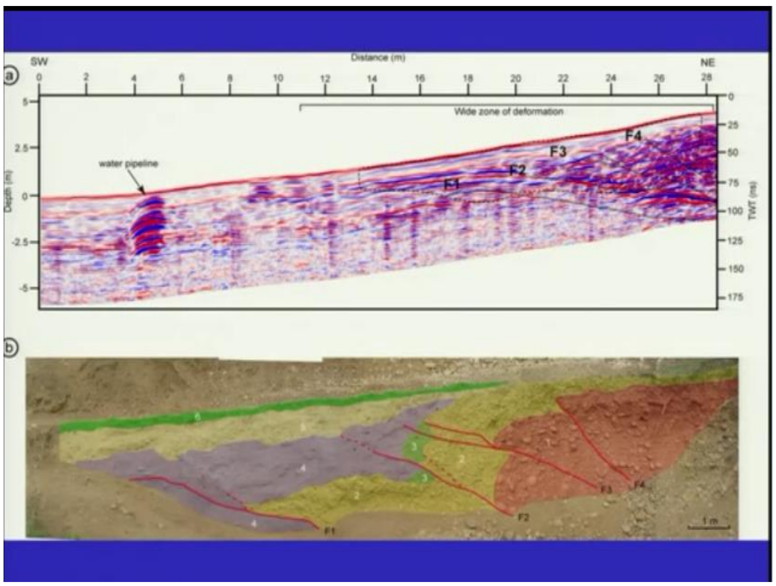

So this is the profile, GPR profile, which we collected and we were very able to precisely locate the water pipeline, which was sitting far away from the area of interest and then finally, when we looked at the GPR profile the deformation in the subsurface was quite prominent in the upper part of the scarp. Hence, we restricted ourselves not getting and digging up to the up to the water pipeline. So this also in a way, it helps.

It reduces your time, money and you can precisely target the area where you would like to dig the trench. So this portion we dug and the profile of the black dotted line or the box, which we has been drawn here is exactly the trench area, which has been shown here. This is the log or the trench wall, which was exposed by digging the area. So with this that is a GPR survey, if we were able to comfortably go up to the depth of say around 5 to 6 meters.

So this profile, it shows the depth here as well as the two-way travel time. So the what I will do is, that because we are using extensively GPR for carrying out this study and GPR is one of the best robust technique, which is in our understanding is the geophysical technique, which is available and is extensively used. So we will try to give you one lecture exclusively on the GPR, how it works and what are the working principles and what all information we should have with us, when we are doing GPR.

So we will give one lecture on this, particularly in GPR and how we try to locate and what are all parameters we try to consider to get the best profile. So moving further this is like what I was showing in the previous slide comparing the like seismic reflection and the trenches, which we have been dug in other part of the world, even with the help of resistivity survey people have done and then open up the trench and they were able to compare whatever the results they got by doing the geophysical service.

So in a way, this will not tell us that what is the age of those layers okay, but when you open up the trench, you collect the samples and you date the events that is required. So geophysical technique in short is not going to help you in characterizing the fault, whether it is active or not, but of course when we know one thing that the area in which we are conducting the survey is very young surface, which is displaced okay.

So the younger displacement preserved in the sediment section to some extent can also be taken as a preliminary interpretation that this is a trace of the active fault.

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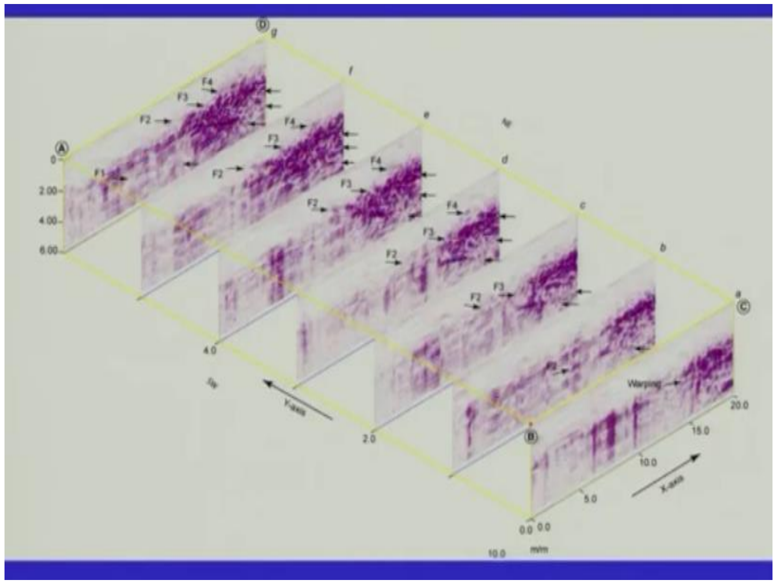

Now with the help of GPR survey, you can also perform three-dimensional mapping and that what we did. The grid has been shown here. So this is the grid which we took almost 20 meter by 6 meter here and we took multiple profiles and when we club this. So the previous one was 2D profile, we have and this is the 3D profile in the area of interest what we wanted to do and this also helped us in identifying and interpreting the depth of the fault with changes.

So the best section which we obtained in the dimension if you see we are having like around 10 meter section, we have cut and we have done this and then we are having around 20 meters in this one okay, so sorry this is 6 meter. So you have 6 meter and then you have 20 meter. So this direction is across this scarp. So what do you see is, this is the scarp here. So we moved our GPR in this fashion okay.

So whatever the data what was most been collected, this profile is not topographically corrected one, but whatever the data was obtained with the help of in the three-dimensional pattern, then we were able to fix up the geometry of the fault here. So the best portion, we picked up and we open up the trench there. So this is one of the best method, which we feel is available, which can give you the profile of shallow stratigraphy.

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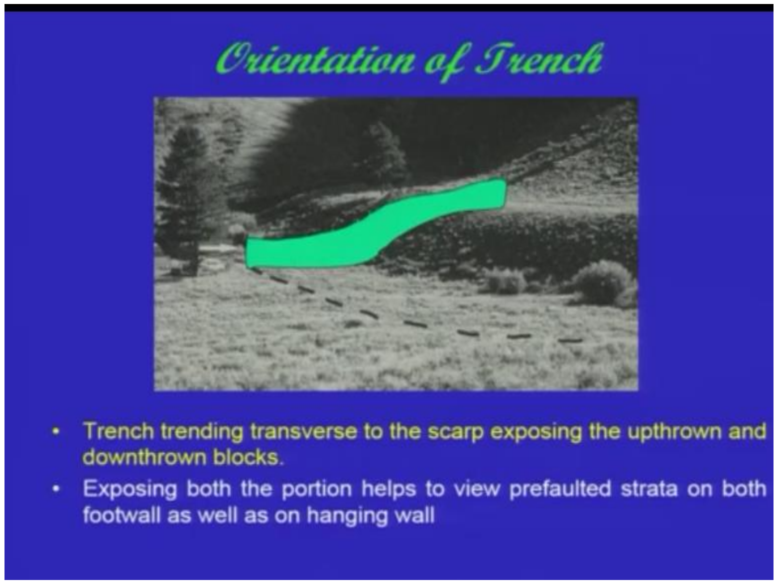

Now the orientation of trench, I hope this is bit clear because what we have discussed in the previous two slides, that we took the GPR profile here and then we opened up the trench across this. So always it is ideal, if you are having an scarp like this and then it is ideal to open up the trench covering the area like what has been shown here. So what we are doing is, we are covering the area of the deformed units and the undeformed units in the footwall side.

