Earthquake Geology: A tool for seismic Hazard Assessment
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Lecture – 56
Earthquake Geology: A tool for seismic Hazard Assessment

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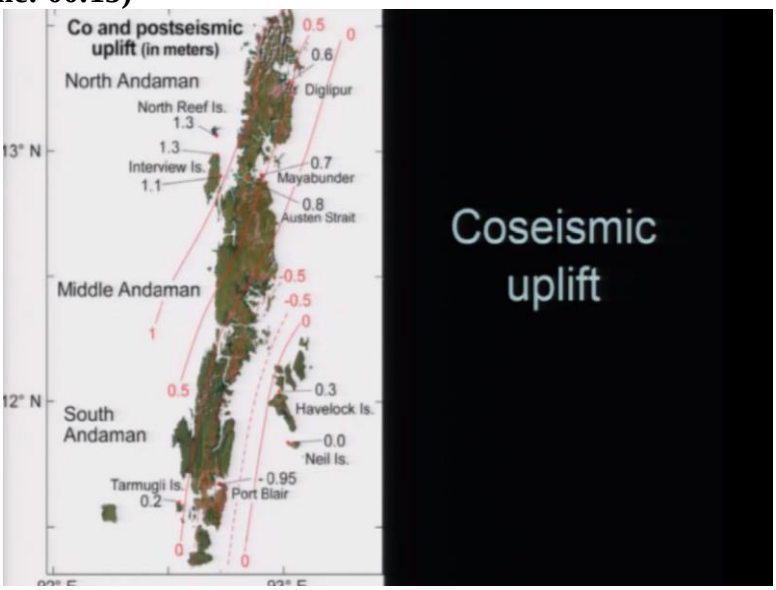

Welcome back so in last lecture we discussed about how to identify the tsunami deposits and we discussed mostly the example from Andaman the research which we did that IT Kanpur. Now a few more things which are left out in this part is about the what we observed in the coral micro atolls. And I have already discussed this part this particular this map which you see on your screen about the land level changes which took place in during 2004 Sumatra Andaman earthquake. So let us see couple of signatures.

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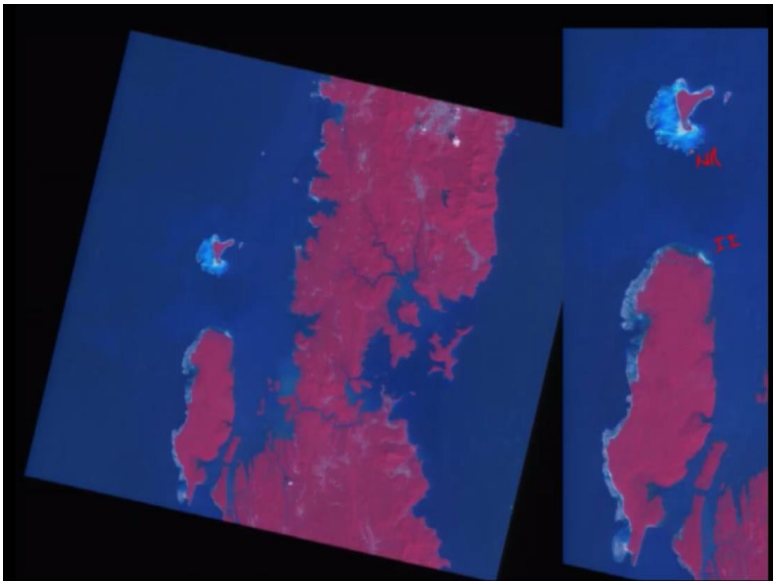

Which were preserved and which clearly indicated as the uplift which took place in the area along the west coast of Andaman. So, the example which I am going to talk now is from this that is North Reef Island and Interview Island. Now there is our the satellite images of the area like this is your North Reef Island and this is your Interview Island and what we see here is the emergence of the coast and this is emergence of the coasters. I will revealed by the upliftment of the choral micro atolls or coral reef and this Island.

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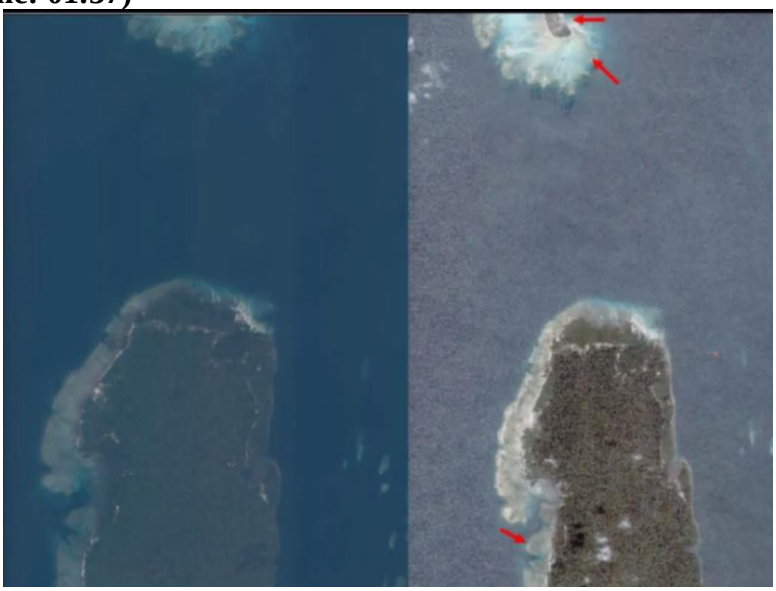

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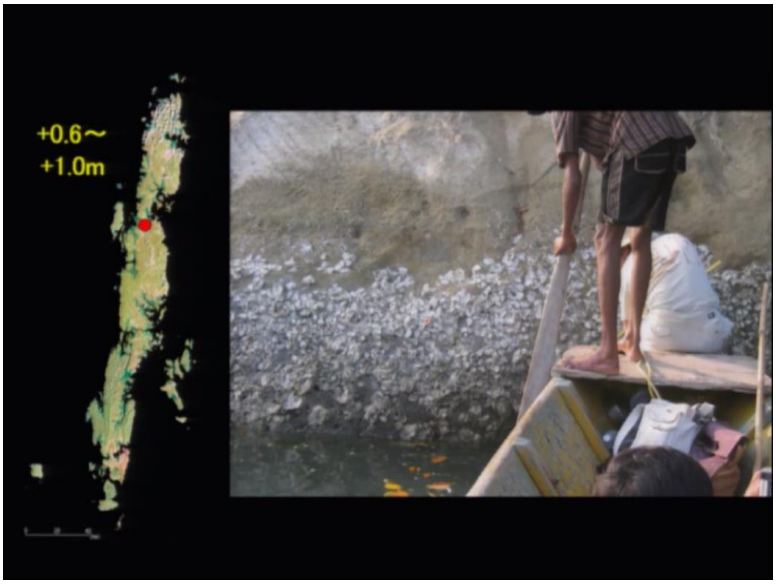

So this was the image taken before and this was after which clearly indicates the area was uplifted due to 2004 Sumatra Andaman earthquake. So what we did was we conducted fieldwork and as I was showing one example from Japan in one of my previous lecture that the dead micro fossils or the dead living organisms or the shells were been dated to identify the old earthquake that was that occurred during 1780 and 1923 or so this was the signature.

Which we identified the because of the uplift the land was raising up and the in the highest survival layers line is highest survival line for the organisms were exposed so if you did this then you this will give the age of the uplift.

