Earthquake Geology: A tool for Seismic Hazard Assessment
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Lecture – 13
Seismic Zonation of India

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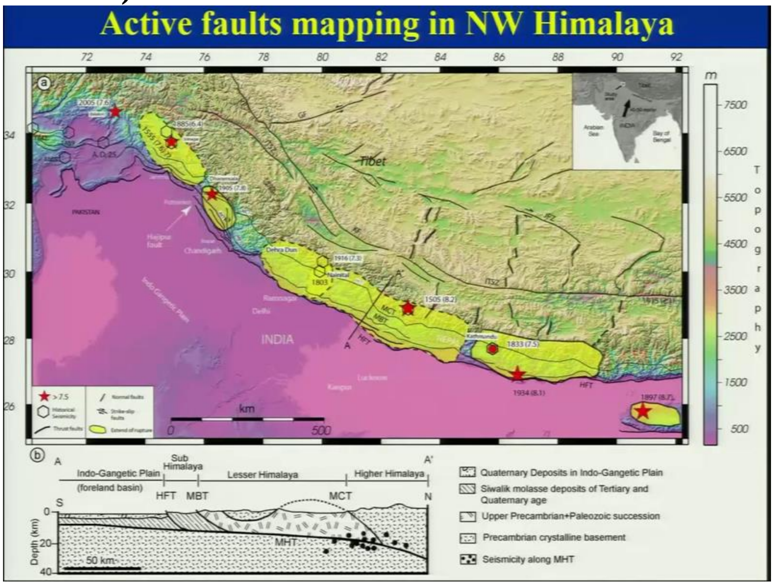

Welcome back. So, in previous lectures we discussed about the distribution of fault is important along with that the distribution of the seismic event is also important and basically, we are looking at the historical data. Now, whether the historical data what we are using and what has been experienced in the recent past is complete or not that is again an important question.

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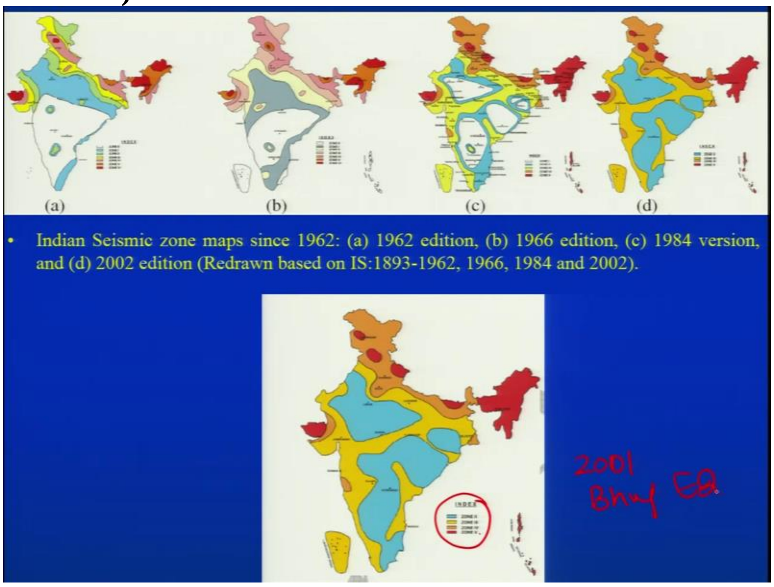

So, this figure usually it has been seen or been taken into consideration when we are doing the town planning and all that and those are all the figures which shows that all the time within the input of the data. This seismic zonation map of India was been revised. So, the seismic zonation map has been taken into consideration for the development of the building course also.

Because this will tell us at which area will experience more ground shaking as compared to the another one and with respect to the seismic zones. Because what we were looking in the previous slide that in Himalayas, in the recent in 20th century, we had 3 major earthquakes 1905, 1934 and upper Assam 1950. And with this the different seismic zones were been categorized, and we are even taking into consideration the Andaman region, which is also and warn able zone in terms of triggering the earthquakes as well as the Kachchh regions.

So, these are all been marked in red. So, in Indian seismic maps since 1962. So, the first one the a is 1962 edition and then it came up in 1966 within slight revision, the 1984 and 2002. So, this was before the 2001 earthquake. So, now what we have we are following the recent one that is this one within 4 seismic zones were zone 1 has been, it is been removed actually. So, we have zone 5, we have zone 4, zone 3 and zone 2. So, this was revised again based on what the intensity of shaking we experience because of the 2001 Bhuj earthquake.

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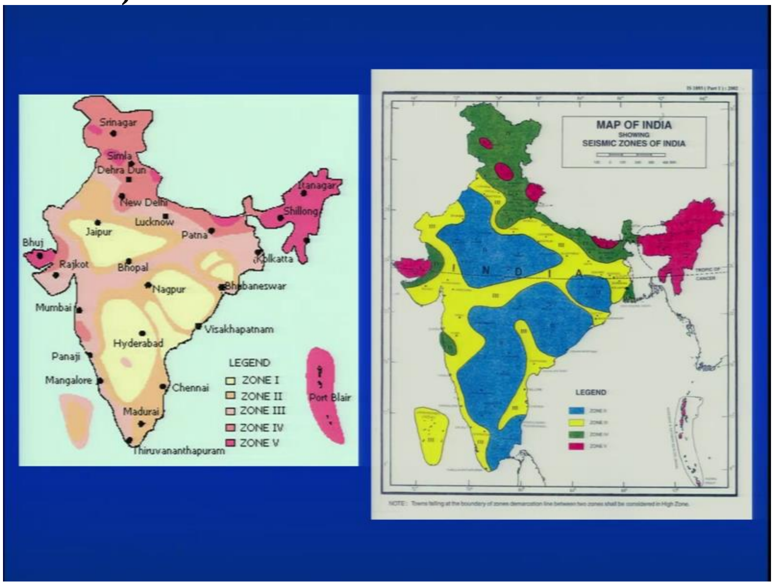

So, the point here is that if you have better data of earthquakes and you have the understanding of the pattern of earthquakes, your map will get revised and the paleoseismology will play an important role and filling up the gap in terms of the record of the seismic events. So, on the left, what we have the old map with 5 zones, zone 1, zone 2, zone 3, zone 4 and zone 5 and the recent one that is after 2001 Bhuj earthquake.

