Earthquake Geology: A tool for Seismic Hazard Assessment
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Lecture No 1
Introduction to Earthquake Geology (Part-1)

So very all welcome to all of you in this course on earthquake geology and I hope you will enjoy this course as you have enjoyed the previous courses also given by me.

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Basically this earthquake geology, what we are talking about is one of the very basic and important tool towards seismic hazard assessment and in this course we are going to talk mostly or we can I go I would say that totally about the earthquakes and related hazard and also I will try to cover mainly or focusing on the landscape features or the signatures which are preserved in sediment succession.

And how to identify and what are the methods to identify those features and how we evaluate such signatures or the evidence which are preserved in landforms on the Earth's surface as well as in the sediment succession near surface sediments oxidation mainly. So I will try to cover three different domains in this that is the tectonic regimes which details you will learn as we move onwards in this course.

At the same time will try to focus more on the research work which we have carried out in India, because as Indians we should know that which are the regions which are seismically active or earthquake prone regions and what best we can do to minimize the hazard related to such events. And we are not talking about the earthquakes of magnitude two or five but of course even magnitude 5 earthquake bothers us okay.

And for example today we had an earthquake of 6.1 in hindu kush region that is you are in the northwest region of Indian subcontinent and which shook most of the areas and like Afghanistan, Pakistan and some parts of India also and it reached right to Delhi. So everyone is very much bother as soon as Delhi shakes not only by the earthquakes but other reasons also but of course yes the earthquake bothers everyone.

Because it takes more lives than expected because of the buildings and all that. Okay? So we will, I will try our best to talk about the secondary effects of the earthquakes in this course and about the basic tectonic framework of India. As well as or mainly I would say that we will focus on the regions which are seismically active like Himalayas, Andamans and we have Gujarat, that is Kutch region. So we will focus on this three and also few examples from the other part of the globe we will try to cover in this course. Okay?

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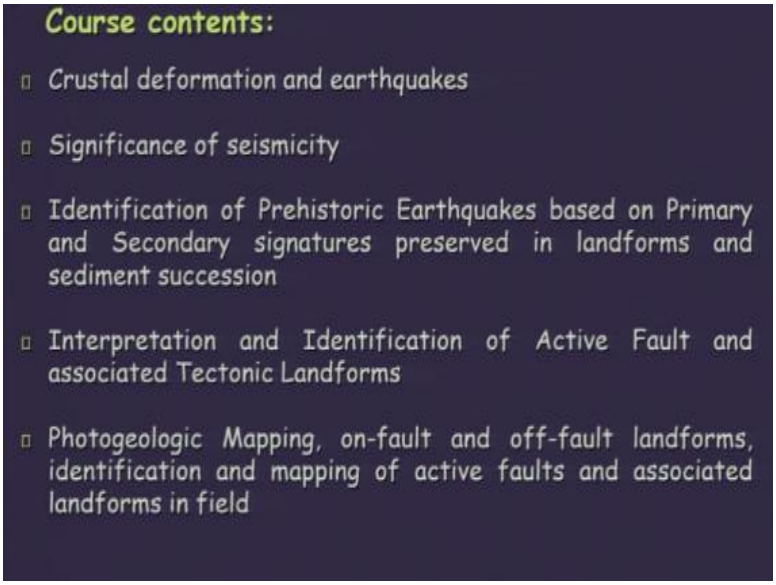

So let us, get started and see what are the course contents. course contents are all to be available with you in the template but as we move in this course there is no boundary that and the specific lecture which is will listed, will be delivered on particular week. But of course we will try our best to confine ourselves with the list which we have provided. now before going

to that I will just like to mention here is that any question if you have please try to write to us our emails.

My email has been given below as well as the TS to this course. the emails are been given and as I told that this course basically has been designed in some of like some in somewhat innovative way because we will be focusing also not only on the labs or they not only in the lectures that is the classroom talks and the labs which we will be doing in terms of the remote sensing part.

But also we will try to take you in field and how we locate the features and field and how we try to identify what all methods we use to map those features or the signatures on the surface as well as in the sediment succession. So we have we will try our best to deliver that and I hope you will enjoy that part. Okay? So course content if we take then as soon as we talk about the earthquakes.