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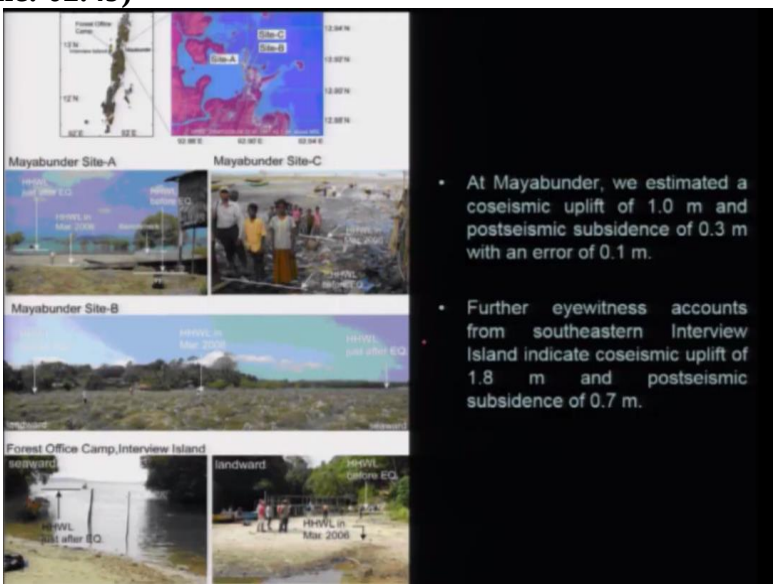

Similarly we also and at some fieldwork close to Mayabunder we with the help of the local people were staying along the coast we deconstructed that what was the highest higher water

line. And then at after the earthquake and in 2006 and so on and that helped us in identifying and understanding that how the land level was affect land level change affected the local environment.

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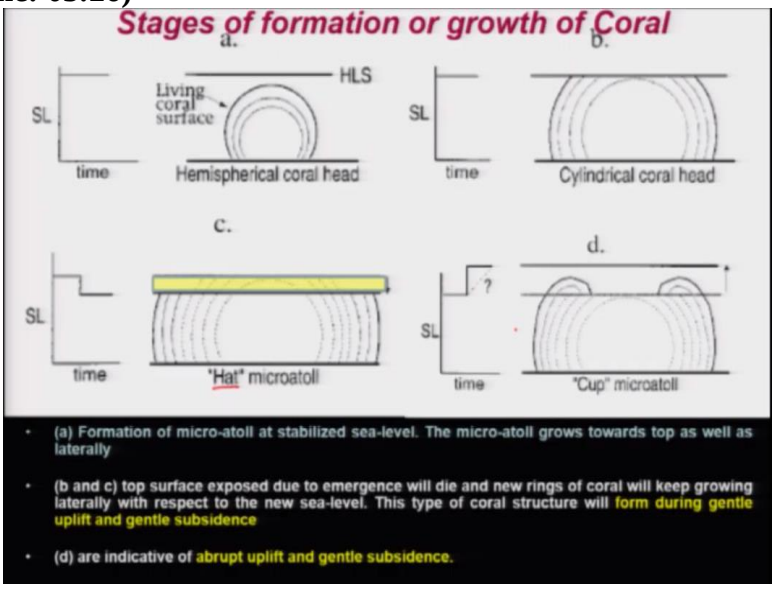

And so this was the part which we were talking about that the different stages of the formation of but corals and we discuss that usually the coral will grow vertically up and try to reach the higher level of survival that is a low tide and then it will keep developing or will start developing on laterally. So vertically as well as laterally so these are the this signature which you will see usually.

When we are having the growth of the coral with respect to the sea level so if there is some change in the water level or sea level or because of the area getting uplifted then the exposed part will die and then the coral will keep growing laterally. So you will see a sort of shape of the coral which we can term as an hat shape coral that is even have the edge like this and then the top will be exposed which is dead part and the coral extend its because this will be the higher level of survival.

So the corals will keep growing like that again. Where is this part which was exposed? Because of the uplift will die so this part is the dead coral and this is already like with respect to the HLS your it will keep growing laterally whereas in the case of the land level change where there is an subsidence so this was an uplift and this is your subsidence. So if there is and subsidence then the corals will keep growing further vertically as well as laterally so this

part is the older one and this is the new one which is coming out. So this is an indicator of the uplift and a gentle subsidence this is.

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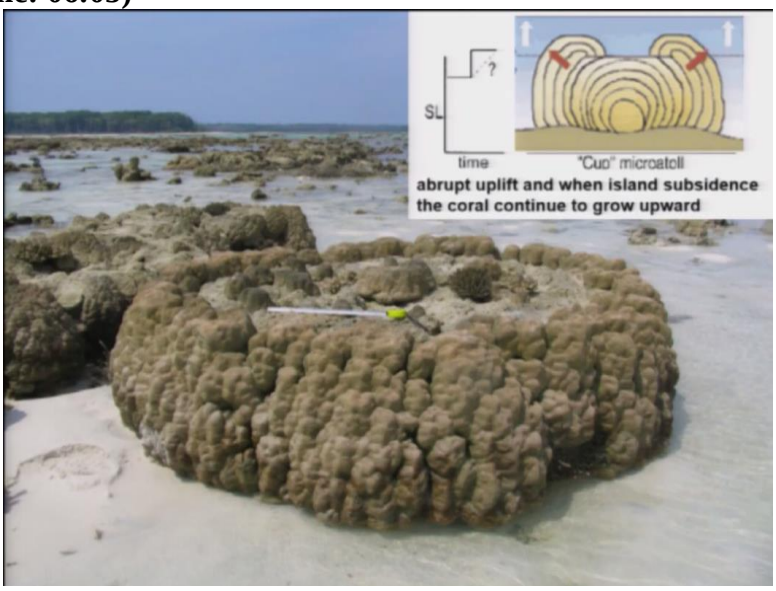

And so now for example if you look at this one here so this is an abrupt uplift here. So you have the abrupt uplift and when Island subsides the coral continues to grow upward. So uplift will expose the coral but the subsidence will again allow the coral to in grow laterally.

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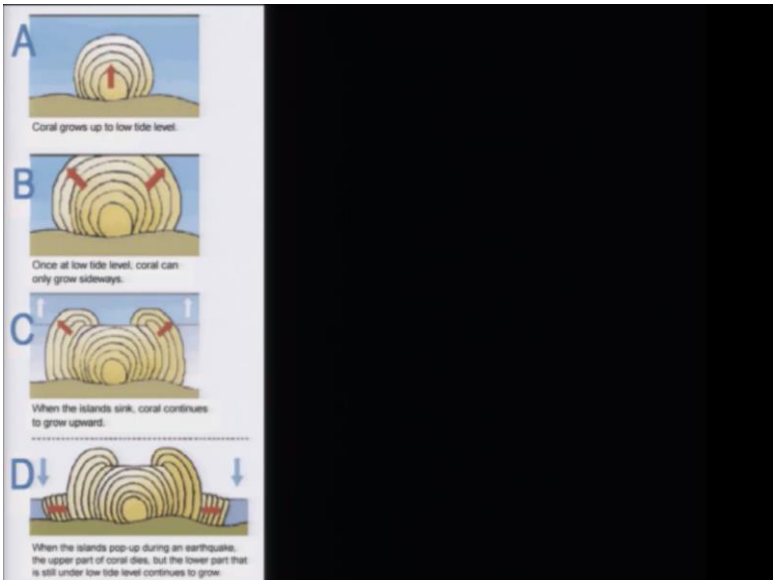

