Earthquake Geology: A Tool for Seismic Hazard Assessment
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Lecture – 29
Lab & Field Techniques in Active Mapping and Paleo Seismic Studies (Part -IV)

Welcome back so let us move ahead and see what more we have in the field technique okay. So as we have seen in the previous lecture, we were talking about the detailed mapping of the surfaces so let us see what more is left out in this field technique part.

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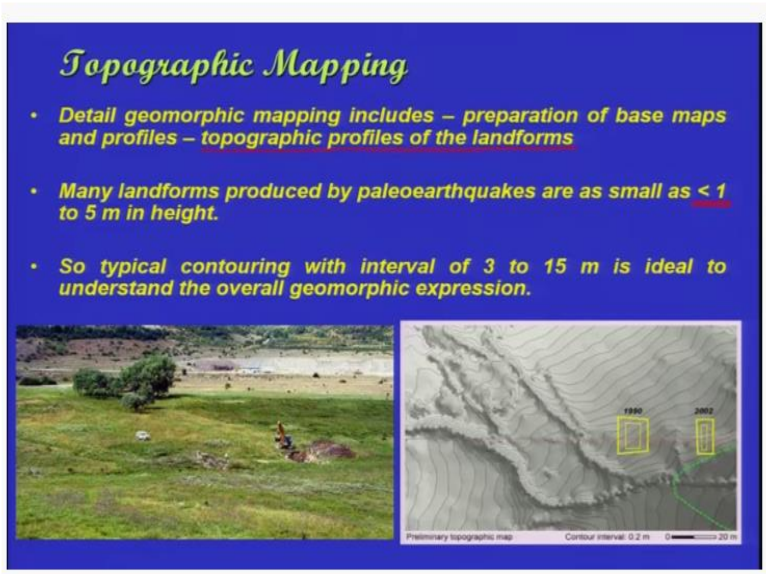

So the most essential which comes with the base maps and all that is your topographic mapping in the field. So detailed geomorphic mapping includes preparation of the base maps and profiles and mainly we are talking about the topographic profiles of the landforms that means your deformed landforms.

Many landforms produced by Paleo earthquakes are as small as 1 to 5 meter in height. So in some cases the question which comes in mind in our mind that how we will be able to map the features using or identify the features with height less than 1 meter where we are using the satellite data with resolution of height 2.5 to 3 meters and this this always remains a question.

So what experience we had while doing this such type of surveys not know we of course we have demarcated the fault traces using high resolution satellite photographs but and then moving to the field area at that particular site we also consider if we come across any feature or the land form with the deformation could be less than 1 meter and that that probably is the indicator of the paleo earthquake.

So we should not miss out even the features which are present in that region which has the height less than even 1 meter. So what we do is we generate a very detailed map using GPS or using the total station and generate the contour maps with an interval of 3 to 15 meters or even less than this you can do and very high resolution topographic map you can generate with the contouring and which is ideal to understand the overall geomorphic expression.

The example which has been given here where you can you will not be able to identify the deformation very clearly on the satellite data but in field the detailed mapping helped in identifying the deformation which has been shown here and then contouring a contour interval was even less than what has been shown here even that what it shows is around 20 centimeters of the contour interval.

So this portion helped in identifying the offset of streams here and that was taken into consideration that this was probably the fault line and across this the trenches were been open, and this is from the northern Anatolian turkey northern Anatolian fault where the trenches were open in 1990 and 2002. So you can have such maps and with an high resolution contours which can help you in the demarcating the landforms which you will be unable to mark using high resolution satellite photos.

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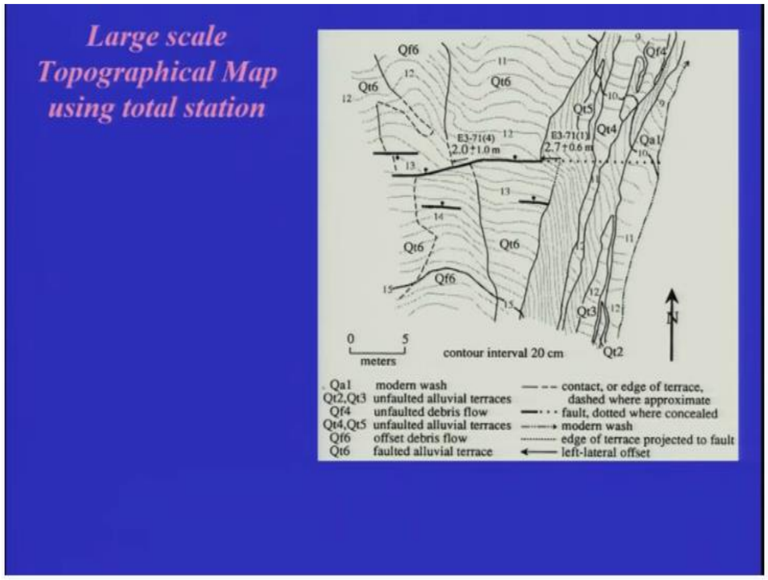

So topographic mapping in the field is extremely important and there is another map which shows from us with the contour interval of 20 centimeter which helped in identifying the displacement of the terraces.