The expected intensity, which was marked for zone 1 was not correct and it was been revised as you have seen in the previous slide. Since 196 to there were many revisions. Now, this revision took place or was been carried out after 2001 Bhuj earthquake, which was experienced by the existing population. But if you have do not have any record that exist in the historical chronicles, then you are probably going to undersize or underestimate the hazards related to it.

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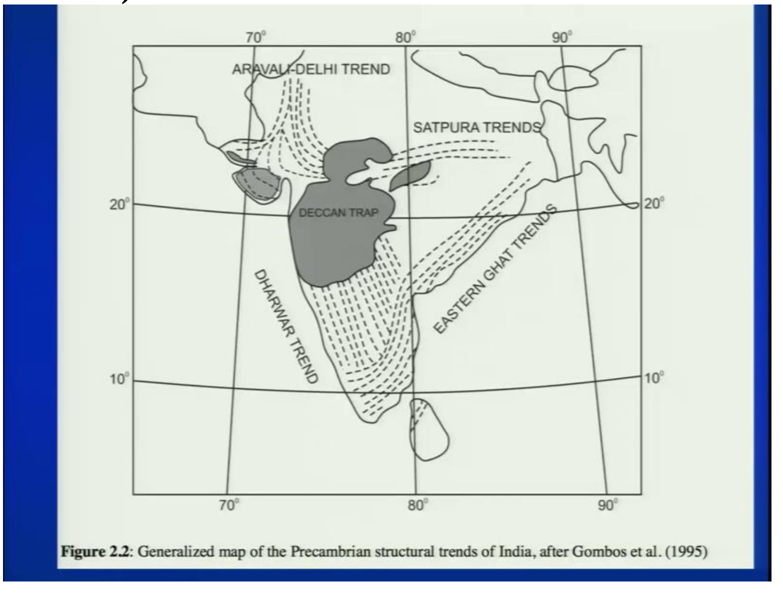

Figure 2.2: Generalized map of the Precambrian structural trends of India, after Gombos et al. (1995)

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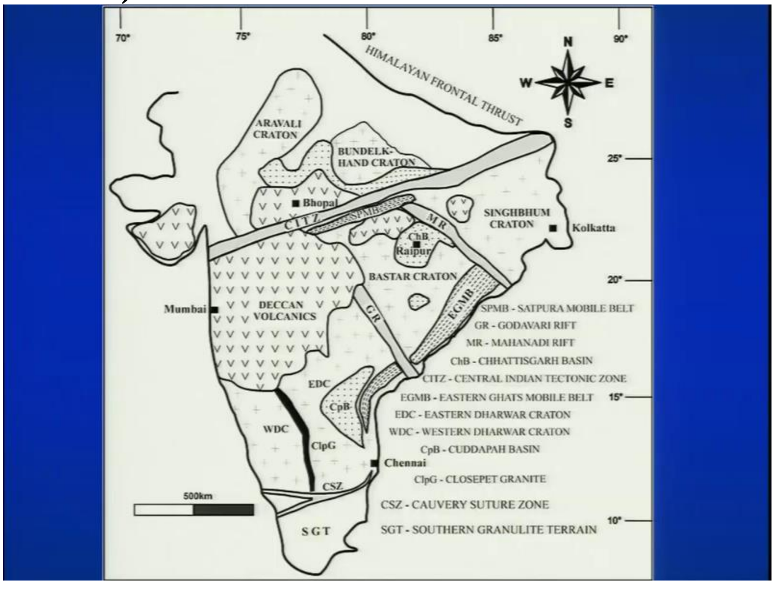

So, we have several active zones in India that we have had been talking about in some of the lectures.

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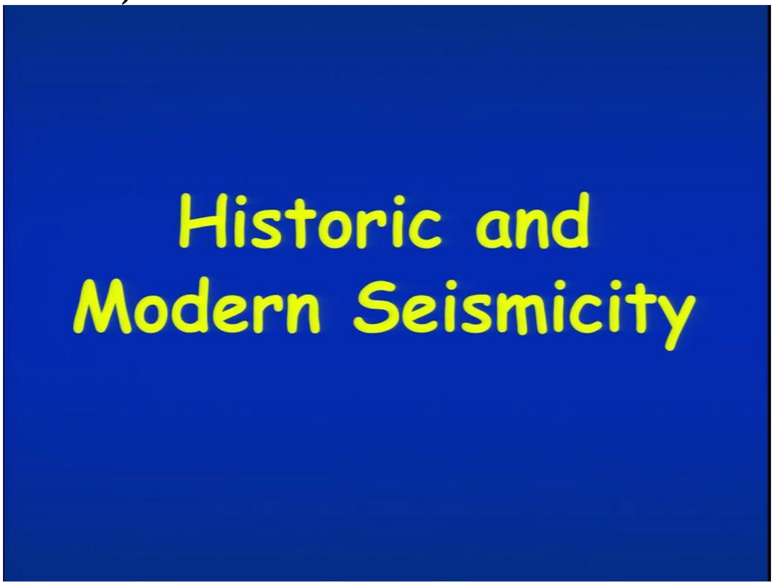

Now, the most important part, before we get into the detail of the paleoseismology, a synergy is to look for the historical and modern seismicity. So, whatever the data is available we take into consideration to understand the pattern of earthquakes the distribution of earthquakes, along with that, which are in the historical chronicles as well as the modern seismicity based on the instrumentation data. This part we will keep discussing when we are talking about the ARCA seismology part also, but let us see what one can infer based on the existing data.