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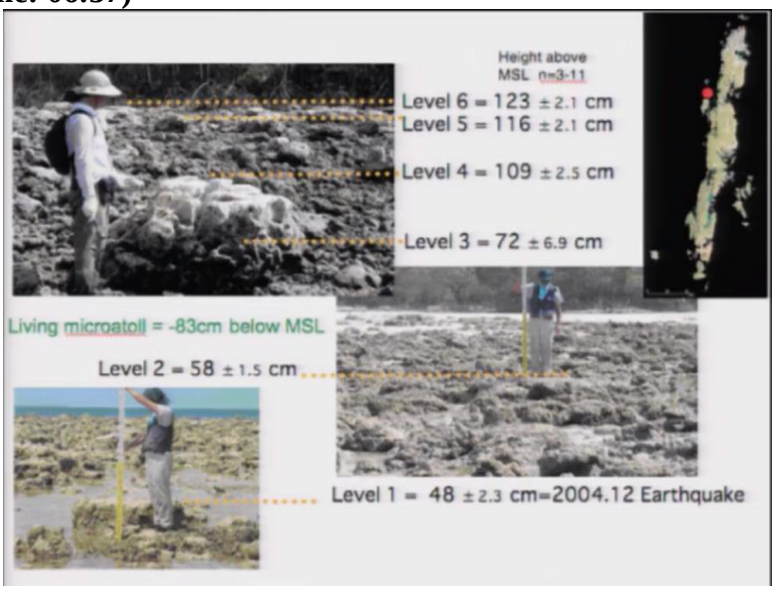

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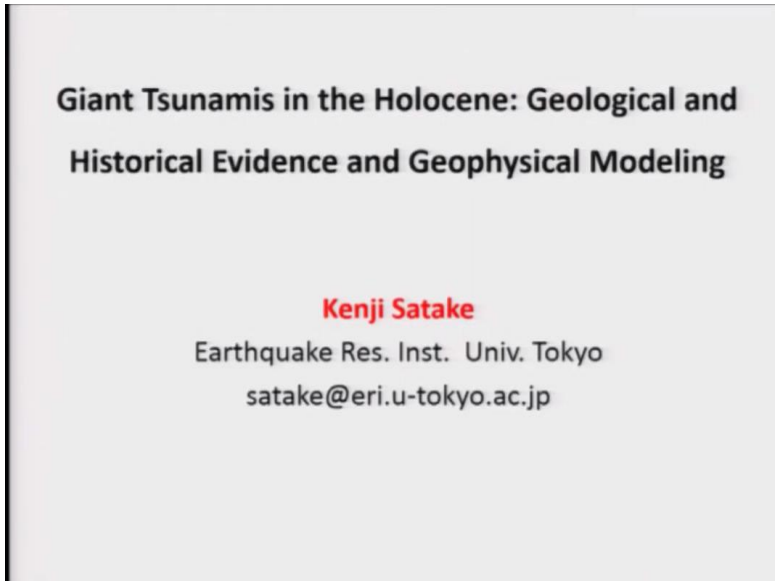

So this part we have already discussed so I will just go ahead now coming to this important part which was been collected from professor Kenji Satake from earthquake research Institute University of Tokyo about the Giant Tsunami in Holocene and Geological and Historical Evidence.

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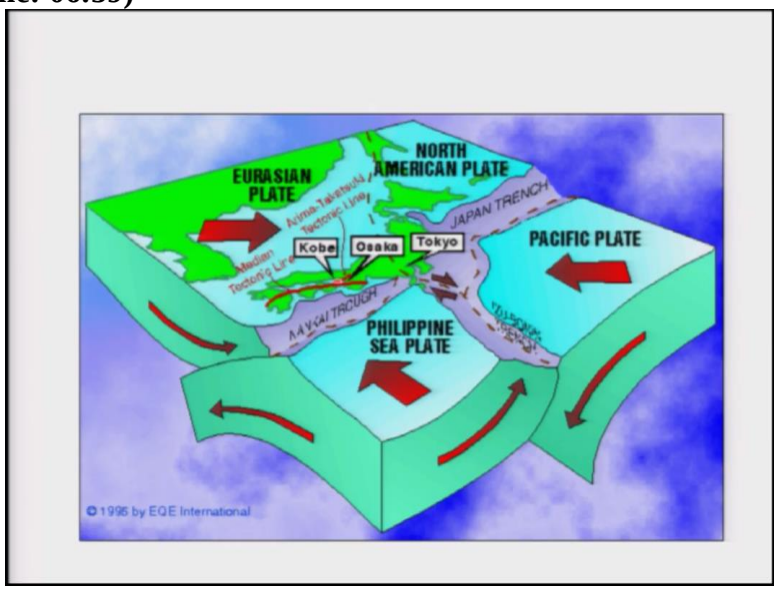

Now if you look at Japan then what we see is that we have the very prominent subduction zone which we call as the Japan Trench and where the Pacific plate is subjecting below the North American plate as well as the Philippine plate and then we are having the Philippine plate subducting below the Eurasian plate. So some very complex tectonic setting and a absolutely ideal for triggering large magnitude earthquakes and tsunamis.

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So in 2011 this was the wave condition of the tsunami. Which was generated by a 500 kilometer long rupture but as I told in one of my lectures the effect was much greater as it was in miss age based on the 500 kilometer rupture because of the submarine landslide.

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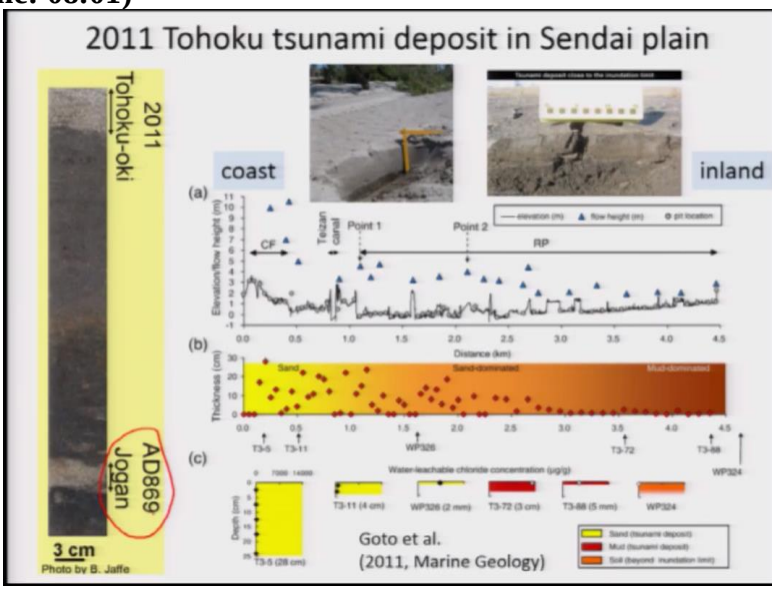

So new inputs which came in during this survey that is just after the 2011 Tohoku tsunami deposits and what it was been found that usually what we do is that we see we do identify the Paleo tsunami signatures and the inundation because of the Paleo tsunami which took place during the ancient or historical and pre historical times then what basically we take is the extent of the sand or the deposits. Which are indicative of the past tsunami but what then usually what used to be used to do is that we used to say that fine.