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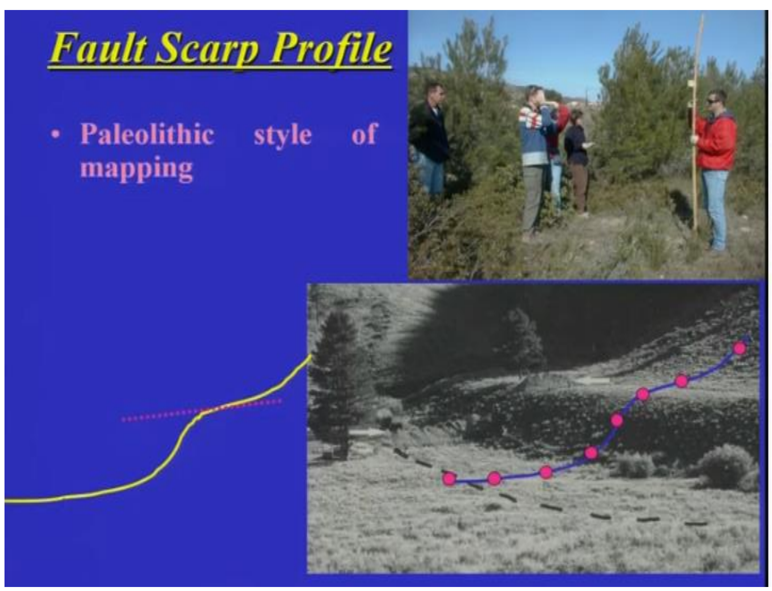

Now fault scrap profiling paleolithic I am just using this word because we have the ancient culture which usually the archaeologists take into consideration the Paleolithic chalcolithic and all that. So paleolithic style the ancient not very ancient but of course then style of mapping the landforms we used to use theodolite or maybe we have used to use and calibrated post here and then with the intersection of the eye here with this person leveling here and he will say okay fine whether the your the point is intersecting here with this then he will say yes then this point will be marked as in height of this point here okay.

So this pole this will give the height of this particular point. So this is what we have the paleolithic style we used to do and then we came up with the total station mapping using high resolution like what we are having digital data. So we have we when we see or identify the fault scarp here using high-resolution satellite data and as well as we have demarcated or located this feature in field it is most ideal to take the profile across this one and this black dotted line is showing the probable trace of the fault.'

Because this portion is already showing you the retreat retreated or erosional scarp, may be the scarp got eroded then the faults on the surface lies here. So it is ideal to take the profile which crosses the undeformed area and the deformed area. So you have to decide and finalize your transit accordingly so that you cover the undeformed flat area as well as the deform portion. So multiple points you can take crossing the this curve or the landform.

So there just the points which you can decide, and you can take and that can help you in generating the topographic profile. So if you have this profile which has been shown here and if you draw a line here and parallel to that here in this and the undeformed surface in the deform portion of the hanging wall or the foot wall then that will give view the height of the scarp.

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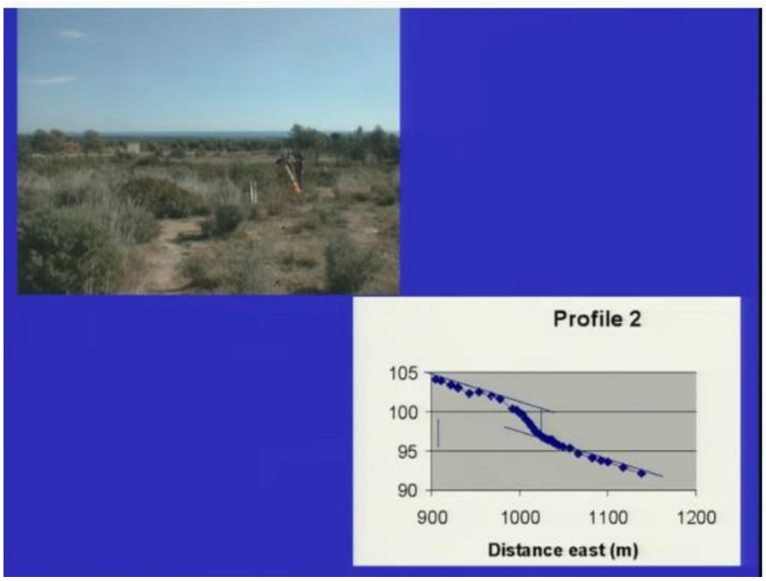

Further now we have started using the total station which keeps the millimeter accuracy points and this will give you this points what we will get will be having x, y and z. So you will have the coordinates of each point which will be given here and with the help of the best-fit line which has been drawn here you can talk about the height of the scarp here.