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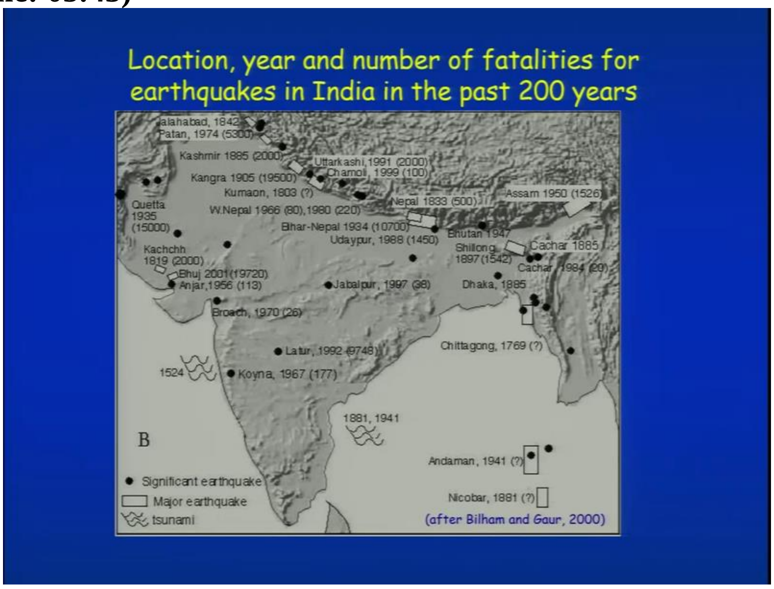

So, this map was published way back in 2000, which shows the distribution of earthquakes and it can be clearly pointed out that this region that is the most seismically active region is has hosted how many large magnitude earthquakes as compared to the rest of the portion of the Indian plate. Nevertheless this region has also experienced the earthquakes like Jabalpur

1997 Latur, Koyna earthquake, this was related to the reservoir into seismicity. And we have earthquake and couple of large magnitude earthquakes in this region.

That is you are A 1819. Then 2001 was the recent one and in the 1956. This says map was published in 2000. So we do not have the location of the 2004, Sumatra and Andaman earthquake that also was triggered somewhere over here for the south of the Andaman Islands. And along with this, what information has been given here is the number of people got killed.

This one, the bracket we have the number of people got killed. And in Himalayas if you see the large number of people got killed in 1905 earthquake almost around 20,000 people were killed here and recent earthquake which occurred in Kashmir was 2005. Around 80,000 people got killed.

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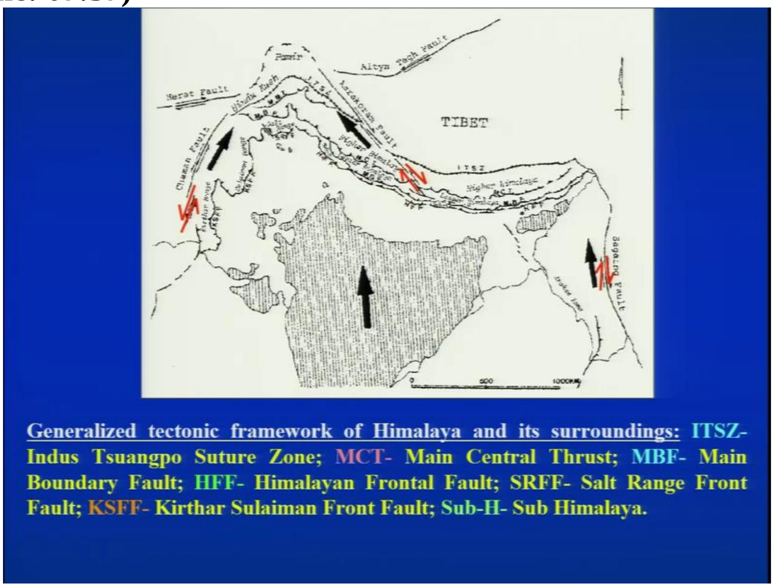

So, along with from the regional tectonics or the global tectonics we are coming down from the global to regional one. If we see then we have to look at that what are the distribution of faults and what are the type of faults exists, because this will help us in identifying the pattern of earthquakes as well as the type of earthquakes and mostly. What we have learned in the previous lecture that this region will mostly host shallow earthquakes.

But gain we will have different type of earthquakes in the sense whether we are having thrust earthquakes, we are having normal faulting earthquakes or we are having strike-slip fault. So, major boundaries that exist on the eastern side are the right lateral Sagaing fault system. And then in the other portion here that is at the central part or maybe you can say along the Himalayan arc.

We have mostly the compressional tectonic environment and we see thrust faults and we have different plate boundaries different plate fault system mainly like Himalayan frontal thrust, main boundary thrust and main central thrust. And as I was mentioning that one of the transform fault system that exists and Himalaya is your right lateral Karakoram fault system and if you come towards the western side, then we have the Charman fault system.

So this is we are here trying to understand what exactly is happening with respect to the ongoing deformation between the Indian plate and the Tibetan plate in this region. So, we have the Charman fault system in the West, which is left lateral fault system and we have Karakoram fault right lateral along with that we have the deformation which is indicative of compressional tectonic environment and some places we also see oblique slip here and then we have in the eastern side we have Sagaing fault system.

So, different type of earthquakes will occur of course in this region will have comparatively deeper earthquake as compared to what we see in this region. So, we have the ITSZ that is your Indus Tsuangpo Suture zone then MCT is Main central thrust fault system MBF or in MBT main boundary fault system or main boundary thrust system than Himalayan frontal fault system or Himalayan frontal thrust system.