If we found sand heat up to this point then this was the inundation limit of the particular tsunami but in 2011 because it was the life case and when these scientists variable to look at the deposits and the inundation limits what they found that even the mud dominated portion. Which was carried by the but the mud dominated portion also indicated that the tsunami not only just talked here but the tsunami waters enter further inland.

So this is the distance which has been shown from the coast they have 0 to 404.5 kilometers but otherwise usually what we used to take as that the sand stopped here so we will say that fine the inundation was 3 kilometers only and this information is important when we are talking about the modeling part so based on this information which we collect from the past tsunamis. Then we meet we incorporate this information in the tsunami modeling or the tsunami simulation.

And that gives us the inundation heights and all that but here this was an additional information. Which we got which is again an important and that also indicated that we need to relook at least some locations to understand that the inundation was limited to few kilometers or it in the inundation was much higher than it was envisaged so these are the signatures will miss similar to what we were talking from Andaman.

So in the section what they found was that the 869 was one of the major tsunami event in Japan and that was named as Jogan tsunami compared to your in comparison with what you see in 2011 Tohoku, Tohoku was also considered as an similar comparable event to 869 Jogan tsunami.

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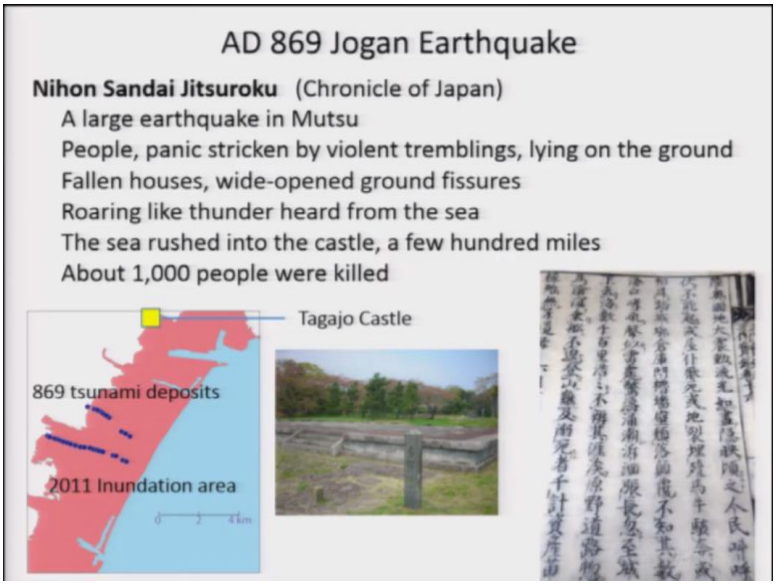

Now Japan has an very good historical records whereas in India we failed to have such type of records available to us so in other sense it becomes easier for them to reconstruct the history of past tsunamis with the help of even the historical documentation and also try they try to identify that what was the inundation and all that and let me tell you here that the day they knew about this not there is going to they are going to experience a large tsunami very much similar to 869 Jogan tsunami.

And that what the they had in 2011 so this is the from Japanese Chronicle records the lately the text Japanese textiles about the Jogan tsunami and this is a reference or the decoding what they have done so it says that a large earthquake and Mutsu was took place 869 people panic stricken by violent trembling. So it was a large earthquake house where houses were fallen wide open so this is related to again the ground fissures.

Which were developed and about 1000 people were killed and so on so along with that the teams which worked or carried out their research in that particular region also did the Paleo tsunami studies and identified the limits of 869 Jogan tsunami and also compared these inundations which they collected base after the 2011 tsunami inundation.

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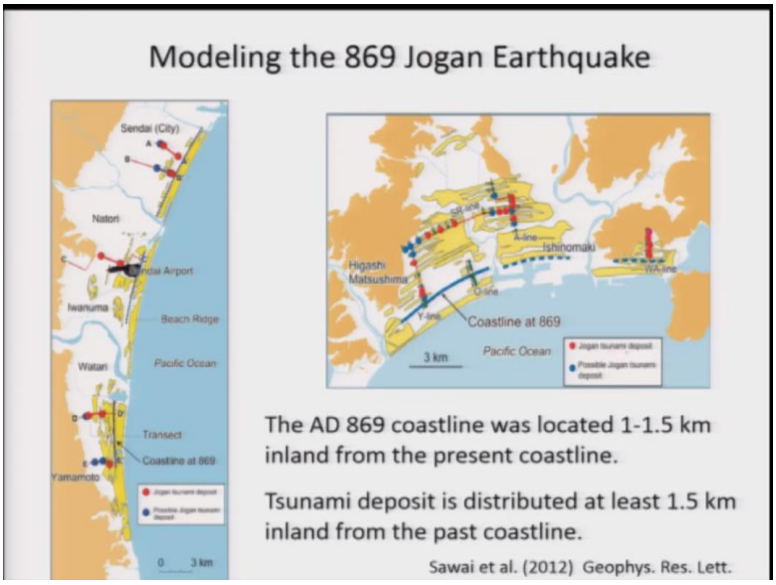

So modeling eventually helped them to understand that what will be the indentation pattern if a similar magnitude tsunami will be triggered and this tells the AD 869 and coastline was located here. Which was because this coastline will keep changing slightly and depending on the erosional pattern as well as the sea level change if they if at all it is there so the coastline of 869 was located almost along 1 to 1.5 meter inland from the present coast.

There is the present coast here where is the 869 coastline was located 1 to 1.5 kilometres inland. So now my deposit is distributed at least 1.5 kilometer inland from the present coastline so does they were able to confirm compares that the locations of the Jogan tsunami that is here 869 the locations and based on that they have incorporated this.

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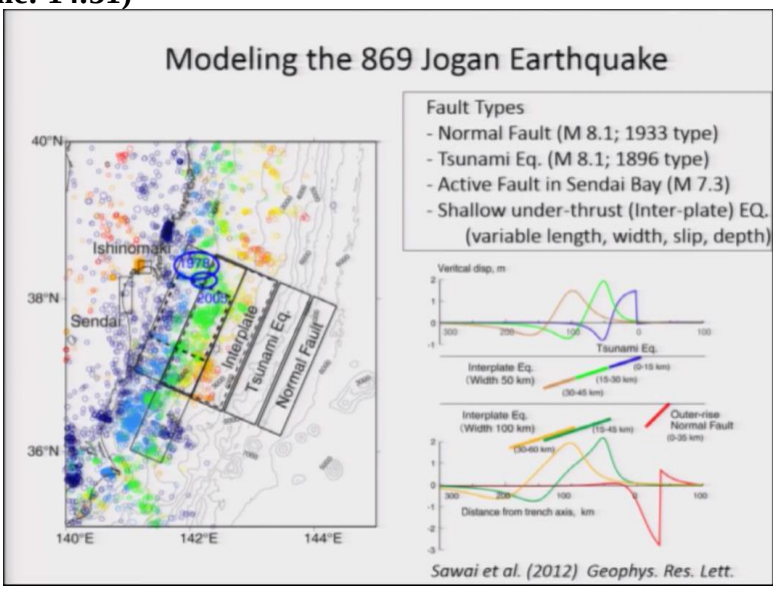

And in their model they also compared that with the help of different locations of the earthquakes if suppose the earthquake occurs in the deeper part along the plate boundary at around like 30 to 45 kilometers then what will be the scenario of land level change here so this portion will be uplifted this will subside and if it is occurring at a depth of 15 to 30 kilometers this will be the scenario.