So trench trending transfers to the scarp exposing the up thrown and the down thrown block. This is extremely essential, because this will help us in and identifying the events okay. So the exposing both the portion helps to view the prefaulted strata on both footwalls as well as on the hanging wall. So this is important. If you just dig this portion, then you may not be able to compare the units, which existed before the faulting.

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Figure 2A.19: A large benched trench across a 23 m-high normal fault scarp on the Wasatch fault zone at Mapleton, Utah. Note the deep inner slot which is shored, and small vertical boards on the first bench, to assist in climbing up the trench. Preliminary results are described by Olig *et al.* (2005).

So this is one type of trench, which has been shown here and mostly this type of trenches are very narrow trenches, are been dug in US. So they method remains the same. You open up the section here and what they have done here in this one very narrow trench, you have and to protect the walls here, because looking to the loose sediments, quaternary sediments will be very loose and chances of collapsing of the trench wall is very frequent in such digging. So they have put the jacks here to support the wall and prevent the collapse.

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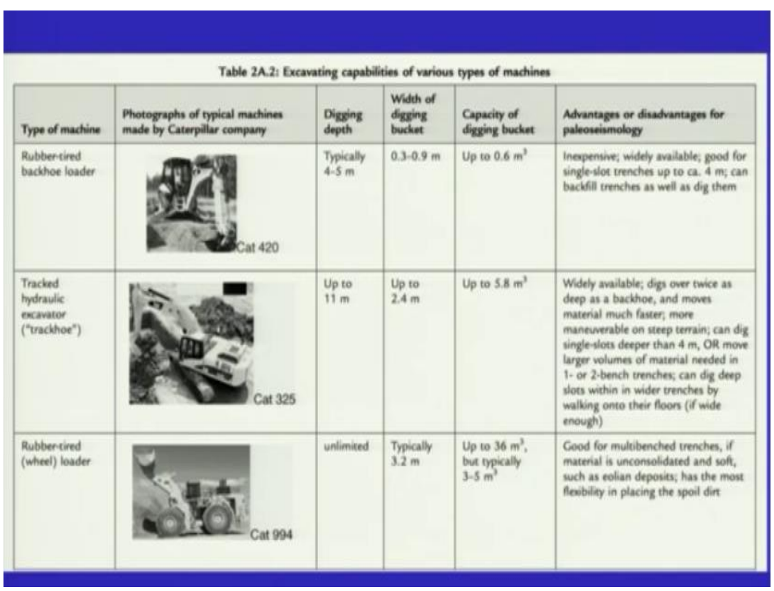

Table 2A.2: Excavating capabilities of various types of machines

Type of machine	Photographs of typical machines made by Caterpillar company	Digging depth	Width of digging bucket	Capacity of digging bucket	Advantages or disadvantages for paleoseismology
Rubber-tired backhoe loader	Cat 420	Typically 4-5 m	0.3-0.9 m	Up to 0.6 m^3	Inexpensive; widely available; good for single-slot trenches up to ca. 4 m; can backfill trenches as well as dig them
Tracked hydraulic excavator ("trackhoe")	Cat 325	Up to 11 m	Up to 2.4 m	Up to 5.8 m^3	Widely available; digs over twice as deep as a backhoe, and moves material much faster; more maneuverable on steep terrain; can dig single-slots deeper than 4 m, OR move larger volumes of material needed in 1- or 2-bench trenches; can dig deep slots within in wider trenches by walking onto their floors (if wide enough)
Rubber-tired (wheel) loader	Cat 994	unlimited	Typically 3.2 m	Up to 36 m^3, but typically 3-5 m^3	Good for multibenched trenches, if material is unconsolidated and soft, such as eolian deposits; has the most flexibility in placing the spoil dirt

There are different type of like digging, which has been shown here depending on what type of machines, which are available in the country. You can go for digging. If you want to go deeper, when you use the backhoe, which has been shown here with the chain in the wheels or maybe you can use this smaller one, usually what we do in India and that what we call JCB.

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So this is the machine usually we have been using for trenching purpose. This is we did in Kangra and this is easily available in the local market. You can hire this and you can use for digging your trenches, but you have to be extremely careful, when the digging has been done, because the operator does not know that where exactly to dig and how deep it should the operator should go in terms of the depth and how much should be the width and all that and which portion should be dug in the deep, for the greater depth and which portion should be shallow down.

So with the experience, we have been digging. Initially, we used manpower, but that was a very time consuming affair, because digging the trench by hand will take lot of time and that may also eat a lot of money as well as the process will be extremely slow, but using the backhoe or the machines JCB bale, then that can help you in digging the trench in one or two days. Now, as we discussed in the previous couple of slides that using GPR and having some idea about the subsurface deformation, we can restrict our digging.

One of the slide which I was showing in the previous one here, so this trench has been opened for very long. Actually you have the scarp is quite high, of course but the trench which is opened is quite long here and it was across 23 meter high scarp, but in some locations we do not go so high, because it is dangerous and it may collapse in some portion.

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So GPR in our knowledge and with understanding, it is a very robust technique which is available. Hence, we will give you one lecture on this, so that you understand about the process of the GPR. So shape and style of trenches varies from location to location and also from country to country. So the previous slide which I was showing the long trench was an American style. So usually the Americans, they are very much happy opening the trench very long trench and a very narrow in width okay.

So numerous fatalities have occurred, when vertical walls have collapsed on geologists, who were crushed or crouched at the base of the trench and let me just share this with you that I was just saved when one of the trench wall collapsed, when we were digging the trench in Gujarat. So we have to be extremely careful, while digging the trench. We should not allow the machine to be for a longer time on the trench side or the trench wall.

And we also do one thing that we try to you know put the whatever the excavated material from the trench to be away from the trench walls. So that it does not come roll down into the trench. So these are few things which we learn with the experience, but we have to be extremely careful.

So we need to, because we should not load the trench wall by putting the excavated material on either side.

So that has to be extremely careful and then as I told that we should put this away from the trench a little bit. So that we have the space here available and we fix up that this material which is sitting on the top. It may contain all fluvial deposits and all that big boulders or cobbles, which may roll down when you are working in the trench, because you need to do a lot of work to identify different sedimentary layers, grading of the wall and all that. So you need to be extremely safe, when we are moving in the exposed trench.