We need to discuss and talk most of the part is the crustal deformation and the related phenomena and that crust deformation. When we talk about and immediately it comes in our mind is the mountain building activity and the resultant. What we see is the sudden release of the strain which has been developed or is your earthquakes. Okay? Then, significance of seismicity or the earthquakes;

What are the reasons for that and why we want to know more in detail about the earthquakes in the seismically active region? so of course the question comes and in one sentence you can say that we know that this area is active but which location in that area particularly is most more active and which location or the fault lines that we will talk this nomenclature I am using right now but this you will get as we move further in this course.

So I will try to cover some basic parts also, basic like the fall for charm in this region geological structures mainly and so that you are aware of that what type of faults? We are talking what type of tectonic environment? We are talking when we are getting into more details of this course and why seismicity is important? And basically as I told and the beginning as you see in the title also, that this is the one of the basic tool for this towards the better seismic hazard evaluation.

So and then comes the identification of prehistoric earthquakes based on primary and secondary signatures. now this is an very basic part that is primary and secondary signatures because there are features or the signatures on the landforms as well as the signature is preserved in the sediments which are primary and that is those which are formed or developed at the time of deposition or the formation of that particular landscape.

But later on they got modified that is because of the crustal deformation so this portion of the of the course is important to start with because this will help us in differentiating between the primary and the secondary signatures preserved in land form as well as sediment succession. so this will be the first step, we will move ahead with and then we will see more in terms of the interpretation and identification of active fault. Okay?

So this is the most important one for us so and so the faults different type of faults what are those from this time different type of Faults and what type of Faults one can expect in a particular tectonic environment and the active. What we say is, because this shows that the particular fault; if they are active then they are hazardous in terms of because they are the locations which are likely to produce earthquake of large magnitude in near future. Okay?

So we would say that interpretation and identification of your active faults and because of this deformation what are the associated landforms. We will try to identify that because whatever deformation is taking place. We are talking about, if we say the crustal deformation then everything gets preserved on the surface as well as in the sediment succession nevertheless the systems are very dynamic.

So there may be some locations where they might have got eroded, but in most of the locations these are preserved. For example; as the gigantic ranges of Himalayas they are the result of ongoing tectonic deformation or crustal deformation since last 55 million years from now. So even though the erosion is active in this those regions some residual deformation will be always preserved.

So that what we are trying to find out and this is what we will talk about in the active Faults and associated tectonic landforms. Now as I mentioned that this particular course or the topic which we are talking about is related to the tectonic landforms. So first we will start with the

land, so identifying landforms we need to look at the plan view or the aerial views so for that we need to have and very good handle on the photo geological mapping.

So we will try to give you some lectures which we will talk about how we are using the high-resolution satellite data or photos and what are the ways to see the landforms or the landscape or the Earth's surface in three dimension. So 3D prospective views we will try to generate and how they are being generated what data one can use because the National remote sensing agency provides very good high resolution data which one can use for identification of such landforms preparing a detailed morphological maps.

So geomorphology which is one of the important parts or the topic of this course, so landforms understanding of landforms and identification of landforms will be extremely important in this. So with the help of high-resolution satellite photographs one can easily map and prepare detailed maps for both active faults and associated landforms. So we will look at the remote sensing part here and then the evidence or the signatures which are preserved on fault. Okay?

This is this is on fault we are talking about close to the fault or near to the fault or exactly on the fault and off faults. There are away from the fault. So these are the two different domains I would say within the one major domain where we will try to look for the landforms. Which are associated with the faulting but what are the landforms which are close to the fault and away from default identification and mapping of active faults and associated landforms in field.

Now one which we can do is of course a basic identification as there and this will further we used to this information which we will generate using the photo geological interpretations or the satellite data interpretation we will also try to map those features in field. So what are the techniques which we use because quantification of this landforms how high they are? How so mainly the distribution on the usual distribution of such landscape or the landforms?

We will try to map using either high-resolution photographs or there are other means of mapping this either using the total stations taking the topographic profiles or the elevation or you use UAV unmanned vehicles.