And if it is occurring in the uplift portion that is ranging from 0 to 15 kilometers then this will be the uplift and subsidence. So during different scenarios and earthquake occurring on the plate margin or along the plate then different effect will be experienced on the surface so not always the land same area will subside or same area will get uplifted like for example here if we take then in the case of the earthquake which will occur at a depth of 15 to 30 kilometers then this portion will be uplifted on surface.

Whereas if the earthquake occurs at 0 to 15 kilometer then the same area will subside so this difference needs to be understood and this has not been done in the case of the Indian side. So we are proposing to undertake this type of studies. So that at least we can come across and the sequence and the cycle of the earthquake or the pattern of the earthquakes and how different it will occur in near future.

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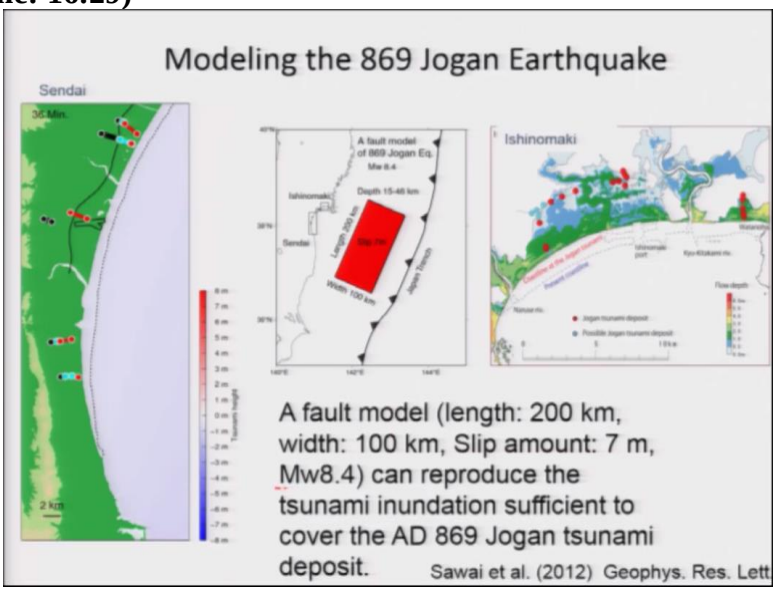

So they again as I was talking about the day they considered the means in the past the older coastline and then according to that they only and they did the modeling part so if you carefully see this is the time which is going on and the tsunami which has been triggered. So

this shows the model or the inundation of 869 tsunami so this shows the inundation of that and then they compare this with their the deposits which they identified.

So red dots are showing the location of the tsunami deposits and based on the model also they were able to prove that this was the inundation limit. So here what they took into consideration the length of the fall fault and the width the length was 200 kilometers the width 100 kilometers slip was almost 7 meters and the earthquake magnitude was when 8.4 and which can produce the tsunami inundation sufficient to cover the AD 869 Jogan tsunami a deposit so if you remember the magnitude was above 9 for 2011 and this Jogan was 8.4.

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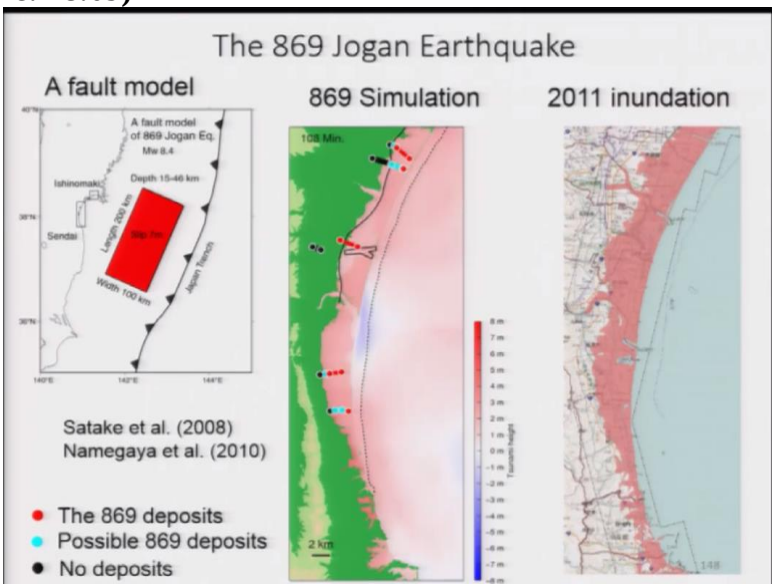

So similarly this is again the simulations for comparing both they the 2011 and this one is 869 a tsunami so in 2004 if you just compare this portion here that is the same portion so it was the inundation was slightly larger as compared to that.

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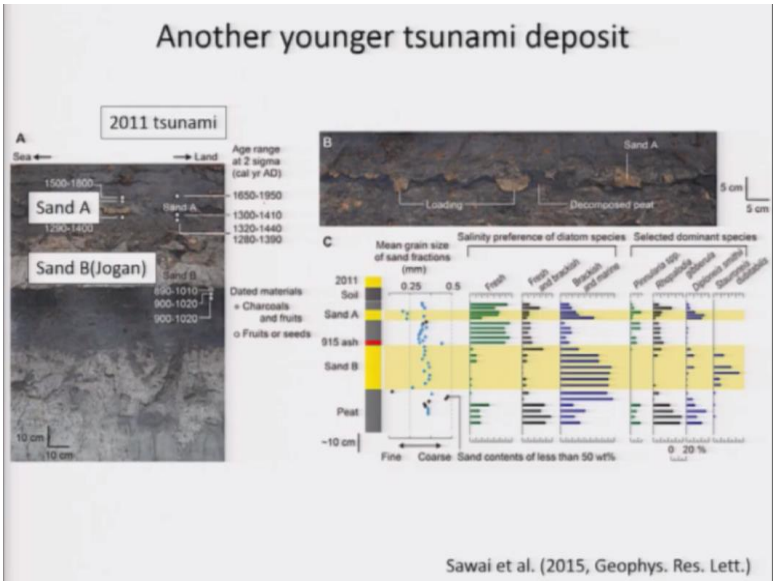

So another younger tsunamis when the sections were also identified as we have been talking this is these are the younger tsunamis indications here where this one is your 869 where is the younger indications of the smaller tsunamis have been reported here.