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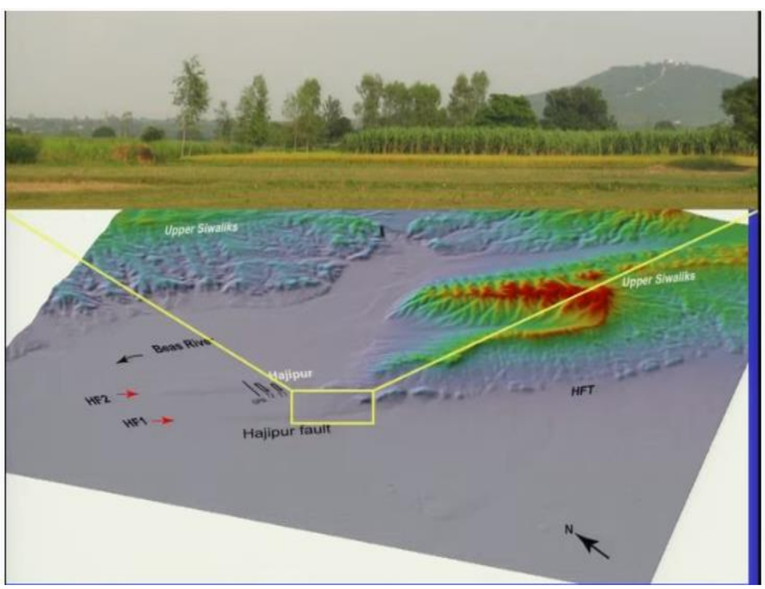

Then another way to identify the deformed landform is to generate the shaded relief map draped on the satellite topographic mission data or the DM which has been generated using any high resolution data within stereo pair visual capability. So this you can easily make out in a very flat surface this slightly raised landform here which are indicative of the fault traces. So ground truthing when we did here you can see this part in the ground, so this is slightly elevated hill and then you have the flat surface.

So this is from Himalaya so this portion here is your Indo-Gangetic plain and this is your sub Himalayas and this contact is your contact which we call Himalayan frontal thrust or the plate boundary between the Indo-Gangetic plates and the overriding Eurasian plate. So ground photograph of this you can look at with this one okay, so you have the hilltop which has been seen here as this hill and then the elevated portion which you see over here.

So if you draw the profile here then you have something like which goes here there is an elevation here which increases at this point and this is the same here what you see from the ground. So this is your elevation which has been marked here exactly the same area. So we can pick up this deformation using different trace or the techniques which are available, and it can be easily used either you are using high resolution satellite photos, or you are using aerial survey data, or you are using the digital elevation model and draping the images on the digital elevation model.

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So again the next step will be that you identify the fault scarps and you select the trench site so if we selected the trench site over here and this portion.

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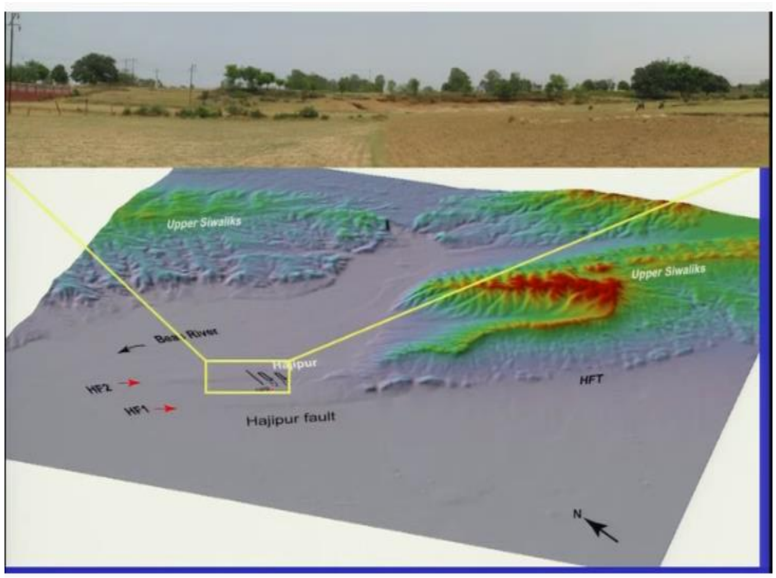

So what we did further was not this is another fault which I was showing in the previous image. This is the same image which we have and the round photograph if you see is this one here okay so the previous one was from here and this one is another fault which you see the portion which is up and this down that same you can see the up and down here okay.

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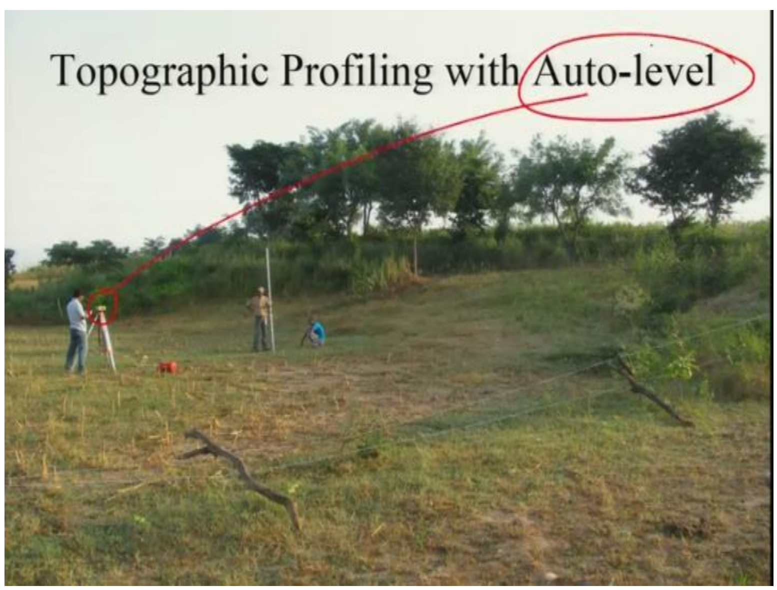

So earlier we used to have we used to do the topographic mapping using auto level. But now we have with the more development in science and technology we have high resolution total stations with which we can generate a millimeter accuracy and maps.