We are having and then we have a few more that is on this side that is we are having Salt Range Front System and we have Kirthar Sulaiman Front Fault is over here and then in the frontal part the boundary between the indo gangetic plain, this whitish part is the indo gangetic plain and the sub Himalaya is sitting over here the boundary between that is marked by the Himalayan frontal fault system or Himalayan Frontal thrust system.

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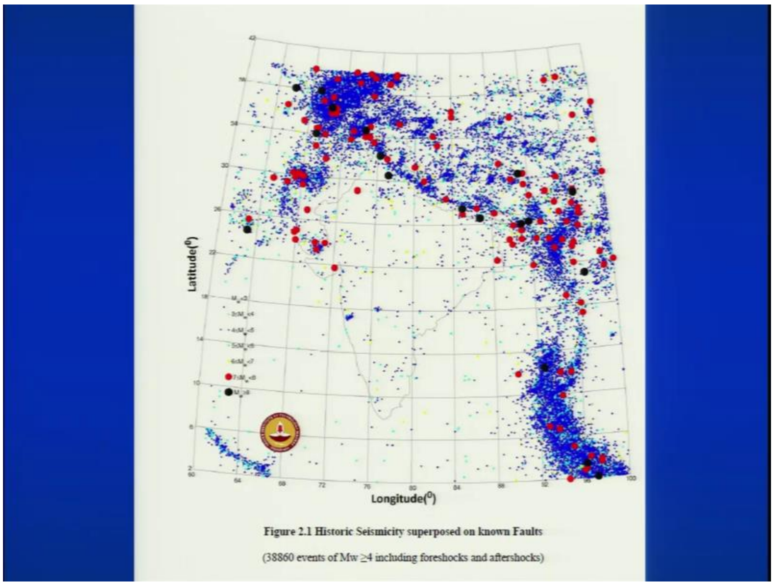

So, if considering those boundaries, what we see is not very preferred distribution of earthquakes, which includes of different magnitudes. And of course, we will see that we have the earthquakes which are occurring in terms of the type that is, either we classify in terms of the depth we have the deeper earthquakes here we have shallow earthquake it is an intermediate. Whereas here mostly we will see the last magnitude and shallow earthquakes along with that will also keep experiencing the moderate magnitude and small magnitude earthquakes.

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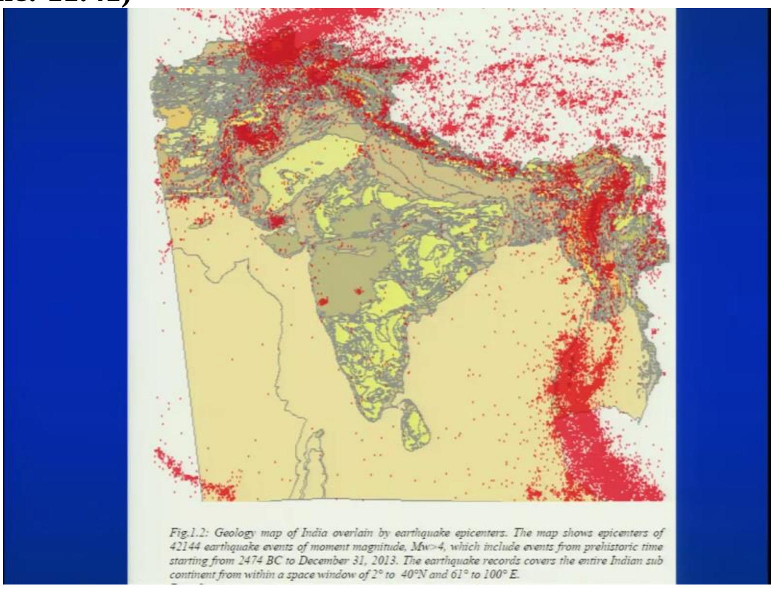

Further, this also shows the distribution and in one of this slide, I was showing that we have few more suture zones which exist and this is another one which is active, which forms the Narmada linear moment and then we have the Kachchh region.

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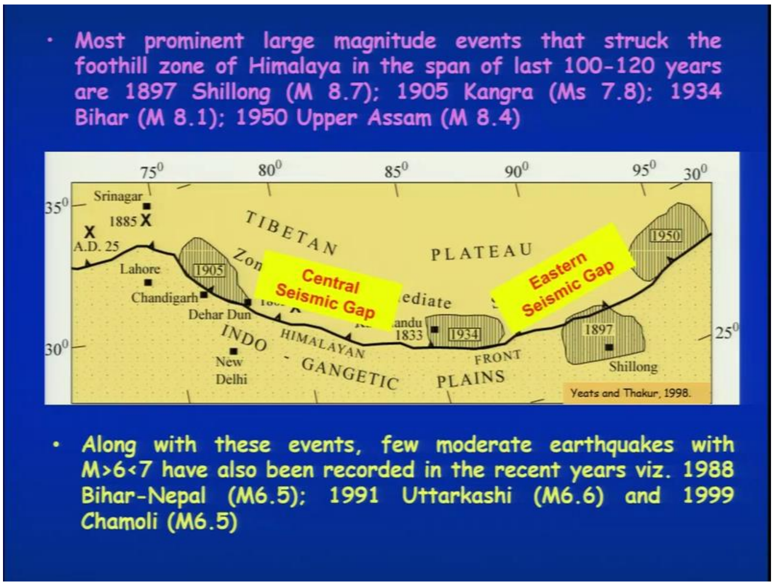

Now most prominent large magnitude earthquakes that struck the foothill zone of Himalaya in the span of last 100 and 150 years Shillong earthquake and the 1905 Kangra 1934 Bihar Nepal earthquake and 1950 upper Assam. Some of the scientific groups have excluded this from the Himalayan earthquake because this earthquake lies further south of the Himalayan belt and this has been excluded from the earthquake which was related to the Himalayan tectonics.