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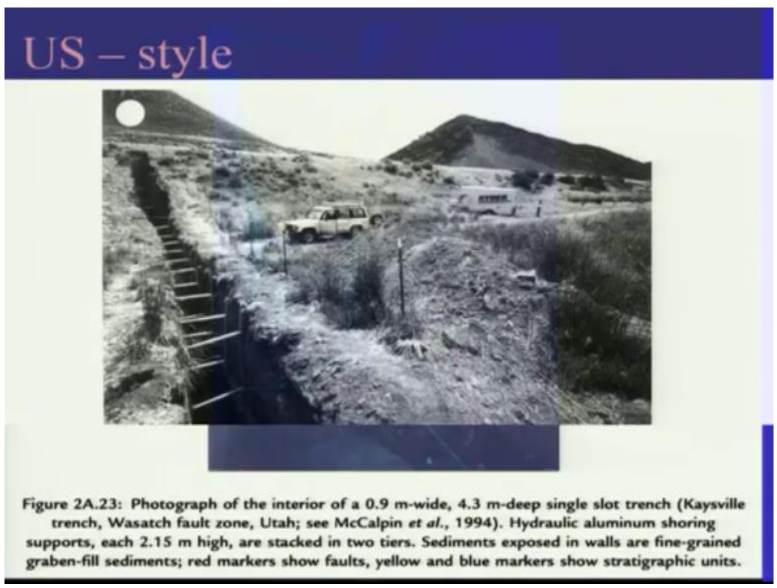

So this is what I was showing you that the geologists in US usually use a single slot trenches into the face and this has been done in 8 meter high normal fault scarp. So you have this part is the in normal fault scarp. This portion will be your stationary wall and this is the hanging wall. So they have opened a very long single slit trench. Now this is in US and they have put the supports here, so that the walls are not collapse.

And as I was saying that the material which has been dug from here should be put away from the trench. So this portion should not be covered by the excavated screed, because this may create pressure on this and it results into the collapsing of the wall. So this is US style.

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Figure 2A.23: Photograph of the interior of a 0.9 m-wide, 4.3 m-deep single slot trench (Kaysville trench, Wasatch fault zone, Utah; see McCalpin *et al.*, 1994). Hydraulic aluminum shoring supports, each 2.15 m high, are stacked in two tiers. Sediments exposed in walls are fine-grained graben-fill sediments; red markers show faults, yellow and blue markers show stratigraphic units.

And this is another photograph of that. So you do lot of detailed mapping and before getting into the mapping, you need to clean all the walls and all that and by brush you can do that. So usually we use the painting brush and very fine and with the soft hand. We do not apply much pressure, but with the soft hand we keep on cleaning the wall very precisely and also this top surface has to be clean very properly.

Because this also will help when we are measuring the amount of displacement during single events or individual events. So the top unit should be very well clean along with the section, which is exposed in the trench.

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There is another way of trenching, which is very common to the opencast mining, which has been done here. So it is a very wide trench and this is more or less very safe in the sense, because you are creating steps; you are not creating the steep wall and if you are doing this type of trenching, then you can go deeper. You can reach to the deeper portion of the fault or the displaced units.

Now again what you see here is that you have a very small slit here and then they have gone into the deeper portion here. So this is the area that where the maximum layers are displaced. So this is the fault zone. Hence, it has been opened deeper to study the more events as compared to what you see here. So this is of course is important because these are the prefaulted layers, these are faulted layers and then here also you will have the prefaulted as well as post faulted layers, which will be exposed in the area.

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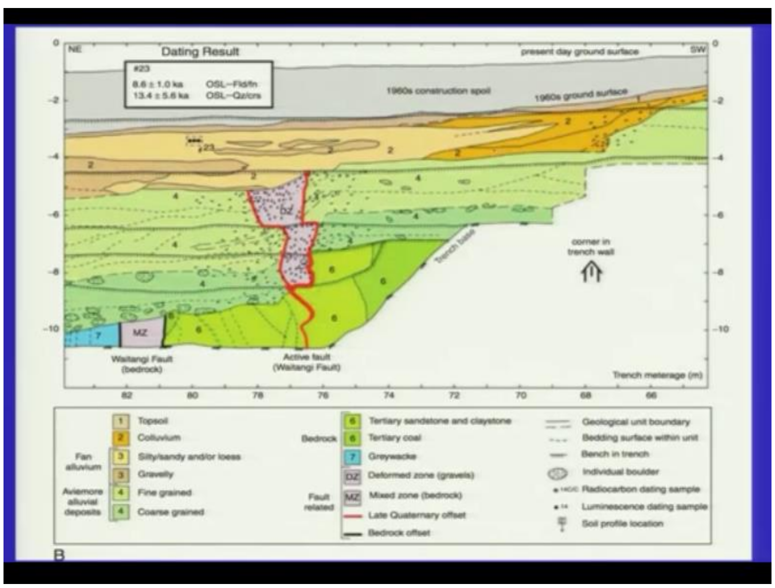

Then what we do is, that after we open the trench, I will show, this exercise what we usually we do in more lectures, which we will be giving on as a case study, then we will be talking that, but in short here what we would like to show here that we have traced all this, so before, like after the trenching we cleaned up all the whole wall and then demarcated the contacts between different layers based on the physical properties.

So that includes your grain size, that includes your color and then whether we are looking some soil formation or ancient soil, which have also been displaced and also we try to fix up the topsoil and all that and then after the classification you can prepare a detailed sketch of this and on a tracing sheet, because you will put in grids here. So you can have the whole wall can be created either in 50 by 50 centimeter or one meter by one meter square.

And that grid can help you in mapping the respective units as well as you that will help you in locating or sketching the fault which it crosses okay in the trench and then you can prepare a legend which is given here like you have topsoil, colluviums, silty sand and different. So these are all been classified. You can see that these are based on the grain size and also based on the color.

So you can do that and you can discuss in detail while writing the description of this individual or respective units that what probable environment they are reflecting, either they are showing the coarser deposit, for example indicative of the channel deposits or dealing the high-energy conditions and final probably reflecting your over bank deposits and all that. So this is one way.

So in this exposed trench or another important point which you can note it down that there are like older rocks are also been exposed, which also helps in understanding that this fault has remained active and is deep-seated which has displaced the rocks as well as the younger sediments, which are overlying the country rock here in this area. Now moving further, so in this one important point is that the exposed section of the trench also shows that the older rocks are displaced along the fault here.

So this one point is important here that when you come across in any region where you are able to expose, not exactly the basement rock but the older rocks and then it is good in a sense, because that will help us in identifying and characterizing the fault that the fault is deep-seated and it has displaced the older as well as the younger succession.