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So we use either real time kinematic this is what is been shown here this is in total station we have and then with the help of the line of sight you will be carrying one prism which is mounted on the post and this this post or the rod is calibrated so you have the height of this. So this part we will talk when we are talking the detail about the total station all that. So with the line of sight you can easily map the and the area or putting your the pole at different location of your interest as it is it has been shown here.

So you have the total station here and this person will keep moving and try to map the topography or they try to map the landforms here this is again with the total station and this is what we have we call the either the real time kinematic survey or post-processing kinematic survey using the total station and GPS and further I will discuss this in very quickly in coming slides that we also used to ground-penetrating radar to identify this subsurface deformation.

So what we do in short if you take so we are we are doing the first using the satellite data then we are using the mapping of landforms and field either using total stations and then third we do so this is all related to the surface mapping and subsurface we do GPR before we get into the trenching part. These are the simple steps of which we follow without any constraints or boundaries we must do this.

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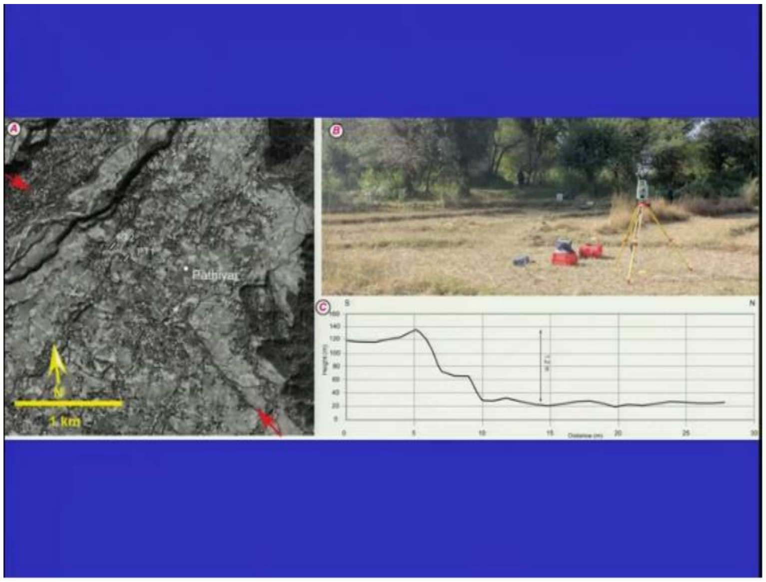

So this is an example of the same what I was talking about that we have we identified the fault trace using the high resolution satellite data. We went into the field identified the landform at that same location we use total station and we prepare the topographic profile. So now you can see that this topographic profile is hardly there the height is 1.2 meter and as I was saying that whether we will be able to pick up the deformation of right 1 meter or less than that.

To some extent yes if the feature is very sharp you will be able to pick up this deformation even on these satellite photos and nowadays with the advantage that you have the digital satellite data okay so you have the data on your PC you can enlarge this area of your interest and then we can view this in 3 dimension that will increase there is at least the resolution which will help you in identifying even the minor features which are having height less than 1 or maybe around 1 meter or so.

So this what we can we what we are showing is not this is with the experience and what actually with it that is with the help of this is carto sat data we were able to pick up this this fault trace and this is the location where we see the topographic variation and then we mark the fault scrap.

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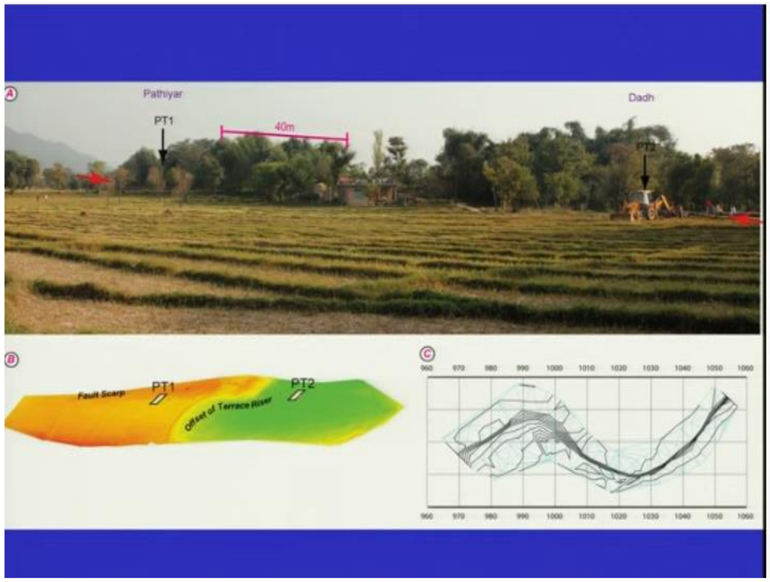

Then after this we go for trenching but this is an one more example where we wanted to map the displacement along this curve or along the surface or sorry displacement of the surface along the fault and the offset of this stream along the fault okay and this what we did we took a number of points with the help of total station and with the simple triangulation we have generated this offset of stream.