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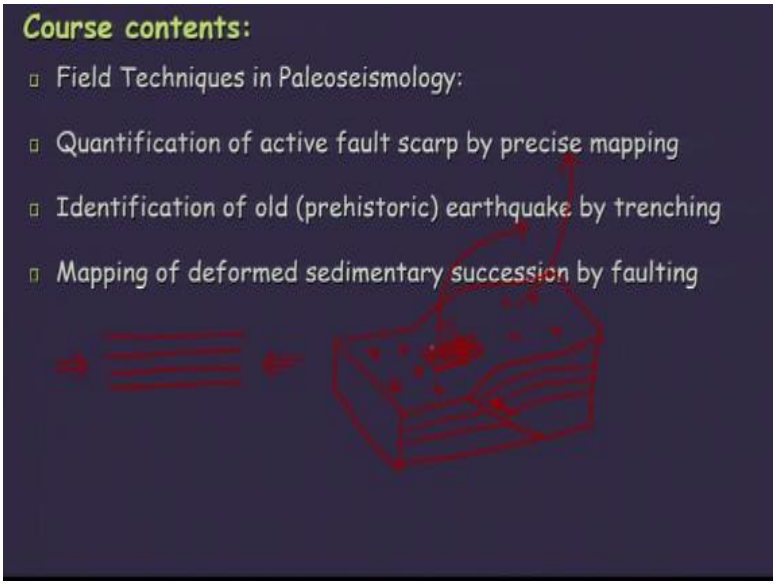

So the most important after the after having understanding of what is the significance of the seismicity and even we will talk in this about the historical seismicity or the historical earthquakes and that takes us in the domain of RK seismology. So we will try to show you some clips of the work which we have done in India and from some lectures which we have borrowed from or from our colleagues from different part of world.

But I will mostly, I will try to focus on the Indian part. Okay? Now after that it is having understanding of the landforms after mapping using the high-resolution satellite photographs we will move to the field techniques. okay? Then this is most important and you one should one cannot do mistakes and identifying those features in field because you need to have a thorough check of the landforms which you have identified.

So whatever identification has been initially done we call that as a preliminary active fault map or preliminary geomorphic map. Because in field, it may be something else because similar type of features can also be mimicked or may be confused we can get confused with the similar type of features and which are non tectonic origin. so one has to be really careful about that so we will talk about those features also.

As I told in the beginning, that we need to have understanding of the primary and the secondary landforms as with a structures of it. Quantification of active fault scarp by precise mapping. This is very much important because this will tell us that how many earthquakes were responsible for developing a particular landform. Of course the question if you are not talking how many earthquakes where triggered to develop the Himalaya?

I do not have the answer but of course yes many, many you cannot counter that. So must be because it is the deformation is going on since last millions and millions of years. But we will be interested in having the earthquake database or the understanding of last ten thousand years and the reason is not because the recurrence interval, worldwide which has been identified based on the Paleo seismic studies or the earthquake studies.

Suggest that the large magnitude earthquakes in active regions are having and sort of what we can say the recurrence of hard around 600 years or 1000 years again. Like for example in Himalayas; we have 600 to 700 years for the large magnitude earthquakes which are greater than 7.8 or near 8. But in you talk about the Andamans, we have recurrence of the mega earthquakes.

Andamans I am not just talking to the Andamans but Sumatra Andamans region subduction zone region we are having recurrence of around 400 to 450 years where is the large magnitude earthquake so this I am talking about mega earthquakes which has magnitude about 9 and less than 9.5 because the largest earthquake which was recorded on earth till date is 1960 Chilean earthquake.

And then second-largest was Alaskan 9.3 or people talk about 9.4 something like that but we have taken into consideration the Andaman earthquake or Sumatra Andaman earthquake of 2004 as 9.3. So this becomes almost second or third largest earthquake so far recorded it. So similar type of earthquakes in Andamans have recurrence of around 400 to 450 years whereas the large magnitude earthquakes ranging in magnitude greater than 7.5 and 8 are on less than 8.5 is almost around 820 years.

So the quantification of active fault calls with precise mapping and that what I was talking about that we will use different techniques different tools to quantify this landforms and best what we can use is total stations and then we can also which will give us the elevation variation and with the help of dating which will also be in one of the important part the dating the landscapes or the landforms sorry and the events which have taken place or took place in the past. Okay?

Now further the identification of old prehistoric earthquakes by trenching. so what we do is basically for example; I will just quickly draw some sketch here, so suppose you are having in a feature like this existing on the surface. So this is sort of a slight undulation but that undulation is developed because of the tectonic activity. So if you have to put the fault here are the worst faults then this will be something like this.