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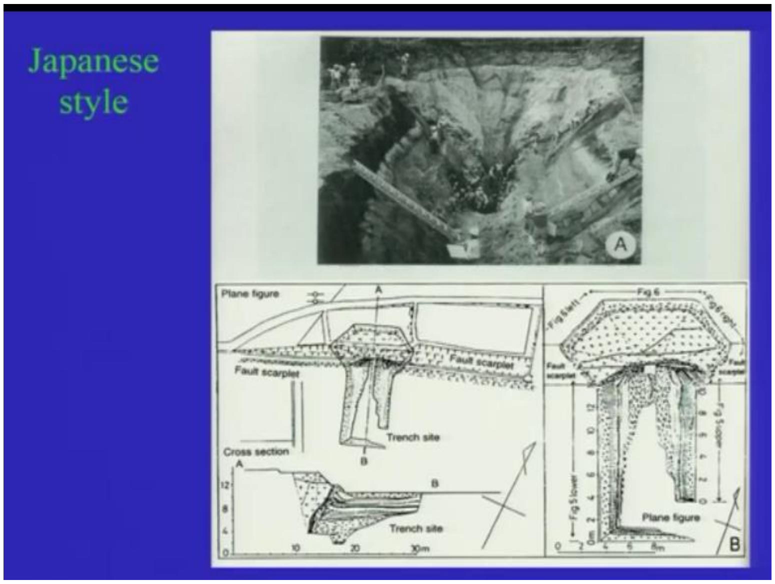

Now another style of the trench as compared to what we have seen the single slot trench of US, the Japanese trenches usually have been seen, they open very wide trenches and one basic parameter which they include is that they keep the walls inclined and this is for the safety purpose and with the inclined trenches you can go deeper and the sketch of the plane view of the trench which has been shown here.

This shows that you have the fault trace, which goes over here and this portion has been excavated for more deeper particle and then you can have, this is the section which has been shown. So this portion is comparatively deeper as compared to what has been shown here. Now this ramp is usually has been given, because when you are digging the portion here, the machine can easily come out from this portion.

So the Japanese trenches usually what we see is some wider trenches. So if you can compare this the width also here, it is around 8 meters wide and then you have the length of the trench and more deeper portion has been open where you have the fault trace or the fault scarp.

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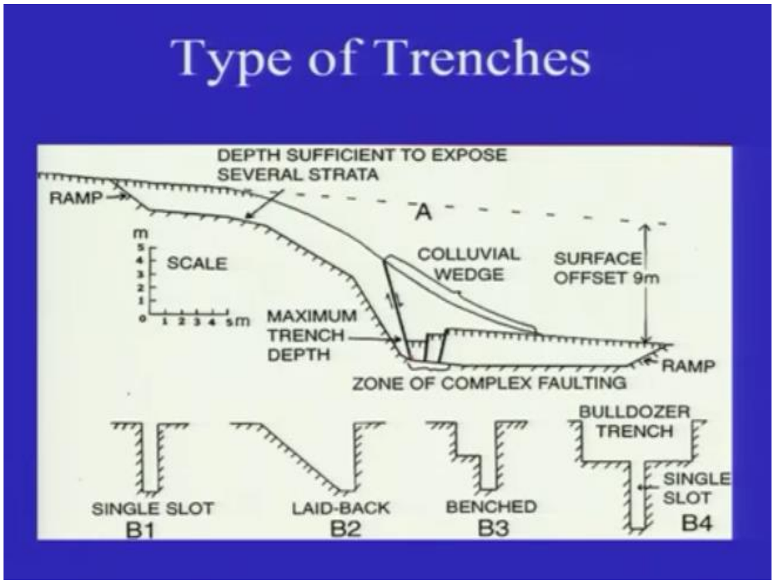

And type of trenches in different areas, if you look at then you can have the single slot trench, then laid-back trench, you have the benches which we have discussed and then you have the bulldoze trenches within single slot which goes for the deeper part. So the ideal way is to open the trench is your across this scarp that is transposed to this scarp and the portion where you exposed the fault, you can go deeper in this area.

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So as I was mentioning that one can use the manpower to dig the trench and this we did in the area of Northeast in Siliguri region, where we expose on the Ganga Brahmaputra fault. We can imagine that how many labours, we have put to dig this trench and very small trench had been dug here and we also face problem of water logging in this region and mostly in many trenches you face this.

So you need to have the water pump, which keep on removing the water from the from the trench, because you need to keep the floor dry to some extent and then that also helps in also while mapping the trench walls you can use some small machines to dig the trenches if you are opening just for the recognitions that you can do or you can use, this is what has been shown with the chain here.

So that can help you go deeper and you can easily put the material on either side of the trench wall. In India basically, what we do is, we also keep to some extent the wall is not so straight or the vertical, but we keep the walls inclined and put the new trench little bit wider up to 4 meters and that also is an advantage, because we need to photograph the complete trench and the distance, ideal distance which we should keep between the SLR camera lens and the wall should be more than 3 meters or so.

So that we can have proper focusing and all that. So that also helps in moving in the trench easily without any issues, if we are opening a very shallow or very narrow single slot trenches.

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So after we do the trenches, which have been opened, this is from India again and the most important part that I discussed in one of the slide was the safety okay. So if you see this, the students we are using the helmets and this was bit unfortunate in that we were not having the working helmets with us. So we bought the helmets which in India people use for while driving scooters or motorbikes and those helmets were being used because we were not having the working helmets with us.

Again this we have done, we have the deeper part here and we have tried to put the material away from the from the trench wall. So you need to do a lot of cleaning here, before you get into the business of mapping, the each unit and then you need to grid was it what has been shown here. So you will have to have a lot of patience while doing this and each and every unit should be properly demarcated before you start mapping the trench and that preparing the detail trench lock.

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So this is the view of that. So you have the whole top surface has been properly cleaned, so that you can demarcate the top layer or the soil unit and we cleaned this portion and again what I in the previous one that the type of sediments we may come across, if you are having the pebbly material, then the chances of caving is very common in most of the areas. So we need to be very, precautions needs to be taken to keep the walls slightly inclined, so that we do not face this.

And this even we put slightly inclined, we face this but then we did not go deeper in this area and we carried out our mapping. So this shows what I was talking about that you need to prepare the grits, so that you can do precise mapping of the trench wall. This is the grid which has been showed here it is one by one meter by one meter. We also use this machine and then we can have the deeper trenches.

But with the normal machines, which I was showing here, this one we cannot go to a very deeper part make, maximum to 3 to 4 meters, but with this you can go for more deeper, because this has and more bigger boom here and then you can have the easy excavation with such machines.

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This was one of the trench, which we opened across the scarp, which was almost like 50 to 60 meters long and as I was talking again you can see that we have kept the material away from the trench wall, so that the load has not been transferred to the exposed wall here and the trench wall is slightly inclined, very well similar to what we saw in terms of the Japanese trenches. Also along with this, if you can see here what we are doing is, we are taking a topographic profile which is important for mapping the landforms.