But nevertheless, the overall the formation which is going on between the Indian plate and the Eurasian plate was responsible for triggering this earthquake also. So, based on the information that we have from the historical data or the instrumental data few zones are the areas have been identified. Which probably you can say the probability of occurrence of earthquake increases in those regions.

So, for example 1905 earthquake 1934, 1950 these are the major earthquakes which were responsible for releasing this stress or the strain which was accumulated in the Himalayan region and the areas in between are been marked as seismic gaps. So, you have the central seismic gap that exists between 19 of 5 earthquake and 1934 and then we have another one which exist between the 1934 and 1950.

And this Shillong earthquake which I was mentioning that this was not along the, plate margin here that was south of state margin hence, few research groups have excluded this from this tectonic and they consider that this way the 3 main events which ruptured the

Himalayan region or the Himalayan plate boundary and the these seismic gap accessed. So, these seismic gaps will be the areas for the next for hosting next large magnitude earthquake.

So, please remember that what we are talking about the seismic gaps is the gap between the location of 2 major earthquakes. So, the central seismic gap which also include the portion of Nepal and that portion triggered the recent 2 earthquakes and that was among the main shock was 2015 Gorkha earthquake.

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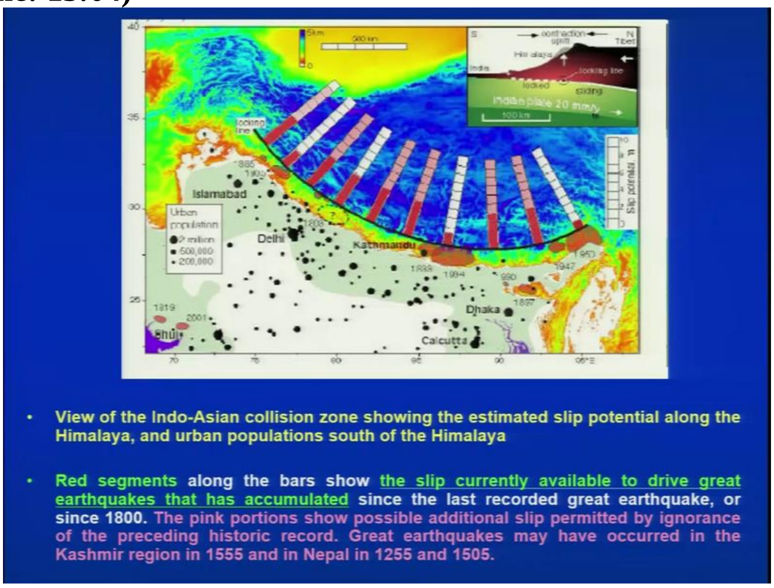

Now, based on the information or the data which was available from the historical as well as the recent seismic events. The theory which came up was that these regions have already released the energy, which was available all along the plate margin. And in between this two like for example, the energy was released in 1995 the energy was released in 1934 and energy was released in 1950.

So, this area will not trigger earthquake or host earthquake in near future whereas, the areas which are sitting in between this 2 events are likely to trigger the large magnitude earthquake in near future. Similarly, between this 2 this whole area is what we call the central seismic gap. But how far this hypothesis is true and that remains a big question.

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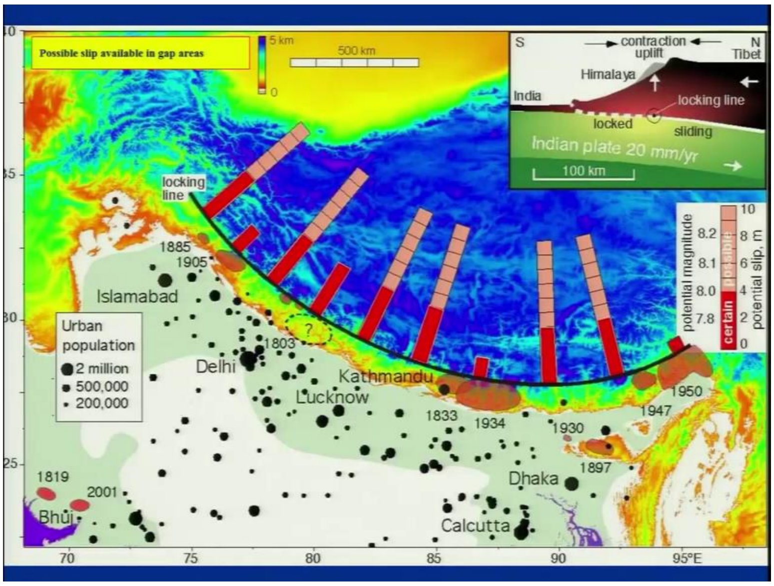

Now, the question is not which fault or the fault system which we have been talking about like different fault system in Himalayas right from if you start from south and then move towards north then we have the Himalayan frontal fault trust system main boundary thrust system and then we are having the main central faults thrust system. So, which fault system was responsible for triggering these large magnitude earth quakes 1905, 1934 and 1950?

So, recent Paleoseismic studies which we will try to cover when we are talking more about details about the case studies and all that we will talk about that. So recent paleoseismic studies have helped to some extent to understand that one of this earth quake that is from 1905, 1934 and 1950 was not triggered on the frontal plate boundary. Because we consider that the frontal part is the most active plate margin and most active plate like default system, but 1905 was not triggered along Himalayan frontal thrust.

So, the question comes is whether still we say that the central seismic gap is between 1905 earthquake and 1934 or the central seismic gap is not the central only restricted to the central part, but also includes further north region of Northwest.