So this I am showing in section and this is on the surface here, so you have the surface which got deformed because of the tectonic deformation. So if you talk about the layers here, we made all the layers something like this. So you can say that this is a warping or the deformation. So initially all the layers would have deposited in a horizontal fashion. so under the Congressional regime this got the form.

So this I am going to talk in detail when I am talking about the Faults and all that but just the initial what we are talking about the mapping and then we are talking about the trenching. So this I would like to explain here in a brief way but more details we will talk then. So what we do is we are interested than how many moment how many earthquakes have risk was very responsible for developing this particular scarp.

So this is the landforms on the surface. So what we do is we open up a trench here, so we will we will dig this portion and try to see this particular section. so this is what we will be doing in terms of the trenching and identifying the old earthquakes and those old earthquakes are preserved the signatures are preserved in sediments. so this is what we will be I will be doing okay?

So this is the part of the new trenching and then also we will be doing the precise mapping here. So further if we look at the mapping of deformation deformed sedimentary succession by faulting, so we will be doing this part in trenches. So we dig almost like 3 to 4 meter deep using back holes. So we will talk that in that how we are going to do in terms of mapping and all that so this will come in the part of your field techniques. Okay?

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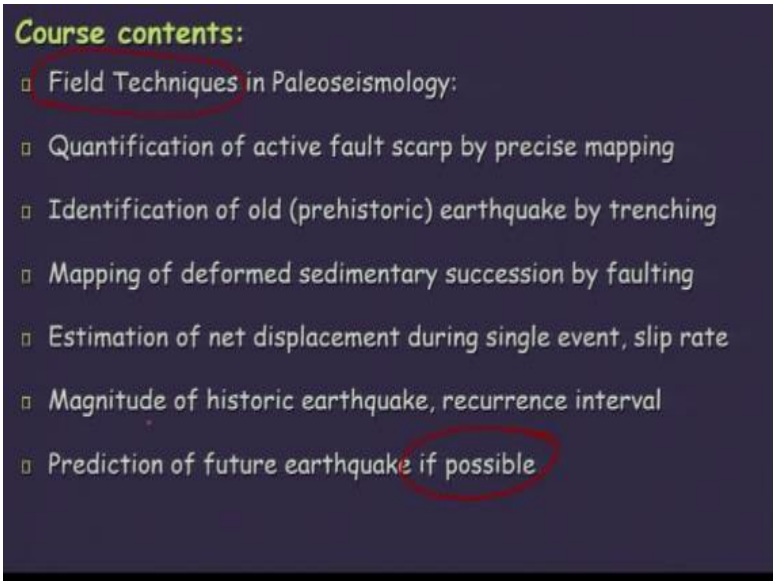

I may remove this, so that you will be able to easily read out all. So now I will just try to remove it as fast as possible. So that you can get out what are the new that is coming in here. So then the follow-up is your estimation of the displacement, so the estimation of the displacement how much these sediments have been displaced during and single event. Okay? And that will help us in also talking about the slip rate.

So what is the slip rate of the individual on the individual fault? We will talk about that then we can back calculate the magnitude. Okay? of the those historical earthquakes or the Paleo earthquakes or old earthquakes based on our trench studies and also we can talk about the recurrence interval, then prediction of future earthquake if possible then this is a big question here because whether we can predict the earthquake?

The answer is not so precisely we will not be able to precisely predict the earthquake future earthquake but at least we will know one that what are the chances of the defaulting on that particular fault and how many earthquakes have occurred in the past and then what were the recurrences between those earthquakes. Okay? So based on this we can talk about that what is the possibility of having the earthquake of a particular magnitude on that particular fault.

So that much information has been given to civil engineers all the town planners urban planners that is going to help us in developing the building codes and that is going to help us in minimizing the hazard. So this whole exercise or the whole topic which we are going to talk about your discuss about will be around or moving around the hazard reduction. So these

are a few points or the course content which you will come across as we move further in this course.