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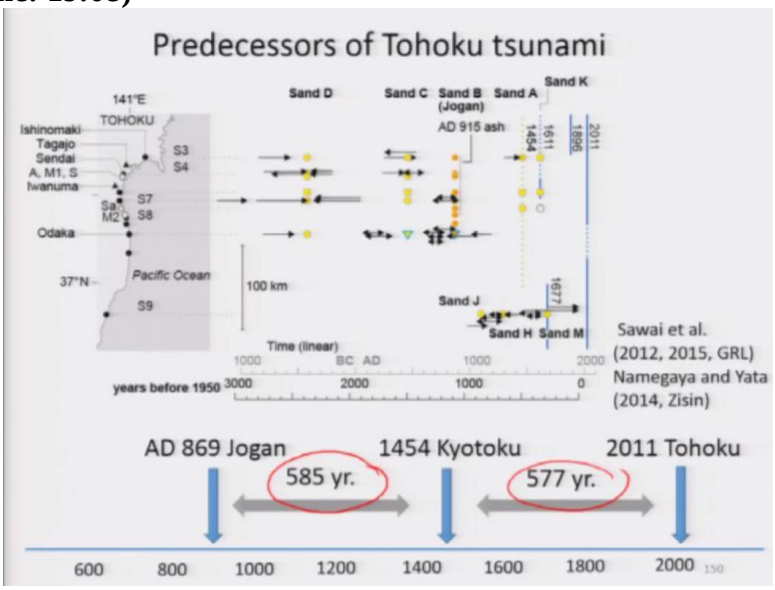

Now based on this what they were able to identify was that the comparable to the Jogan tsunami 869 and another one was in 1454 and third one the interval was quite significantly so almost the interval is 585 years. Now in the case which we need the similar type of studies in India the interval which we got as much larger that is 420 to 750 years and that is but compared to what about the data we got occupying this is the best understanding we have right now up to.

This but we need to narrow down this interval what in the way the Japanese people have done like having in very precise a recurrence interval so we would we are proposing to do more research in that area and try to narrow down the cap which we have identified from Andaman and lastly the crowd of a loss and last 8000 years so this is one advantage of these studies.

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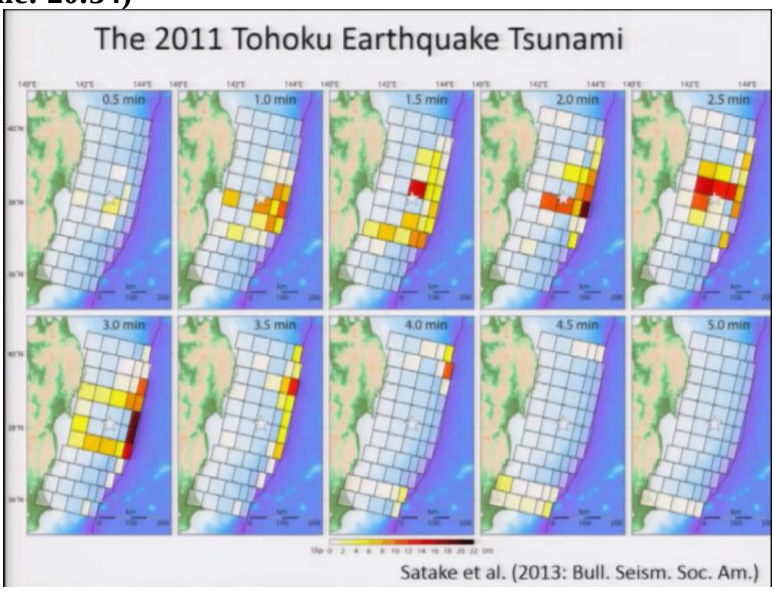

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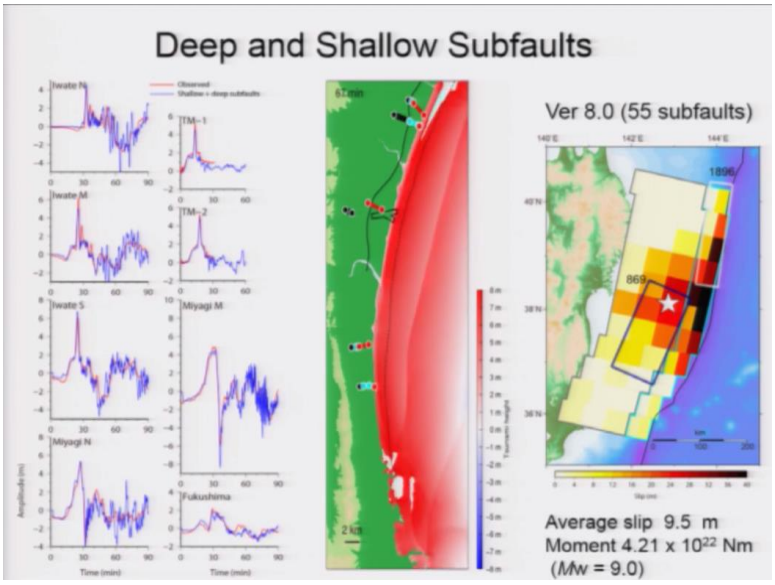

Which they have done so this was the scenario and Sendai and these are the models. Which we have run format for a different time and know how the rupture is propagated and this is the deep and shallow subsurface were sub faults if they displace along that and what will be the scenario of with an average step a slightly larger which has been taken as 9.5. So this suggests that the 2011 tsunami was comparatively similar the inundation was also quite similar.

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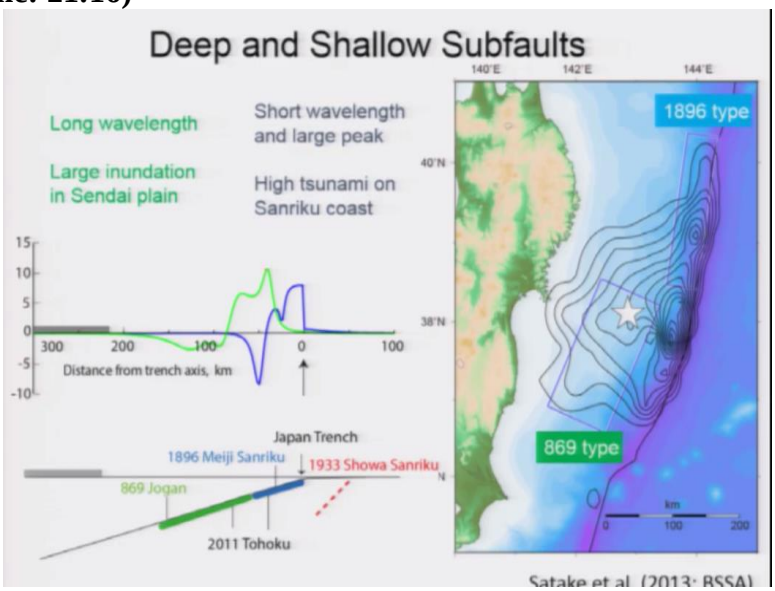

So as we were talking about that the land level change will vary and also the tsunami waves which are generated from the different type of earthquakes will also be different like the Jogan and 2011 were very much similar which resulted in 2 similar land level changes as well as the inundation and then the 1896 Meiji Sanriku earthquake was not along the portion which was ruptured during 2011 and Jogan. But it was up dip earthquake and the effect for

which has been shown is it is different than what we was experienced in 2011 and Jogan on earthquake of 869.