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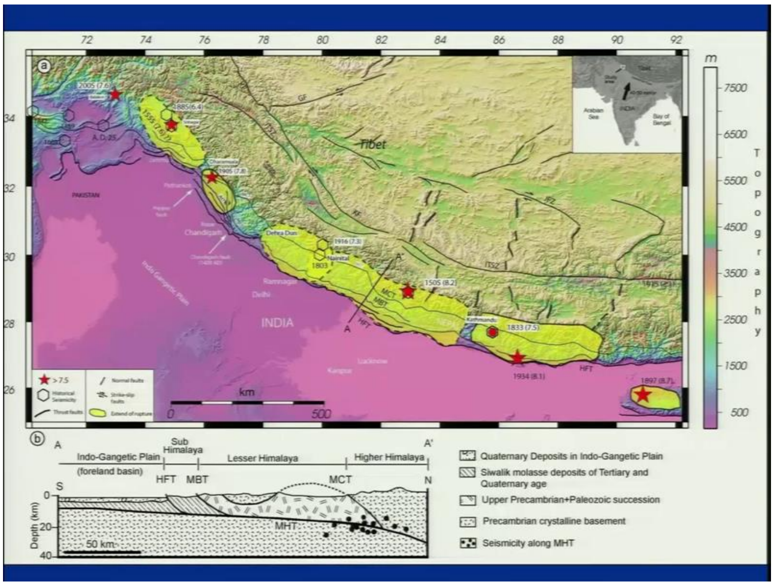

So, there comes an importance that what that where exactly, and those earthquake hosted along which fault particular for. So, we have for example, in faults, which are sitting here this black lines are showing the fault lines and they are the regions which are which will be responsible for triggering the earthquake in future and which also hosted the earthquakes in the past large magnitude earthquakes.

So, if we consider that 1905 as per based on the paleoseismic investigation that this was triggered way far away from that is far away far south or north of the Himalayan frontal fault system, then this area still have the and the strain or the energy available to trigger the large magnitude earthquake as compared to what we have. This is will like 1934 and 1950 so 1934 paleoseismic studies suggest that this was on the frontal part.

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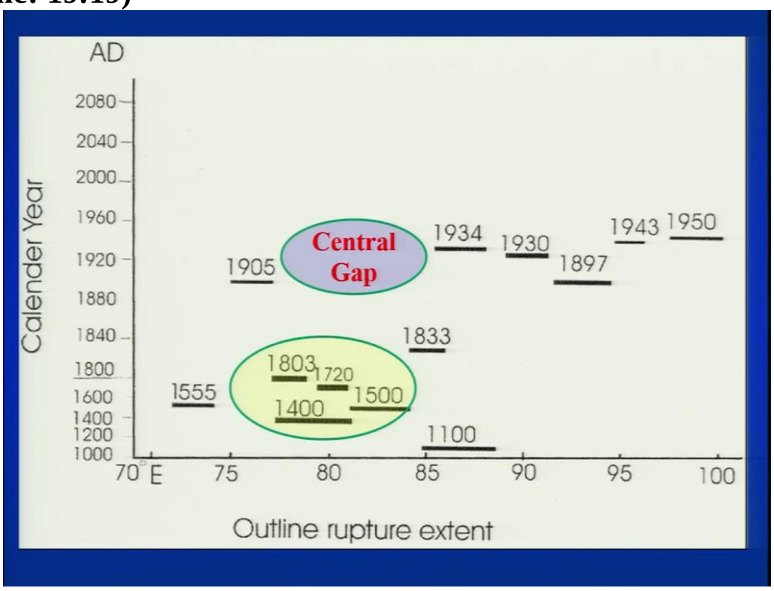

So, if you must combine the existing data including the historical data like 1955, which was which was in Kashmir Srinagar region, and then we have the other earthquakes like 1803 and this was in the central part, this is 1803 and, and few more earthquakes because this is again 1505 again the other paleoseismic studies some extremely serious that they 1505 was along the frontal part and in that case, this will not be central seismic gap, but again we need to understand that which on which fault this was been triggered.

The epicenter which has been shown here based on the damage pattern was really the earthquake was triggered in this region or the earthquake was been triggered along the frontal part. So, anyway, they are taking into consideration all the earthquakes on the existing data historical as well as instrumentation data and the paleoseismic data also this 2 are coming from the paleoseismic investigation there is 1400 and 1500.

So, the paleoseismic investigation carried out along the Himalayan front has have indicated that there were 2 major events which occurred during 1400 AD and 1500 AD. So, taking into consideration all the earthquakes which have been plotted with respect to the calendar ages here, on the y axis and x axis shows the distribution along the latitudes then this is the longitude we have and then this distribution shows that there is a gap which exists between this one. So, this is what has been termed as central seismic gap.

But, if we consider those earthquakes then and this fits well within the central seismic gaps. But if we consider those earthquakes then and this fits well within the central seismic gap and so, the question comes not whatever based on the distribution of earthquake, what we have Mark decentral seismic gap is really the central seismographic system not But nevertheless, since, because in this we have not considered the 1505 earthquake in this region.

So, this may fill up this gap, but then what is the recurrence because if you just see here, not this all earthquakes 1905, 1934, 1930 is that all events which have occurred during this if you screwed this on 1897 then all the earthquakes are in 20th century and this was in the 17th century of 15th century and 14th century. So, whether there is a repeat of or the area is sitting quite, because this no earthquakes were been triggered in this.

During this when that is a 20th century and this earthquake which were triggered almost like 400 or 500 years back will be triggered in this region again if we are having the recurrence interval of 500 to 600 years.