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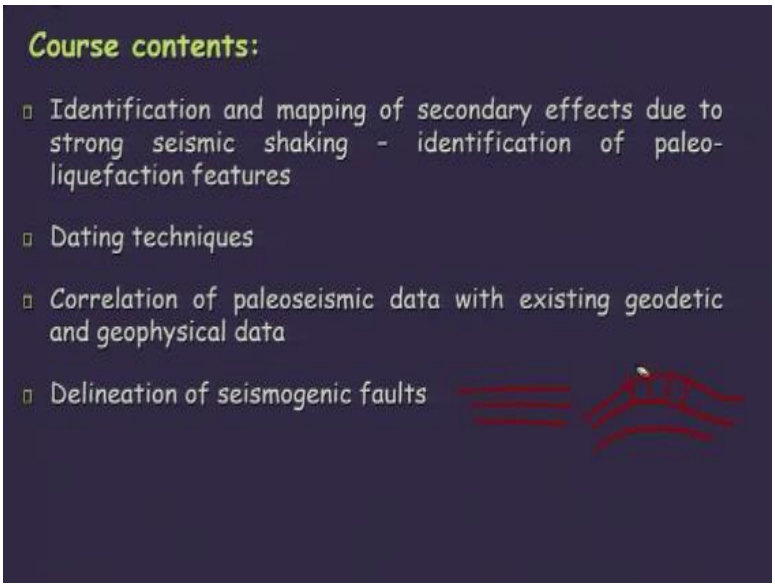

So further if you look at then we have the identification and mapping of secondary effects due to strong seismic shaking, now identification of what we call as the liquefaction features. So why this is important? Because as I told in the beginning that we will be more focusing or more interested and the areas which are seismically active. So we have Himalayas, we have Andaman, we have Kutch.

But why we are bother about the areas which are sitting far away from this region and if we talk about the far regions like maybe sitting 400 kilometres, 300 kilometres away from the from the AP central area or the active regions and that is what has happened in the in today the earthquake took place several kilometres, hundreds of kilometres away from Delhi or the Indian part.

That was in Hindu Kush near Afghanistan 6.1 magnitude, but it shook the regions right up to Delhi and if you are having large magnitude going to have a large magnitude earthquake which was experienced in Nepal 2015, Gorkha earthquake it triggered liquefaction. So this is basically the secondary phenomena which will never be screwed it, if you are having appropriate site conditions to trigger liquefaction.

So what are liquefaction or what are the phenomenon which are associated and what are the important sign conditions which are required to trigger liquefaction will also discuss in this

course. So secondary effect is also important because secondary effect is going to tell you not how much damage is going to be expected? You are going to expect, if you are even sitting far away 250 kilometres or 300- 400 kilometres away from the seismically active regions.

And this is because of the strong seismic shaking because seismic waves will travel thousands and thousands of kilometres but up to certain distance it will create damage and because of strong ground shake. Then comes the part of the dating techniques, now this dating is basically we will talk about the optically stimulated luminescence dating or we will I will look at the carbon-14 accelerator mass spectroscopy.

So these are the two techniques which we are going to use mostly for dating the events or bracketing the events, earthquake events mainly and there are more which have been used like very limited and we will try if possible that will give one lecture on very limited also if possible if time is we have time and enough hours are left out then we will talk about that otherwise will just briefly mention about this one. Okay?

Now the dating technique is important to bracket the events and further correlation of paleoseismic data with the existing geodetic and geophysical data. so this is also a part of this course and but more emphasis will be on the landforms and the sediment signatures preserved in the sediment succession and all that and briefly maybe and one or two lectures will talk about that what is the importance of the correlation with the geodetic data set.

Now geodetic is mainly what we are talking about the measurements we are doing the crustal deformation measurements. we are doing using the high-resolution GPS and this GPS are been installed across the Himalaya by many agencies and we are one of them, we have like only almost 20-25 GPS stations which have been installed across Northwest Himalaya and that gives us the coordinates at millimeter accuracy 24/7.

So any displacement of the moment which has been occurring over the time, over the year then that will be recorded and based on that we will be able to talk about that what is the amount of strain the particular region has been able to accumulate and what are the chances for the future earthquake in that particular area. Okay? So this will help us in understanding that what is the correlation between the earlier deformations which took place.

Because we can also deduce the slip rate using value seismic data and as well as we can also talk about that what is the present deformation rate and is there any variation or the some portions are getting deformed faster and some poor portions are not even active at this point of time. So that also we will be able to pick up if we are correlating the Paleo seismic that is Paleo earthquake data from the landforms and the sediment studies.