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This we did in Gujarat using a smaller machine. The previous one was from Himalayas. Both the trenches, which were dug in Himalayas and this is from Gujarat, Kutch region along Kutch mainland fault. So initially, what you will find is a very crude surface okay and very rough surface, which has been exposed so you need to clean very precisely too, so that the different stratigraphic units are very clear.

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So this is what you can see that one. So the next time we always use the helmets and all that and you can have more of small tools which can help you in slight deeper excavation. So you need to do a lot of labour work, when you are opening the trench and as well as while cleaning the trench and all that. So this is the deformed unit. You can see clearly here. So you have a gravel bed. We are just getting down here and beautiful exposure of the displaced unit.

You can see this one here. So you have sandy layer and then you have the gravel area, which has been folded along this fault here.

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Then, as I told that you have to do after the cleaning, you need to do lot of measurements and you need to have a proper grading, which has been shown here and that is what we are doing is, we are measuring the attitude of the fault. How much the inclination has been seen that is the depth of the fault and what is the amount of displacement, when you fix up the different units. So this is the wall, how you should put it very clean.

And even you can see the top surface has been precisely cleaned, so that we have the proper measurements okay and then we are putting the grids after cleaning. So we use lot of smaller tools, which I am having one of this slide, which will tell you that followed all you need and then we prepared a small board, which you can hang in your neck and that can be used while you are tracing the complete wall and taking noting down all the measurements.

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Figure 2A.32: Cleaning tools commonly used in North America: (a) masonry trowels; (b) claw hammer, claws are used for plucking; (c) geologist's hammer; (d) lightweight gardening mattock; (e) heavier gardening mattock; (f) stirrup hoe; (g) weeding hoe; (h) broom; (j) drywall brush; (k) scrub brush; (l, m) paint brushes; (n) portable water sprayer. Inset: a Nishiri gama hoe from Japan, favored by many professionals.

So these are the different tools, which you should have with you, like you have the hammer which is common, then trowels you have, you should have brushes to clean and then to some extent you can even use the water to spray on the wall that will help you in differentiating between the different layers. If you are, suppose you are having the clay layers and the self layer or sand layer, then the absorption of water by different layers will vary.

And that will give you the prominent demarcation, which helps in differentiating different layers. This is one of the most common tool which we are using, which is known as Nishiri gama and this is usually people use in Japan and this is what has been shown here, the Nishiri gama from Japan and many geologists or the paleoseismologist favor to use this unit and we also use this, which can be developed in India also and there is no harm.

But this is a tool, which usually a common farmer uses in Japan and this helps us in cleaning the wall very precisely.

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So after that you need to do the detailed mapping, which has been shown here. So in some time, if the walls are little high then you have to use the ladder, which helps you in measuring the units precisely. So this trench if you see is almost like 1/2 meter here 1, 2 and almost 3 meters deep. So as I am emphasizing that we need to do lot of mapping here.

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And we need, some time what we do is we spray the water. So this is just a simple you must have seen this type of unit carried by the farmers while putting the pesticides in the field. So we tried to use this to spray on the walls and to clean the wall or to we can say that we use this to make the different units prominently exposed okay and then we do sketching with the help of one of the team member measuring the displacement or measuring the thickness of the units and that has been put in the grid here. The same grid should be reflected on your tracing sheet.

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And as I told that in Japan, mostly what we do is, we put lot of water on the wall and but sometimes this is not very good in the sense, because that that may result in to the collapse of the walls okay, but this spraying putting water here will remove the finer sediments, which are getting coating or which are coating the different layers and that may result into misinterpretation or while demarcating the different units.

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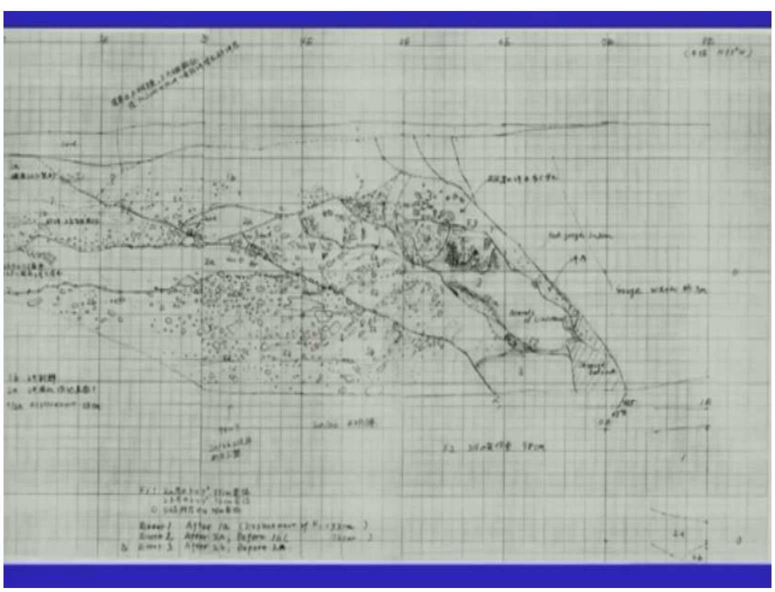

So final sketch, what you look at the this is from the previous trench, what we are having here. So you have this sketch. We have identified different units, even you have drawn here or sketched the pebbles and cobbles which are been seen and the cross-cutting relationship between the different layers, how the different layers have been inclined and what we see in the fault zone.

That helps in justifying that when was the last event and how the different events can be identified using this sketch okay.

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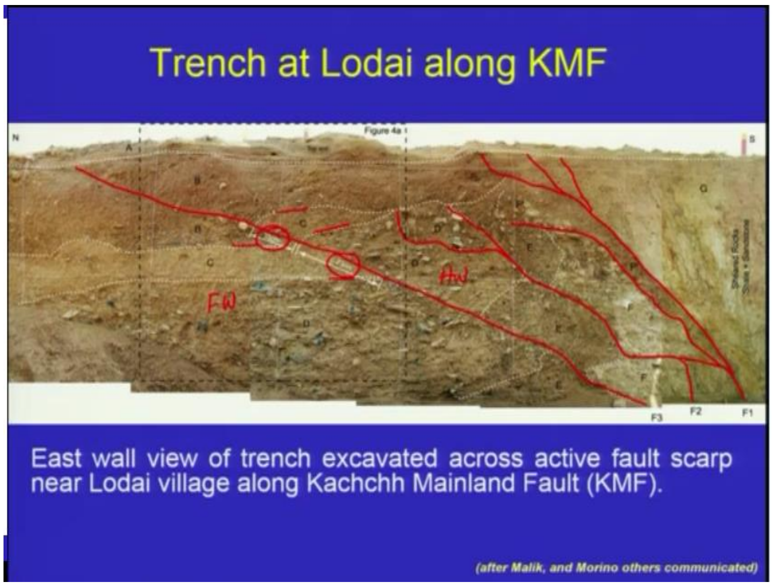

So one exercise which we did, which is important for us that is the trench from, I will just explained here. This is the trench from Kutch which was excavated at Lodai village across Kutch mainland fault and this was the trench the previous slide, the sketch which I was showing was from the same trench. Another exercise which one can do is that, if you have taken a very precise trench photographs and then now, what we do is that we use the styles one tile.