So this streams flow somewhere here like this and then we have this scrap here and then it goes like that okay. So this offset of ridge as well as the small stream which we were able to pick up in the on the satellite data as well as in the field. So we were able to precisely say this okay you could do this putting the tapes and all that the measuring tape and you extend and keep measuring that what is the offset.

But there are restrictions for example there is an house setting here and you may not be able to cross very straightly because you are having trees in between. So the best way is to do a detailed mapping and that what we generated was the digital elevation model. So this portion is the higher ground as compared to this one which is light yellow and the orange one is your the higher ground here which was also seen in the previous photograph over here okay.

So this portion is this one here and the scarps run like this and this is the offset of the terrace riser and then this helped us in deciding the location for trenches okay. So I will get into this business of trenches later on, but this is again another example where we were, we use the data and generated high-resolution contour maps.

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It is coming to the area of Beas what we did was this is at this location here we took the detailed mapping was carried out using total station, but we fixed up the site after doing a detailed GPR survey in this region okay.

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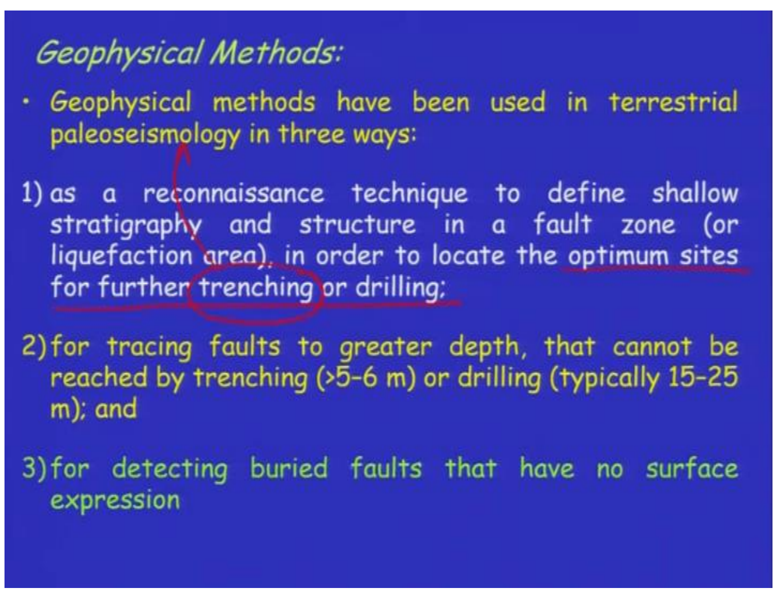

So using geophysical methods is another advantage before getting into the trenching part okay. So as I have been telling that we use satellite data then go into the field do the mapping and then coming down with the before we get into the trenching part, we do the geophysical method. So there are different geophysical methods which you can use that you can use seismic reflection you can even use resistivity survey you can do GPR.

But what we have the good experience with the GPR ground-penetrating radar which can give us a very excellent harder solution subsurface profile of the deformation or deformed layers up to 8 meters or even if you can go up more than 10 meters but for us for putting trenches 6 meter to 10 meter is quite good enough okay. So geophysical methods have been used in terrestrial paleo seismology in 3 ways one is as a reconnaissance technique to define shallow stratigraphy and structure in a fault zone or a liquefaction area in order to locate the optimum site for further trenching or drilling.

So the optimum site for trenching is extremely important because this is going to be in very tedious job because if you miss out the fault you may keep digging the area and which may not be allowed because of the environmental constraints. So you have to be very precise that when you where you would like to put the trench to do a detailed paleo seismic studies. So, the next one is that we usually do the geophysical survey to reach greater depth because with the help of trenching you may not be able to reach greater depth.

So by trenching maximum up to 5 to 6 meter you can go and drilling up to 15 to 20 meters and so but with the help of geophysical technique you can go further deeper to identify the fault trace and finally the third one is for detecting the buried faults that have no surface expression. So these are 3 important steps why we usually do geophysical survey to before we get into the trenching part and to the paleo seismic investigation.

So in our case the what we have done in India mostly we have used GPR to identify the deformation which goes maximum up to 10 meters and so on. But now we are trying with the other methods now if we can go up to more than 100 meters or so.