And the ongoing present deformation using the GPS data, geophysical data basically is important when we talk about that what is the geometry of this false and what is the geometry of what we can say the subsurface deformation features. How they dip? What is the dip of the default in which direction and they are dipping and how they are been connected with the with the major fault system.

So this is important for the zoom of geophysical data other than this, we also talked about that how this features which we have identified like active faults or associated landforms are generating this seismically then the moderate earthquakes. So every moment there is an earthquake. Okay? But how they are aligned? Whether they are this these features which we have identified are still triggering earthquakes of moderate magnitude.

We can say the micro earthquakes of low magnitude so the small magnitude, so that we can correlate with the features which we have identified. Then talk about the delineation of the seismiogenic faults, so again with the correlation of the landforms or the features tectonic features active tectonic features which we have identified and correlating them with the geophysical data.

We can also talk about that whether this false or seismiogenic false or they are just the surficial features, which were developed at the time of the deformation. so those surficial features because there are secondary features also which will be developed, if you just for example; if you have like these are the layers and if you deform those layers, okay? then you will have some cracks which will be formed on the surface because of the of the tension.

So this tensional cracks may not be of course they may show the displacement and any fracture which shows the displacement will be termed as fault. So but this will this fracture of the faults will not be considered as seismiogenic faults.

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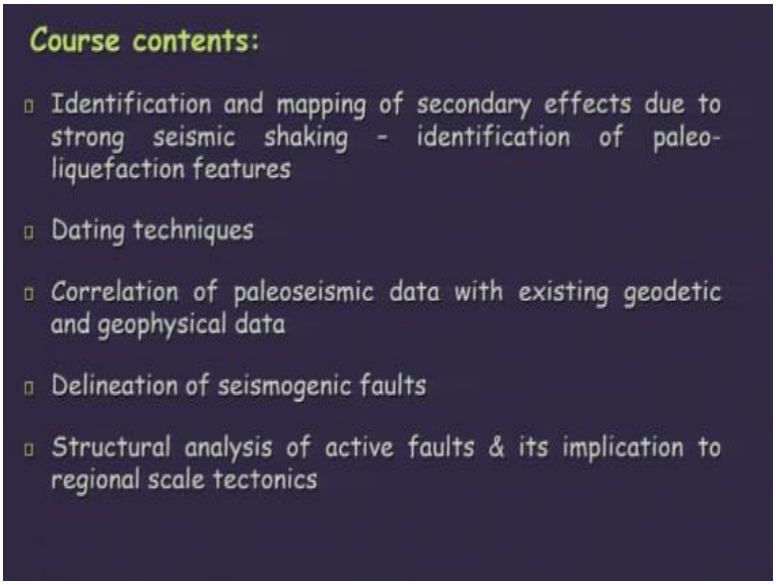

So seismiogenic faults will be the deeper faults which are connected with the formation which is taking place in the deeper part of the crust and they are the centres which will trigger a major large magnitude earthquake. Then structural analysis of active faults and its implication to the regional scale tectonics, so in this we can correlate that what type of active fault?

We have identified and whether it is a reverse fault, thrust fault, strike-slip fault or a normal fault and what are the implications on the regional tectonic framework. Whether these faults are indicative of some segments or they are talking or telling us something about that the pattern of deformation has changed over the time. So this part is important now a few of these topics which I have listed here may not be taken up individually.

But they will be having some sort of connectivity with few lectures which we are going to give you. So you will find those important bullets which are seen here are the part of the major topics which we are going to talk about.

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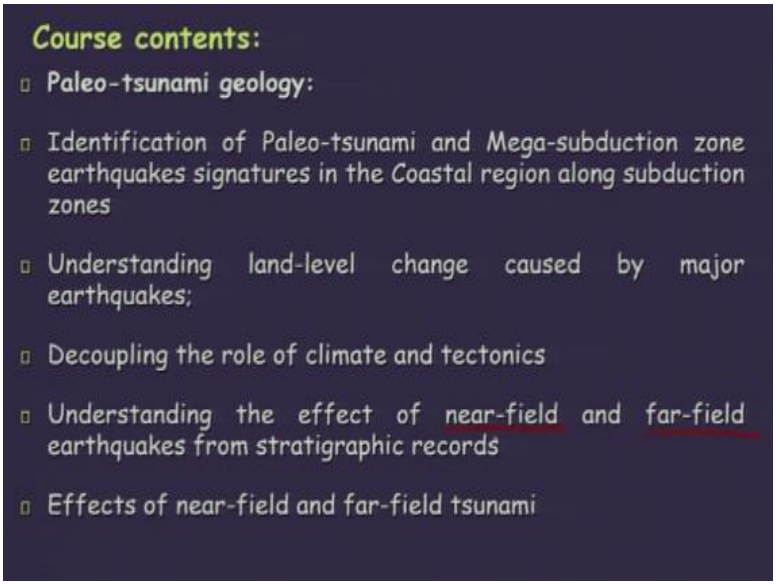