That is one by one meter and this photograph has been put in a number of photographs you will have. For example you have separate photographs for separate grids with some overlap and that you can correct in terms of the size in Photoshop and you can mosaic it and that can help again in very precise mapping of the trench wall.

In one of the lecture, I will just show you that what we have done to have the very precise trench lock. So this again what we did was that since we knew that this is the area which can help us in identifying different events and that was based on the amount of displacement, which we measured between the different layers accurately. So you have like unit C. So the based on the color, based on the grain size, we classified the whole trench in different sedimentary units.

So you have the rocks here exposed. This was mainly the mesozoic rocks in Kutch. We have shale rock comprised of shale and sandstone and this is what you have the fault plain, which are exposed here and then you have the different units here like D and then you have C, B and all that. So you can easily make out the different contexts between the different units and how they have been showing the deformation pattern here.

So what we did was, when we measured the displacement between the C and that is the lower boundary or lower boundary of C and the upper boundary of T here has been marked here and then you are having the upper boundary of the unit D. So the displacement, which was measured here, the net displacement of D unit is 73, whereas the displacement of the gain which we have measured here is the contact and this is the portion here.

So on the footwall, this is your footwall and this is your hanging wall. So we have the upper bounding surface of C sitting here the upper bounding surface with respect to B on this, that is your overlying unit or on C. So you have 33 centimeter here and similarly what we see between this and this is your displacement along the fault is 73 centimeter and similarly between this and this contact, you have 33 centimeters.

So east wall view of a trench excavated across active fault scarp near Lodai village along Kutch mainland fault in Kutch. This is one of the active fault and this was the first trench, successful trench in Kutch, which we open up.

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So trench at Lodai, this was the portion which we took for our further interpretation and what it shows here again. So you have the same log here, which we have cut and we tried to retro deform. So we perform the retro deformation by restoring these stratigraphic contacts of C along F3 fault. This was which is marked here is your F3 fault. So along this, what displacement we saw that as I have explained that it was 33 and 73, then how what exactly this tells us.

Let us move ahead okay in this. So we have 33 centimeter here, which was measured between this point and this point here. So you have the upper bounding surface of C with respect to B. So this is 33 centimeter. So we displaced and matched this one and then we have the 73 centimeter with the upper bounding surface between D and C on the footwall and the hanging wall here. So the displacement along F3 fault strand and particularly of C provided excellent example to understand how two events have been registered along F2.

So you have the latest event, because why we say that this is a latest event, because there is no displacement which has been seen. I will just go back quickly, because there is no displacement which has been seen, which has displaced the B unit further here. A is the capping unit here.

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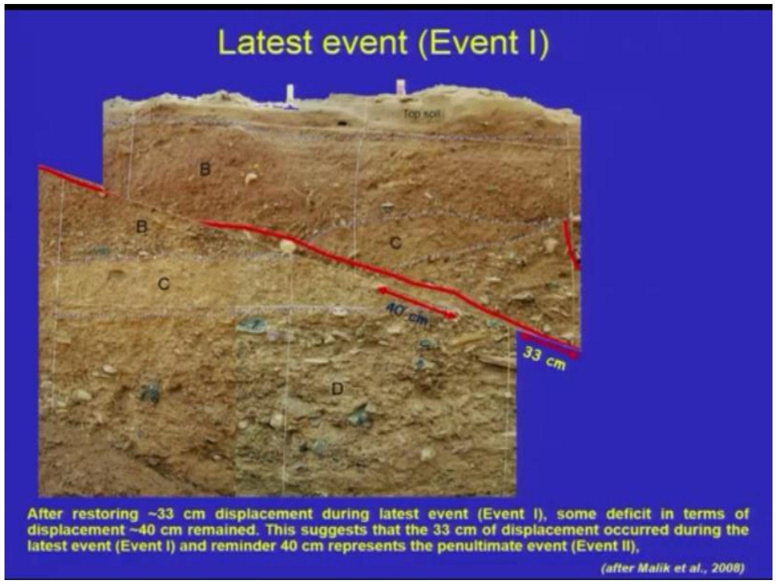

So 73 centimeter and then first we took the 33 centimeter and we tried to match the units okay. So we have, what we have done. That after restoring 33 centimeter displacement during the latest event that was we have marked as event 1. Some deficit in terms of displacement that is around 40 centimeter remained. This suggests that 33 centimeter of displacement occurred during the latest event and the remainder 40 centimeter represent the penultimate event.

So second last event was because there is still this displacement, this layer, this is not matching here; only the top surface here the contact has been matched okay. So still we are left out with this one. So we have 33 centimeter here and then we are still left out with 40 centimeter, then let us do the same for matching the lower bounding surface of C that is between C and D, what we see okay.

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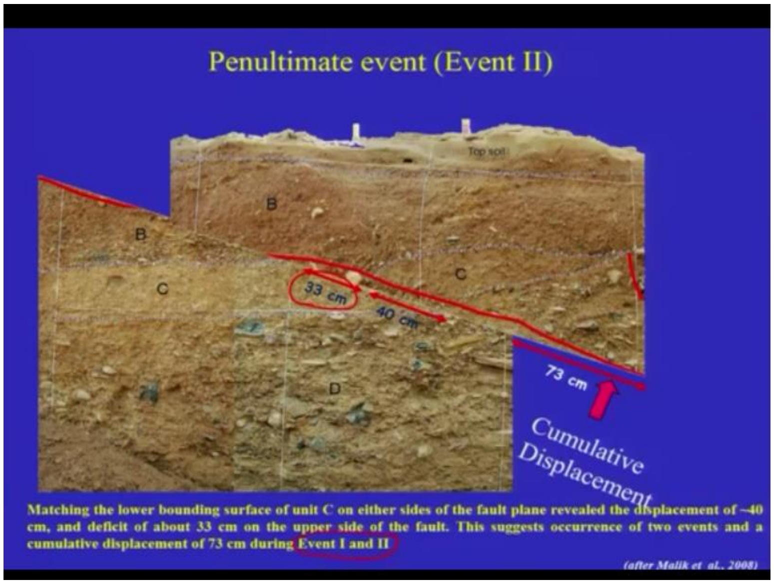

So we have this one here. So matching the lower bounding surface of unit C, lower bounding surface of unit C on either side of the fault plane revealed the displacement of 40 centimeter and the deficit of 33 centimeter on the upper side of the fault. So we have the deficit of 33 centimeter here. This is 40 and this is left out is 33 centimeter on the upper side of the fault. That is up tip of default okay. This suggests occurrence of two events within cumulative displacement of 73 centimeter during one and two event.