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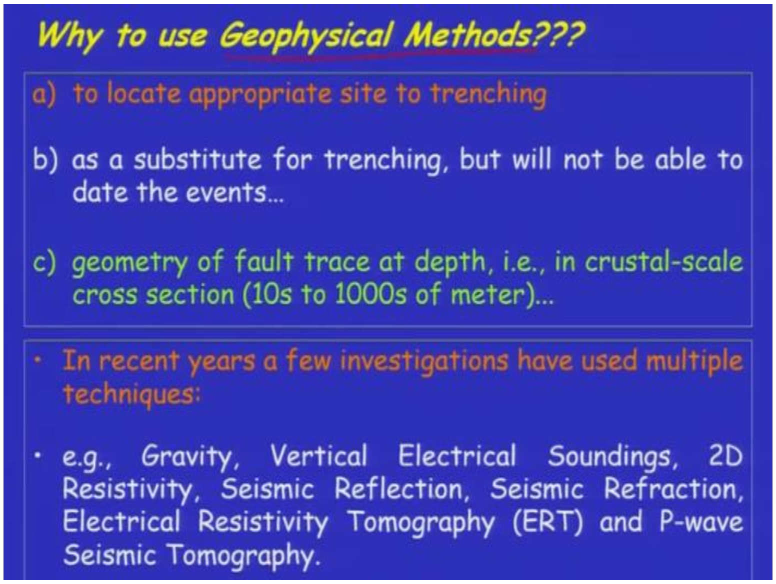

Why to use geophysical method? So there is another question here so the answer is to locate appropriate site for trenching as a substitute for trenching but will not be able to date the events okay so you can do you can identify the deformation at the depth but unless and until you are not dating the deposits or the sediments you will not be able to classify or characterize the fault as an active and you will not be able to date the events the paleo earthquakes which have occurred on that particular fault.

And third we do to understand the geometry of the fault trace at depth okay that is the in crustal scale cross section if you want to do which goes more than 1000 meters or so then you will be able to at least say that there is this method is important to at least understand the geometry or the greater depth. Then in recent years a few investigations have used multiple techniques and those techniques are gravity vertical electrical soundings, 2d resistivity, seismic reflection, seismic refraction, electrical resistivity tomography ERT and P wave seismic tomography. So these are a few more investigations or the techniques which are been used to for the world for the first step as a first step for your paleo seismic investigation.

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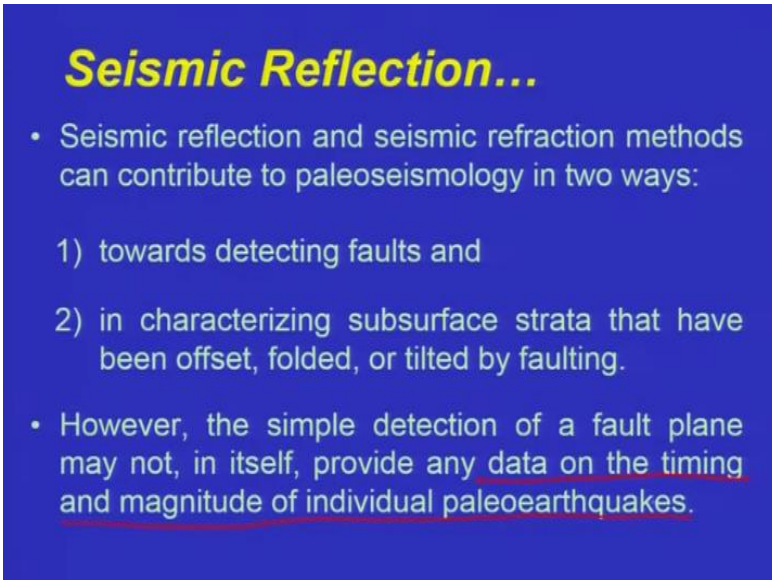

So in case of seismic reflection and refraction methods if they can contribute in two ways to the paleo seismology one is towards detection of fault and second is in characterizing the faults either these status are folded, or they are tilted by faulting. However, the simple detection of a fault plane may not in itself provide any data on timing and magnitude of an individual fault or Paleo earthquake.

So this is important that we need to know that when the earthquake at the last earthquake occurred and when they were more value earthquakes in the past and what was the magnitude of that particular earthquake individual earthquake or what was the magnitude of the previous paleo earthquakes. So in short what we conclude as from this that the; we can use your physical technique but just to locate the deformation and just to understand the geometry of the fault at greater depth.

But we will not be able to use this information in categorizing the fault whether it is active or not but at least to some extent we can categorize the fault being the pattern of deformation whether it is and vertical fault or it is just and pure strike-slip or a normal fault that at least you will be able to categorize because you will get in profile within of greater depth. But otherwise the identifying the paleo earthquakes it will not be possible because you are unable to look at the sediment succession you are unable to date those sediments. So you will not be able to classify or characterize the earthquakes in that region using that.

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Figure 2A.10: Photograph of a seismic refraction tomography line extending from the downthrown block (foreground) up the scarp face (middle ground), from Sheley *et al.* (2003). White flags indicate geophone locations, spaced 0.5 m apart.

This is an example photographs which has been seen for the seismic reflection tomography where the; you have the tomography line extending from down thrown block in the foreground and the up face scrap in the middle here which goes right up to the top. So this is the scarp here this portion is up this is down, and this is what has been done for the seismic reflection.