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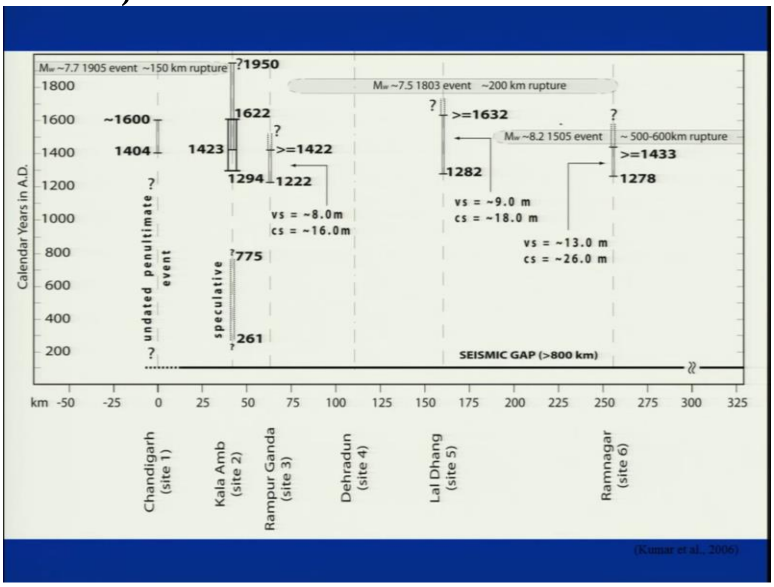

Again, this is what has been shown here, the distribution of different events based on the historical data as well as the paleoseismic data and here it marks all the sites which were been studied with the paleoseismic investigation. So, this is in the northwest Chandigarh area, Kala Amb, Rampur Ganda, Dehradun region these are the zones and the Lal Dhang and the Ramnagar area in the central region or central Himalayas.

So, the question again remains that whether the 15 of 5 earth quake was along the frontal part or not. And if that is true, then again we can say at least that if the 15 of 5 earthquake was triggered here, then it is almost like 500 years North because when triggered in this one, so, if we consider that, then of course, this remains has been central seismic gap as if we take into consideration this events like 1905, 1934, 1950 they all triggered in 20th century.

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Terms describing Earthquake Size	
Term	**Magnitude Range**
Small	M<6.0
Moderate	6.0≤M<7.0
Large	M≥7.0
Great	M≥7.8 M≥8.5

Then why not this region. So, another exercise usually what we do is not we try to look at the historical data and this is the first step if we have to move ahead in the paleoseismic investigation. So, in literature, you will find several terms which are describing the earthquake size in terms of small moderate, large and great and magnitude which are been assigned to such terminologies.

Are the small one is < 6 and moderate < = 6 and < = 7 magnitude and large magnitude usually, we say > = 7 and great magnitudes, we have > = 7.8. But usually, what we consider here is not these are been categorized as in large magnitude, and the great magnitudes are magnitude greater than Griffin or equal to 8.5 or so mainly the Himalayas.

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Descriptive Phrases and the Intensities Associated with them	
Words	**Intensity(MM)**
Slightly	III
Felt Slightly	
Felt	IV
Sharp	
Strongly Felt	V
Strong earthquake	VI
Severe	
Very Severe	
Slight Damage	
Very Violent	VII
Damaging	
Buildings damaged	
Walls fell	VII-VIII
Several buildings destroyed	
Heavy damage	VIII+
Town destroyed	

Further because before the instrumentation came in and literature mostly or the damage or based on the damage the individual a or the respective areas will been classified that what is the intensity this is mercalli modified mercalli intensity this we will talk in the coming lectures at what the mean what is this the Roman letter indicates, but in literature you will find that given there are the words or the phrases.

Which have been written as slide felt slightly felt sharp, strong and so on. And then and you will also find that they the noting of pace on the damage has been done talking about heavy damage or the town destroyed completely and if you correlate this data with the intensity then you have the very slide then the intensity was around 3, but if you are having heavy damage and the intensity goes above 8.

So, this also helps us in the back calculating the magnitude. So, like few decades back, Gutenberg, they came up with and relationship, empirical relationship which helped in converting those intensities to magnitude. And such one such as attempt was been made by us in 1999 from Kachchh region, where the very meager data was available.

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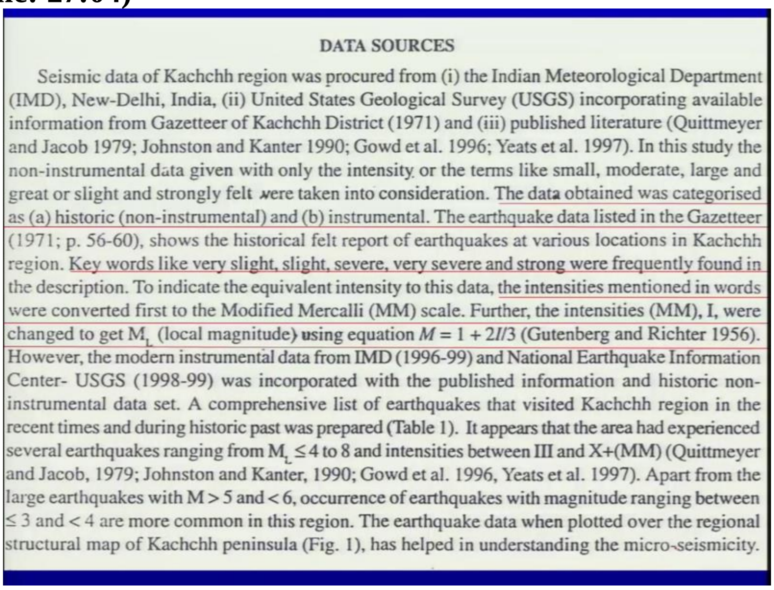