So total what we have is the 73. So you can do this exercise, which can help you in identifying the different events and what it suggests is that the 73 centimeter of displacement on a particular fault strength was a cumulative displacement and the recent displacement, which was observed or recorded in the trench along the same fault was only 33 centimeters. So when you will be able to differentiate different or identify different units and the amount of displacement, that will help you in identifying the different units and amount of displacement there again.

So this spot you see is the cumulative displacement and that is indicating that there were more than two events, because we had handle of that the recent movement was having only 33 centimeters okay.

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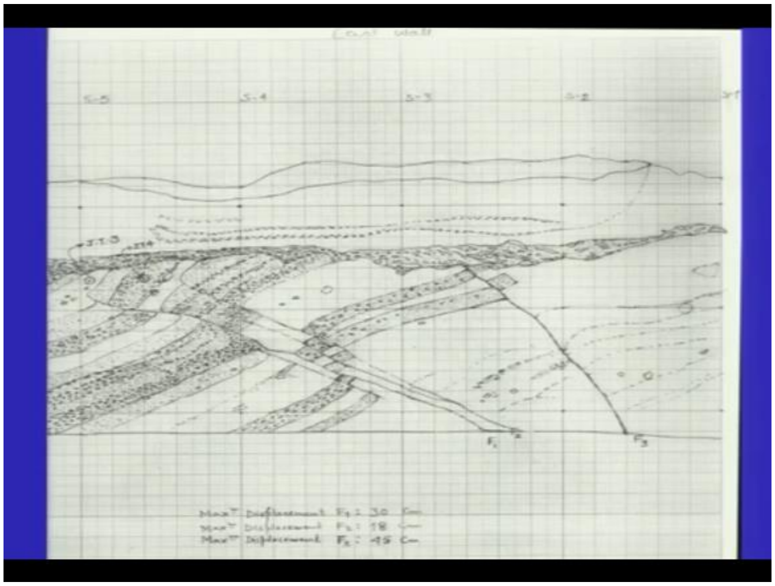

So you can have a very beautiful sketch, which you can prepare with the help of the detailed measurements, you do and this can also help in understanding the pattern of deformation along different fault trench.

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There is another trench, which we dug in Himalayas and which also like, in this trench we were able to pick up the fault, but along with demarcating the fault is not a very easy task, because this type of contact, as we have we were talking in the beginning about the primary and the secondary features, can also mimic with the channel deposits. So we need to be extremely careful, what we are looking at is the primary structure or this is a secondary feature because of the faulting.

So sometime what we experience and that we have followed later on for all trenches that sketching down each and every pebble here to some extent you can do that and it will be difficult for putting the smaller pebbles, but if you are having the larger ones that can give you a preferred orientation, like what we have been able to see in the previous one. So for example, along with that we also take into consideration that along the fault plane, what you will see is the alignment of the flat pebbles.

So this flat pebbles will get oriented along the fault plane or parallel to the fault plane and that what we call shear fabric and sheer fabric the sediments is extremely important to differentiate between the primary structure and the secondary one. So this is surely for sure short that this is what we see here is your secondary structures that is your fault.

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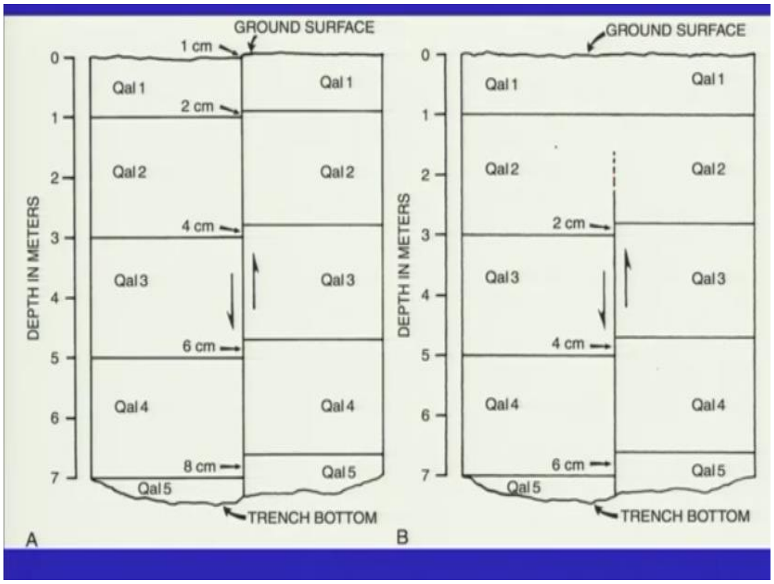

Then coming to the another part that we usually see that in multiple events, you may see that in the top portion the ground or in the up tip part of the fault, you will have minimum displacement. When you go deeper, you will able to see the displacement increases and the another one which is important is that the event horizon. So the last earthquake if you consider that this was the fault and this has displaced the Qal to unit, but has not displaced the qal1.

So this is the capping unit and this was the last event, when it occurred. So you if you sample this to you will be able to bracket the event, when exactly occurred. So before this and after this, and this will be considered as an event horizon for this particular event. So next earthquake when it displaces this here, this one that is Qal1, then this is the event horizon for that. So next one the deposition will cover this, that will be your capping unit.

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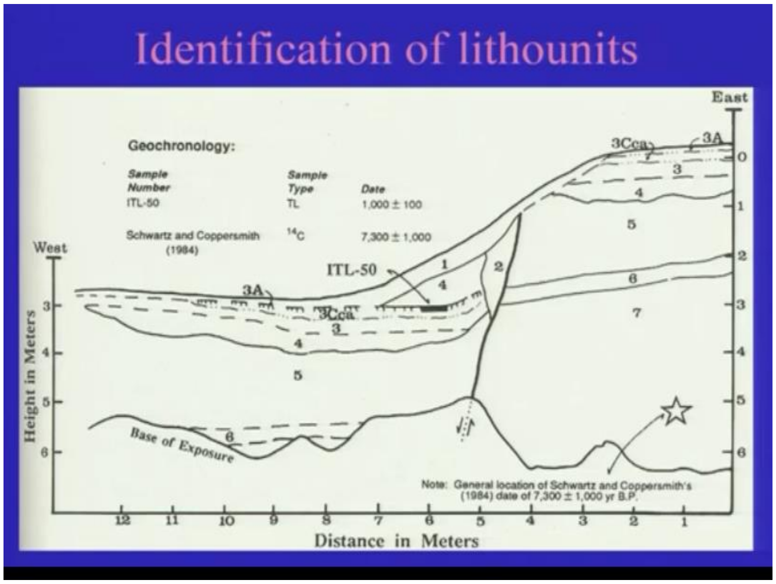

Identification of lithounits will play an extremely important role, because that will help us in identifying different environment as well as the amount of displacement, which we will be able to measure between different layers.