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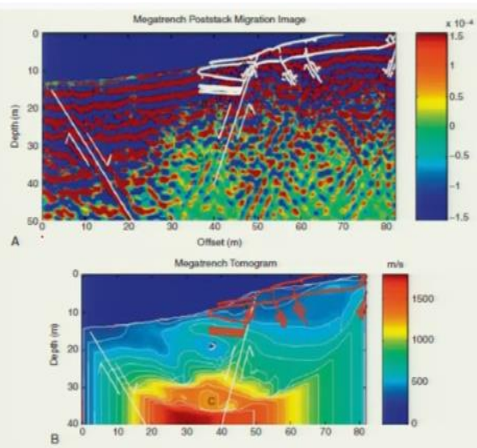

Figure 2A.11: Seismic refraction results from the Wasatch fault (Utah) megatrench of 1999 (McCalpin, 2002). (A) Poststack migration image and (B) refraction tomogram. White lines show faults interpreted by Sheley *et al.* (2003), black lines (red in color version) are their rendition of McCalpin's faults. The ground surface of McCalpin's trench does not exactly match the ground surface from the seismic profile because the survey line was about 20 m to the north and subparallel to the trench. From Sheley *et al.* (2003).

There is the profile which was been obtained using seismic reflection going up to the depth of 50 meters.

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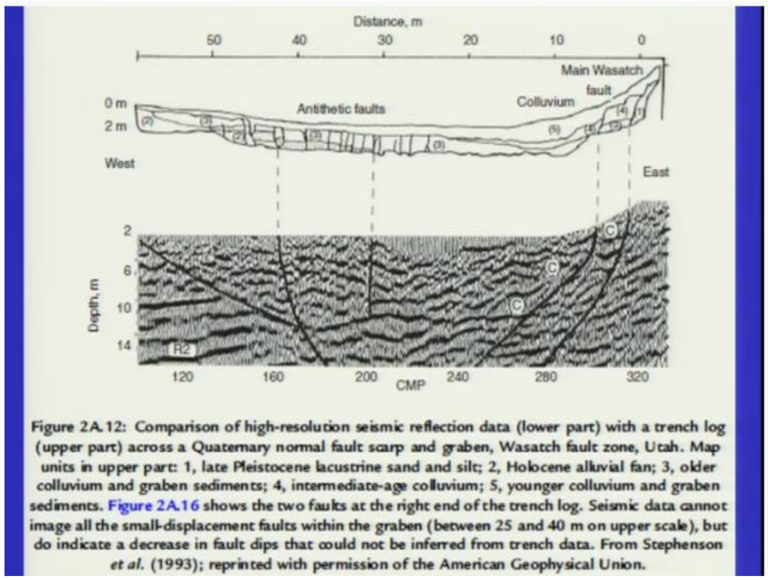

Figure 2A.12: Comparison of high-resolution seismic reflection data (lower part) with a trench log (upper part) across a Quaternary normal fault scarp and graben, Wasatch fault zone, Utah. Map units in upper part: 1, late Pleistocene lacustrine sand and silt; 2, Holocene alluvial fan; 3, older colluvium and graben sediments; 4, intermediate-age colluvium; 5, younger colluvium and graben sediments. Figure 2A.16 shows the two faults at the right end of the trench log. Seismic data cannot image all the small-displacement faults within the graben (between 25 and 40 m on upper scale), but do indicate a decrease in fault dips that could not be inferred from trench data. From Stephenson *et al.* (1993); reprinted with permission of the American Geophysical Union.

Then you can also do the high-resolution seismic reflection when compared with the trench lock. So this has this trench is hardly 2 meters but with the seismic reflection you are able to reach right up to 14 meters or so on.

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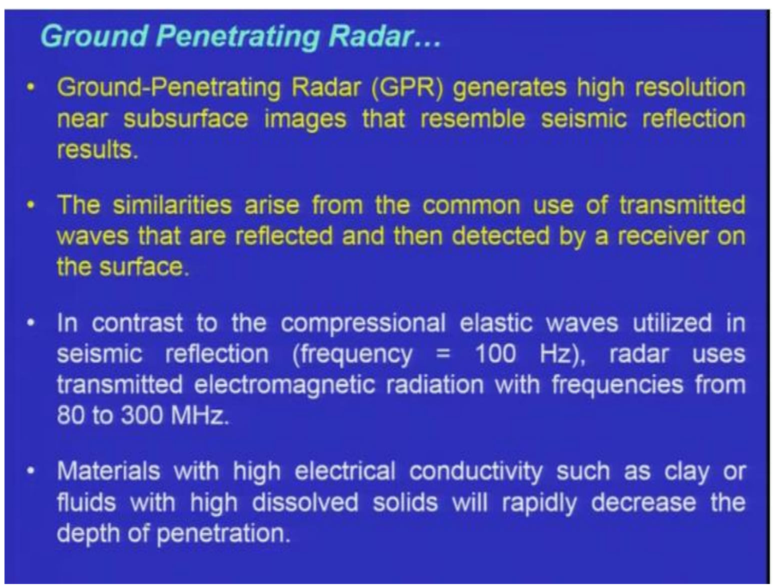

So, ground-penetrating radar generates high-resolution near-surface image that resembles seismic reflection results okay. The similarity arises from the common use of transmitted waves that are reflected and then detected by the receiver on the surface this is very much similar to the seismic reflection data. So in contrast the compressional elastic wave utilized in the seismic reflection within frequency of around maybe 100 hertz a radar uses transmitted electromagnetic radiation with frequency ranging from 80 to 300 megahertz.