DATA SOURCES

Seismic data of Kachchh region was procured from (i) the Indian Meteorological Department (IMD), New-Delhi, India, (ii) United States Geological Survey (USGS) incorporating available information from Gazetteer of Kachchh District (1971) and (iii) published literature (Quittmeyer and Jacob 1979; Johnston and Kanter 1990; Gowd et al. 1996; Yeats et al. 1997). In this study the non-instrumental data given with only the intensity or the terms like small, moderate, large and great or slight and strongly felt were taken into consideration. The data obtained was categorised as (a) historic (non-instrumental) and (b) instrumental. The earthquake data listed in the Gazetteer (1971; p. 56-60), shows the historical felt report of earthquakes at various locations in Kachchh region. Key words like very slight, slight, severe, very severe and strong were frequently found in the description. To indicate the equivalent intensity to this data, the intensities mentioned in words were converted first to the Modified Mercalli (MM) scale. Further, the intensities (MM), I, were changed to get M_L (local magnitude) using equation $M = 1 + 2I/3$ (Gutenberg and Richter 1956). However, the modern instrumental data from IMD (1996-99) and National Earthquake Information Center- USGS (1998-99) was incorporated with the published information and historic non-instrumental data set. A comprehensive list of earthquakes that visited Kachchh region in the recent times and during historic past was prepared (Table 1). It appears that the area had experienced several earthquakes ranging from $M_L \leq 4$ to 8 and intensities between III and X+(MM) (Quittmeyer and Jacob, 1979; Johnston and Kanter, 1990; Gowd et al. 1996, Yeats et al. 1997). Apart from the large earthquakes with M > 5 and < 6, occurrence of earthquakes with magnitude ranging between ≤ 3 and < 4 are more common in this region. The earthquake data when plotted over the regional structural map of Kachchh peninsula (Fig. 1), has helped in understanding the micro-seismicity.

So, what we did was not we tried to look at the information which was available on the Indian Meteorological Department, the then United States USGS, and then Gazetteer the old records of Kachchh way back written in way back signed consent given. So, this we took into consideration and in this study the non-instrumental data given with only intensity or the terms like small moderate, large and great or slight and strongly felt were taken into consideration.

The data obtained was characterized as a historical non instrumental data and be instrumental data are the earthquake data listed and visitors are shows the historical felt reports based this were based on the reports the historical reports were the earthquakes were in failed at various location and Kachchh Region, and then we also took into consideration the keywords like very slide severe pretty severe and strong.

So, this is again the intensity of ground shaking which have been experienced by local people. So, based on this earlier, the Indo seismic maps been prepared and even today, we tried to classify the areas based on the intensity and the damage pattern. And the intensity mentioned inverse were converted first into modified scale. So, in the previous slide, whatever showing is that you are having the terms like slight, very severe, very severe.

Where been assigned in the modified mercalli scale, that is whether it is 3 intensity of 4 intensity or 8 and further, the intensity that is a modified mercalli intensity 5 were changed to ml that is a local magnitude using the relationship which was been given by Gutenberg and director in 1956. So, this is what we did for the Kachchh Region.

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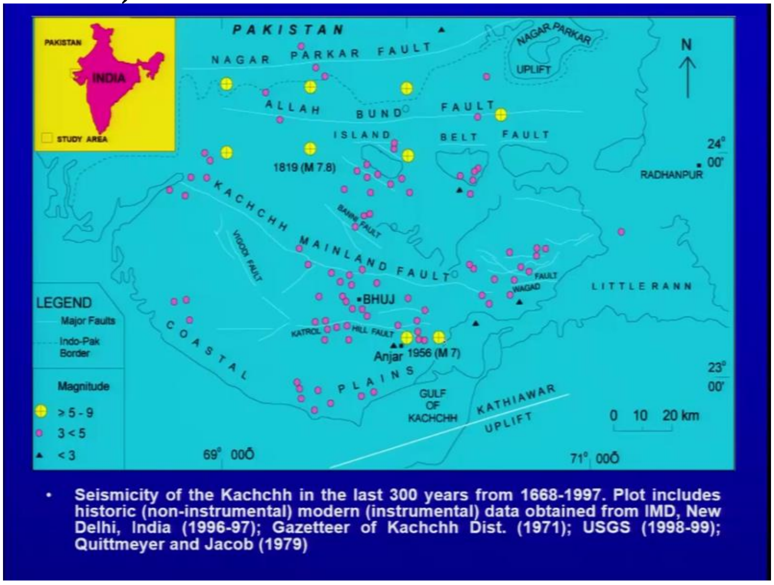

And what we concluded is not that we prepared and complete table and with the appropriate location of the epicenters, we plotted those earthquakes on the structural map. So, this is the structural map or the geological map which we have prepared. And this shows not, it appears that the area had experienced several earthquakes ranging from magnitude < = 4 to 8 and the intensity ranging between 3 to more than 10 actually.

So this what we apart from this large earthquakes with magnitude of > 5 and < 6 occurrence of earthquakes with magnitude ranging from 3 to 4 these are all micro earthquakes were more common in this region. And this is what like prompted us and helped us in understanding the distribution of micro seismicity. And this is what we prepare the plot and this is way back in 1999 we did before 2001 put earthquake.

Where we plotted those are the earthquakes the micro earthquakes were the instrumentations were not so intensively deployed in this region, but after 2001 we see that we have very good record of even micro seismicity, and that also helps us in identifying the seisomogenic faults. So, this is how we do the paleoseismology information and the micro seismicity or you can say the ongoing seismicity complements

Each other in identifying deform the zones which are going to trigger the future earthquake. So if you see in a broader sense the major earthquakes were been plotted when we plotted. These are the fault system Katrol hill fault system, Kachchh mainland fault system. They are all showing very much preferred orientation or the alignment or the distribution along these faults. And then we have the major fault here, which was responsible, that is a Allah bund fault, it was responsible in triggering 1819 Allah bund earthquake. So with this, I will end here my lecture and we will come back in the next one with more details.