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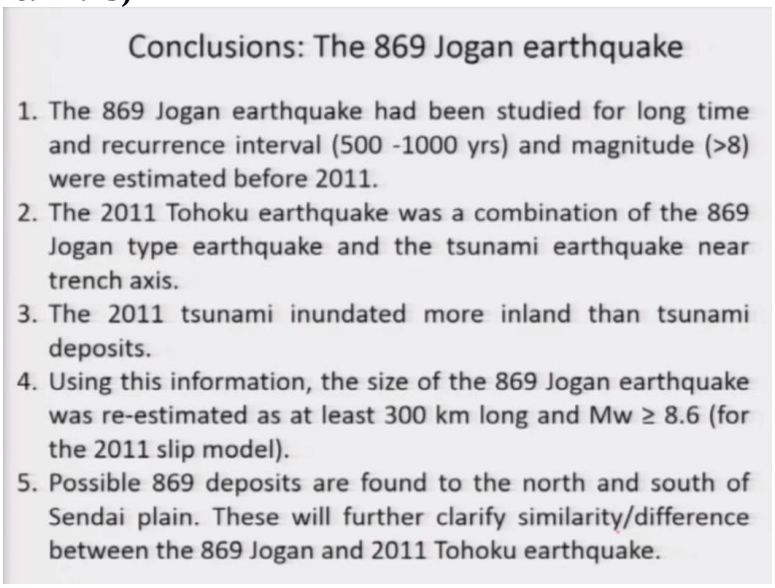

So conclusions it says that the 869 Jogan earthquake had been studied for a long time and the recurrence interval was 500 to 1000 years and the magnitude was greater than 8 which was estimated before on this 2011 earthquake. The 2011 Tohoku was a combination of the 869 Jogan type earthquake and tsunami earthquake near trench axis. The 2011 tsunami inundated more inland world as compared to the deposits.

Which were been identified that I which are that what I discussed in the beginning that even the mud deposits were taken into consideration as an entity inundation limit for the 2011 using this information the size of 869 Jogan earthquake was re estimated as at least 300 kilometer long and the magnitude was like 8.6 for the slip model. Which was incorporated for 2011 so possible 869 deposits are found to the north and south of Sendai plain this will further clarify similarity or differences between the 800 and that is Jogan tsunami and year 2011 Tohoku tsunami.

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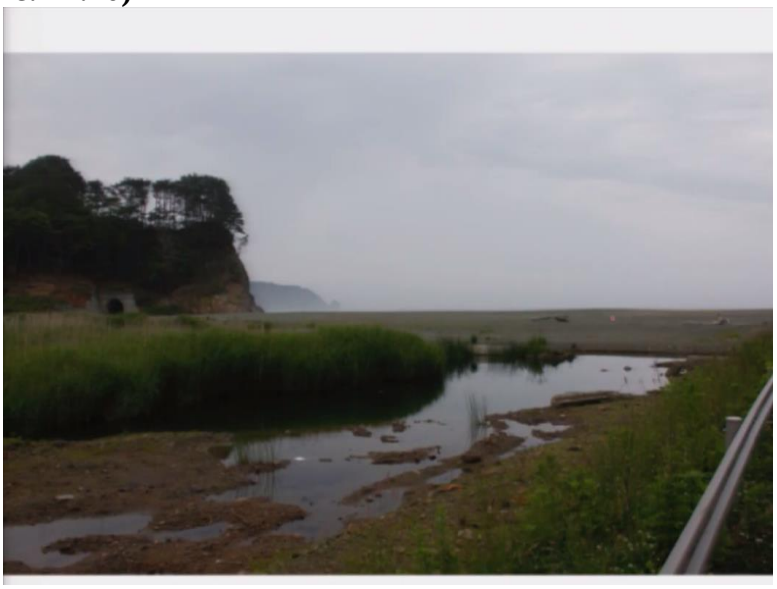

So after that we did as short field work jointly with (())(24:03) Sanriku area and so this was the damage pattern during 2011 and we were looking for if we can find some more signature of similar to 2011 so this is the Sanriku area in Japan. So what we every again as I discussed in one of my lecture that usually we try to identify the lagoon only area or the ideas behind bridge so that we can identify the preservation preserved tsunami signatures. So this was the area which is like and close to because of the beach ridge here and this was one of the ideal locations for us.

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So when we did started our field what we identified that this portion of the mountains the hill were completely shaved walking like the ocean and this erosion of the vegetation was because of 2011 Tohoku tsunami you can see the level up to which the tsunami heights reach this holy are the hill is like that somebody has shaved it already sharply.

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So there is are the deposits which we were able to pick up from that area that these are all tsunami deposits here are sun sheets. We found and then we also did small pets to identify if the tsunami was able to climb up a small terrace and the weather.

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It deposited or not and we found that very clearly so this is the deposit of 2011 Tohoku and further deeper portion we were able to find some patches which are indicative of the past tsunami.

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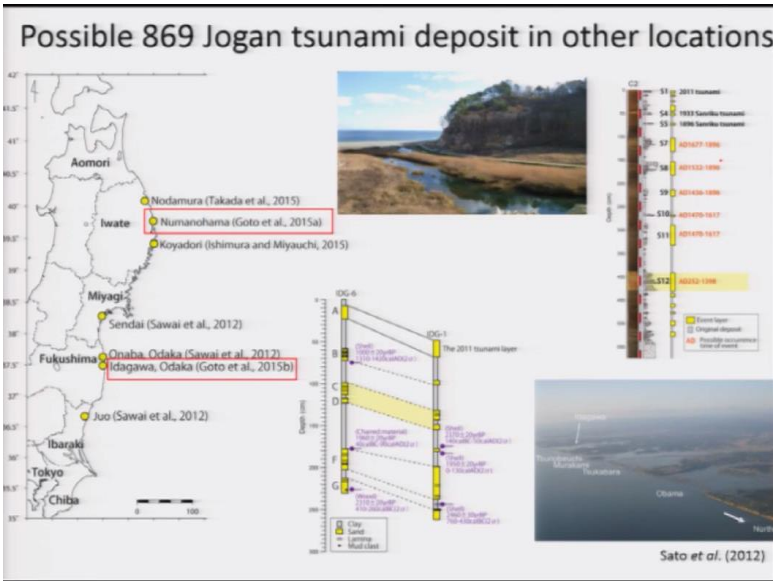

And these are the comparisons and based on the ages which were been done so these are the tsunami deposits from the section. So if you see this these are the ages here, so these are the smaller ones before the 2011 Sanriku tsunami which has been given here.

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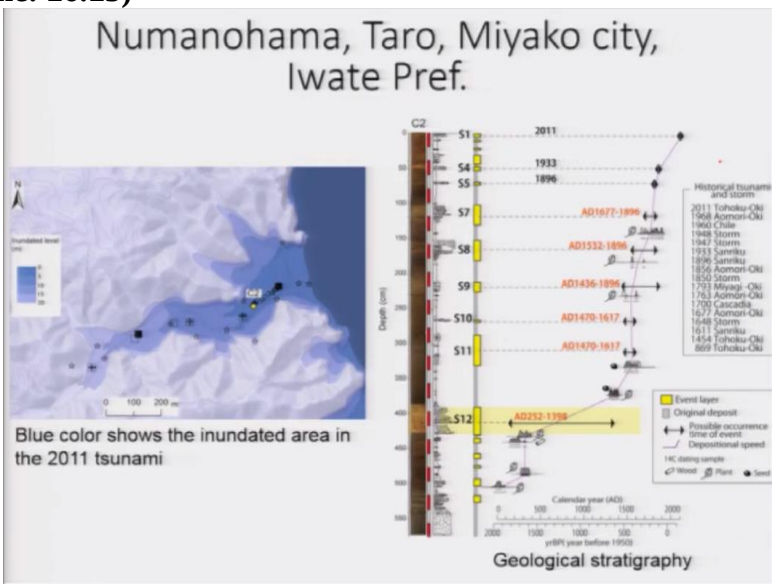

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And similarly more from the same area and we also did slight field work in the other portion of Sanriku and as I told that the 2011 was and the above the expectation of the based on the preview of the Japanese people based on the previous record. So this was the level here and this is the tsunami wall which they constructed and just behind this in this area the whole settlement I was allowed to occupy the area.