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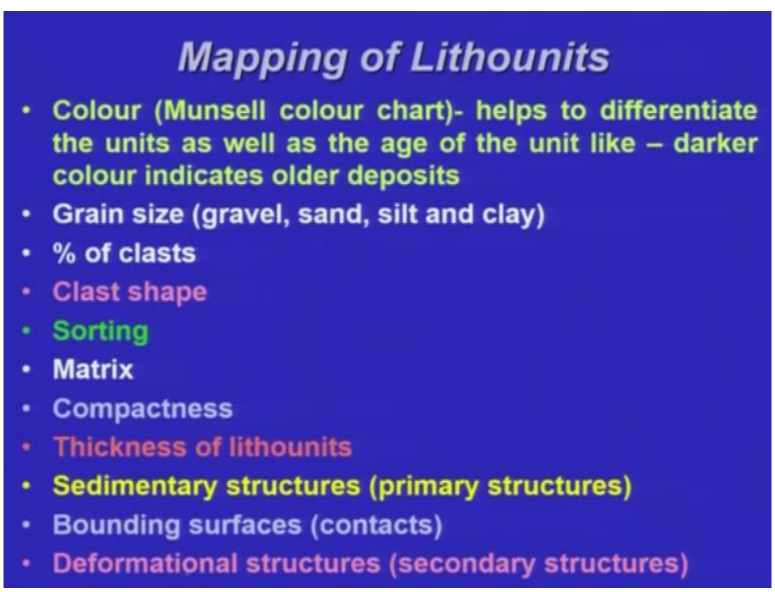

So mapping of lithounits should include a process where we use usually the color chart that is Munsell color chart, which helps to differentiate the unit as well as the age of the unit like darker colors indicate older deposits and so on. Then, we have the grain size either the units are gravel, sand or you can have silt and clay. Then you have percentage of clast, so with this you can talk about whether it is the alluvial fan deposit or it is reflecting the channel deposits.

Then clast shape is also important. If they are angular, then we can also talk about the distance they have been transported, whether they are just the screen material, which has been transported from the scarp which was developed or they are indicative of the long distance. Then also, we talked about sorting, metrics, compaction, thickness of the unit on either side of the displaced blocks, sedimentary structures, primary structures or not.

So these are all important parameters, which you can use while mapping the trench and the bounding surface. There are scant contacts. So you can also talk about that whether you see an erosional contact or depositinal contact and all that. So the understanding of sedimentology is also important while mapping the trench walls and then finally the importance comes as the structural geology part. So you map the secondary structures that is deformational structures.

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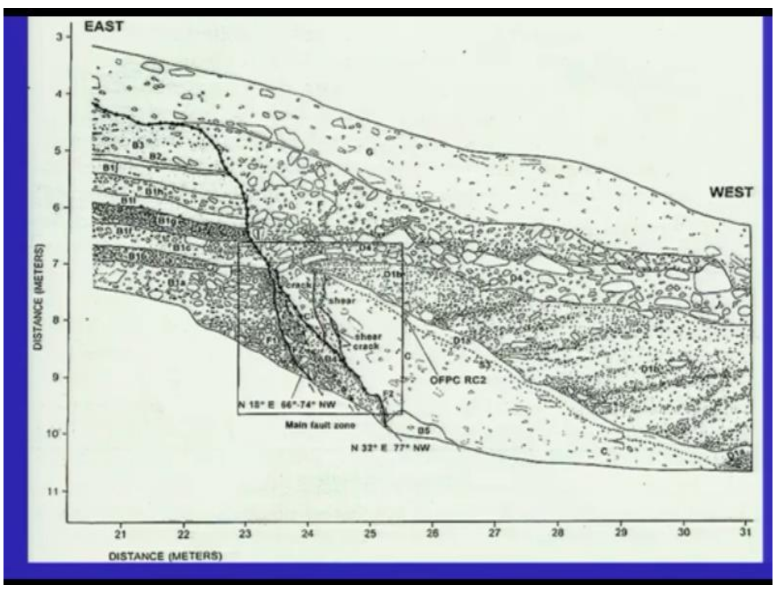

So this trench again, it shows in the normal faulting environment, which shows the angular gravels and then you have the stratified material here and which has been marked in this sheer zone and then depending on that, as I was showing in one of the slide from Kutch mainland fault that depending on that which portion of the trench is exhibiting the excellent detail in terms of the deformation, that portion can be studied in detail.

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Mapping of sheer fabric, this is one example which has been shown and one already I have discussed in from the trench, which we dug in Himalaya that you have the preferred orientation of the flat pebbles, which will get oriented along or line along the fault plane, when they are when there is a deformation and the displacement.

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This is being done in Japan, mainly what we call the geoslicer, but sometimes this is not so good in the sense because you may not be having the good site to put the geoslice, if you are having very coarse deposits. So what has been done that you have in a very thick metal sheet here, which has been pushed down into the surface with the help of crane and the vibrator, which has been mounted here and this of course is an expensive affair.

But, yes, in the areas where you do not have the enough space to dig, then you can easily do multiple slicing and you can use that data very quickly.

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So this is an exercise, which is commonly done in Japan, where the geoslice has been used to locate the fault trace. So here instead of opening multiple trenches, you can easily put. So for example if you identify the probably the fault running somewhere here on the surface. Then you can have multiple slices, which you can take from different location okay and that can also help you in identifying the orientation of the fault. So this is the first plate, which has been pushed into the ground.

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So this is what has been shown here and then you put the cover slit here, which will bring out the thick slice in this section or the thick sediment slice and this one and which can be easily. So this is the cover here which has been put after this portion has been pushed down and then locked and pulled up okay.

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So what we see is that, you will be able to have the complete log of the trench in no time and you can clean it and you can put the net or fine net cloth, cotton cloth and you can have the peel of that trench wall also.

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So you can have peel and then you can mosaic it, which can help you in preserving this in lab. This is one of the greatest advantage of this technique that you can bring home or bring back in your lab the whole trench lock. So the fault traces here, it goes up to this one and you can see that deformation and the deposits.

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Similarly another one, the fault trace goes here, also branching out here.

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So in Japan, this is one of the most common practice that after the trench has been open and studies are been done, they will invite the local people and also the administration to look at that, what exactly is the history of one particular fault, which is close to their homes or it is passing through their cities okay and this is the kind of an outreach program, which they run and similar things we have planned in India.

We did a couple of workshops to train the young people and also we are now planning to invite, when we open the trenches, we will invite the administration and all that and another part of this course, hopefully we will be able to deliver that we are going to give you an additional add-on course or linked with this one only, where we are going to shoot the movies in the field and also what we are doing in trenching and how we excavate the trench.

How we locate the location and what other all methods we used to do map those and all that we will do that in the additional part of this one. Thank you so much. We will continue in the next lecture.