So this you can have more also and even you can have less megahertz frequency antenna, but you can this frequency antennas will give you and very high resolution image geo radar image. So the material with high electric conductivity such as clay in some regions okay if you come across or the fluids with high dissolved solids will rapidly decrease the depth penetration depth of penetration of the radar and this is very much similar to what you will experience in case of the resistivity survey. So there are limitations, but you can increase the gain and try to increase the penetration depth of the GPR waves okay.

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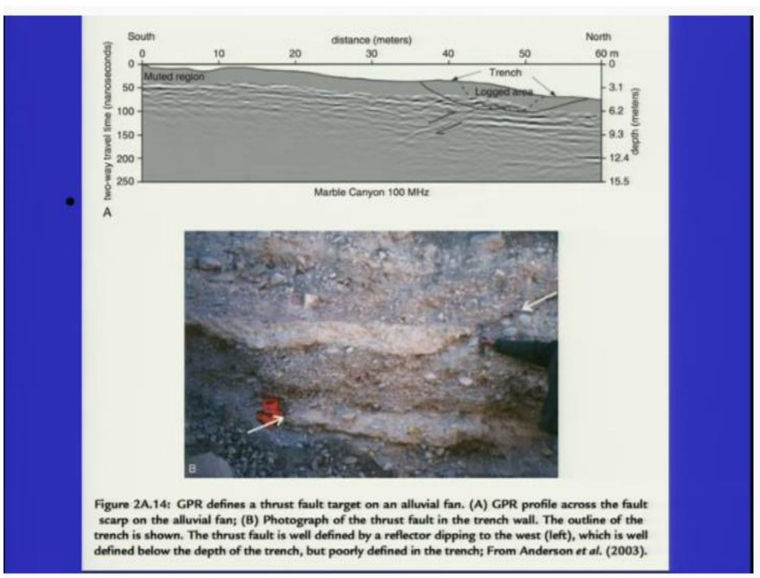

Figure 2A.14: GPR defines a thrust fault target on an alluvial fan. (A) GPR profile across the fault scarp on the alluvial fan; (B) Photograph of the thrust fault in the trench wall. The outline of the trench is shown. The thrust fault is well defined by a reflector dipping to the west (left), which is well defined below the depth of the trench, but poorly defined in the trench; From Anderson *et al.* (2003).

So this is an example of the ground penetrating radar profile which has been shown here they have they have been able to go up to 15 meters so much better than what was been done in seismic reflection and further was it was been compared with the trench which was been dug in this region so this is the logged area which has been seen here and which shows that clear-cut displacement here.

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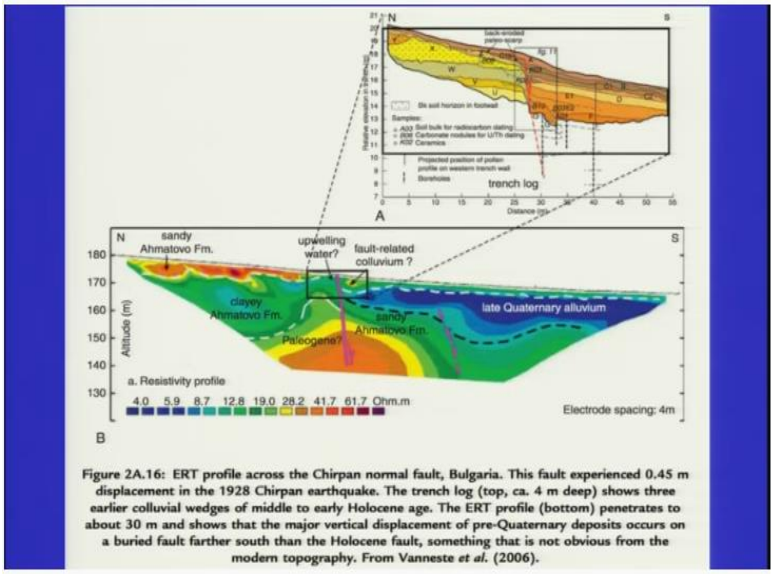

Figure 2A.16: ERT profile across the Chirpan normal fault, Bulgaria. This fault experienced 0.45 m displacement in the 1928 Chirpan earthquake. The trench log (top, ca. 4 m deep) shows three earlier colluvial wedges of middle to early Holocene age. The ERT profile (bottom) penetrates to about 30 m and 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).

Then you have the electrical resistivity tomography which with the help of which you can go up to the depth of more than 100 meters which has been shown here and with the change in the density or the of the material you can easily make out the variation in the lethargy which has been compared here with the trench which was open in Bulgaria. So with this I will stop here, and we will continue in the next lecture and see what is more left out in this part and then we will straightaway move to the respective tectonic environment and how we have conducted the paleo seismic studies in those regions. Thank you so much.