As further as I told, we will not only touch the active force or the areas and Himalayas and Kutch. But we will also talk about the tsunami geology and this is very important and what work we have done from Andamans we will try to cover up here and at the other part of the world also. Okay? So Paleo tsunami geology again we will talk about the identification of Paleo tsunami and mega-subduction zone earthquake signatures preserved in coastal regions. Okay?

Because these are the features which we are talking about is in the subduction zones and the subduction zones one of the most active subduction zones, which we have is along the Andaman Islands. Okay? So this is a Sumatra Andaman subduction zone. so the landforms coastal landforms also tells us about the deformation which took place in the past and ongoing faults, non-going deformation as well as such features or the signatures of the past earthquakes make earthquakes are preserved in the sediment succession.

So we will take near shore sediment successions and we have taken and we have studied in detail and we have been able to identify the mega as well as large magnitude earthquake signatures preserved in sediment succession. Further understanding of land level changes caused by major earthquakes. Now this we learn we experience the land level change during 2004 mega- subduction zone earthquake and that was the Sumatra Andaman earthquake.

So the question as whether such a earthquake did not occur in past or during the historical time or in the geological past the answer is no it is not just that this was the only earthquake but they were many more which took place in the past and we have the information or the

signatures which are preserved evidence which are preserved in the sediments. So it is a land level change causes what are the reasons for that we will talk about this in this part decoupling of the role of climate and tectonic.

Because the change in the climate will also affect the change in the environment and basically the markers or geological markers which we are trying to address or will trying to focus on are in the industry events that is a change in the environment because any land level change takes place along the coastal region will affect the local environment there either for example it is an back Marsh area or it is a lagoon area.

So that part or whether the area was have having the beach, active beach but now there is no active beach at that place so this all be will be affected because of the land level change and of course they when they when we are talking about the land level change we are talking where we are getting into the effect of the sea level. So if the sea level has remained stable since last thousand years.

Then any change in the environment which took place probably correlates with the tectonic activity in that region. so we need to decoupled a role about the tectonics and the climate part. Understanding the effect of near-field and far-field earthquakes from stratigraphic record, so this was one of the major questions which came in our mind when we were doing studies in Andaman but we have experienced the 2004 earthquake which was far-field earthquake.

Which was located very far almost like if we talk about Port Blair then more than 500-600 kilometres, if we talk about the southernmost step of India that is the great Nicobar then or Campbell Bay then we are having almost like 300 to 400 kilometres. So the even the far field earthquakes and associated tsunami which is the main and secondary phenomena affected our territories or the areas and aligned along the Indian Ocean.

So but the near-field earthquakes will have different effect will have much more hazard and the risk posed by those events which are taking place in the near source. so we will talk about that how we can differentiate using the sedimentary course and then effect of near-field and far-field tsunamis, we will talk about this in very much similar to this so as I told that the earthquakes and the near and far field tsunami which are the tsunamis we will listen associated phenomena.

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Now books which you can refer this there are many books which are available on net also but whatever the information which we will provide you through this lectures and discussions and the labs as well as the field investigation. We will I think that will be more than enough for you people to learn about the earthquake geology. This is one of the important book earthquake geology by Yeats, Paleoseismology by McCalpin.

Tectonic Geomorphology by Burbank and Anderson and you have Active Tectonics and Alluvial rivers by Schumm, Tectonic Geomorphology and mountains by Bull, then journals are many so few are Indian journals which will also have published the papers of the Paleo earthquake geology and many more international journals are available online and if you are not having if you are interested in looking at those journals or the papers you please contact our TAs teaching assistants.

So they will be able to provide you some information on that, so with this I will end my lecture here and we will continue in the next one. Thank you so much.