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But the tsunami was much higher than this one so you can see the poles bend caught bended because of the tsunami waves and the height was much higher which caused this whole wall.

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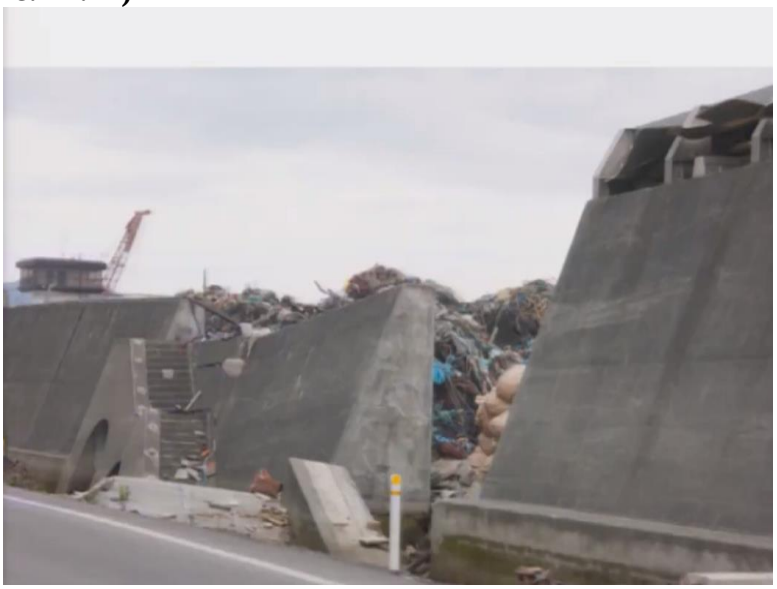

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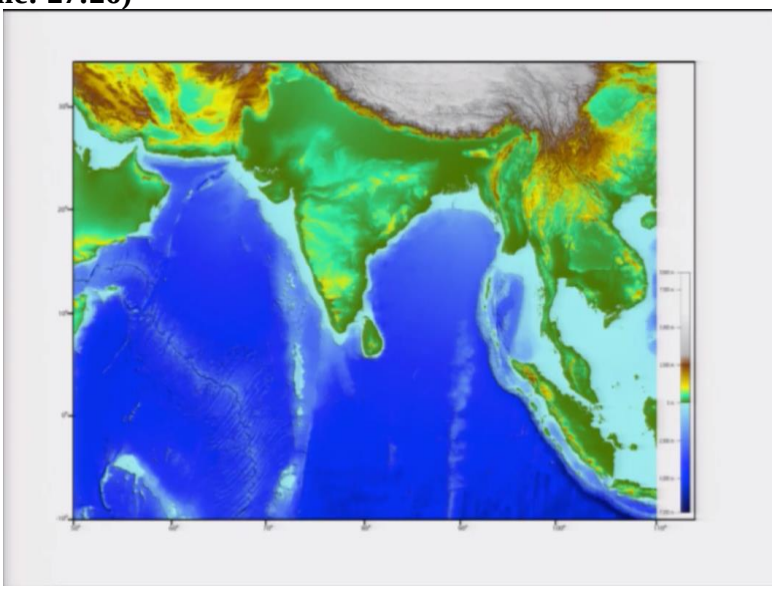

So this was the scenario and the energy conditions of the tsunami was much higher than expected now coming to this part here what we did I was also from Gujarat area and also we did some simulations based on.

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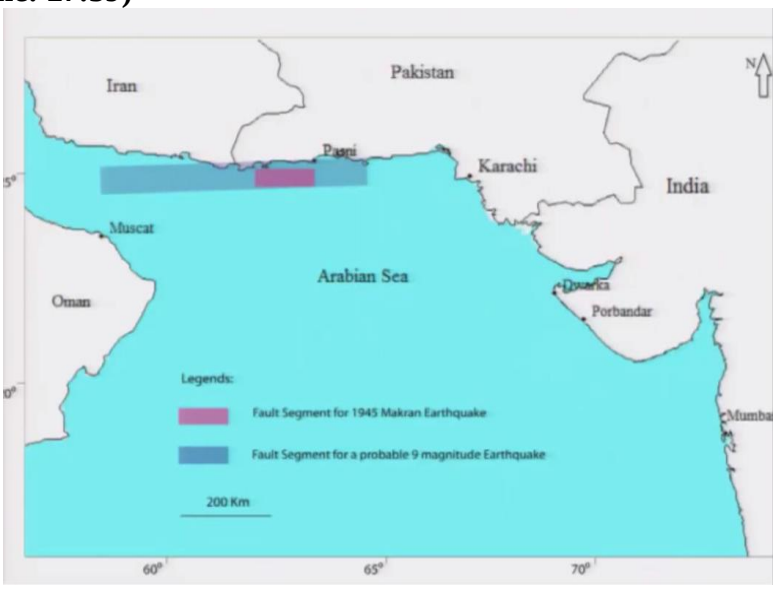

Our information which we gather from the Makran subduction zone and what was the effect here still we have not dated this portion or the material. Which we got from the Gujarat coast around work area but yes of course there are some indications.

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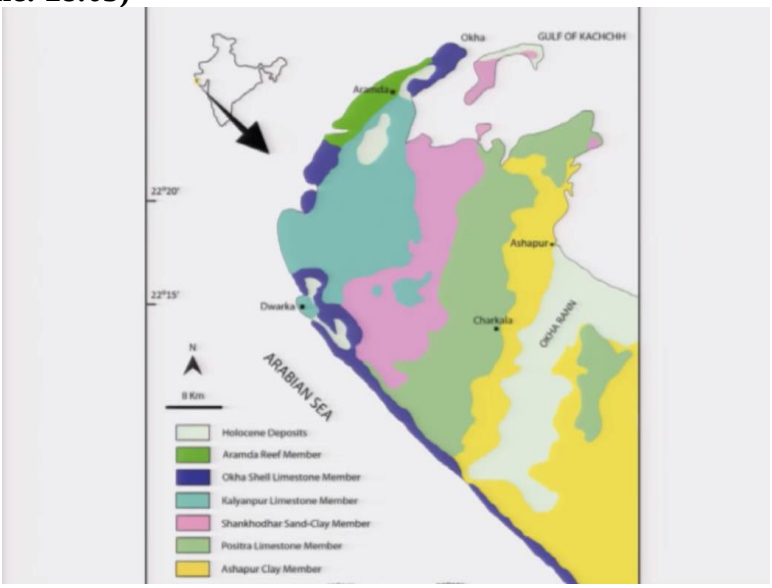

Which tells us that the 1945 earthquake along Makran was probably was much larger and I was capable in generating effective tsunami which affected the coastline of Indian Peninsula also that is the west coast line of India.

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List of major storms in Arabian Sea

S.No.	Year	Cyclone/Storm	Area	Category
01	1998	Gujarat Cyclone	Karachi	3
02	1999	Sindh Cyclone	Karachi, coastal Sindh	3
03	2001	Gujarat Cyclone	Gujarat	3
04	2007	Gonu	Oman, Iran, Coastal Pakistan	5
05	2010	Phet	Oman, Coastal Pakistan, Gujarat	4

So we also looked at the storms or storm record from in this region in the previously experienced not only in particularly clutch. But also the areas where the landfall was experienced again Karachi and Oman and all that.

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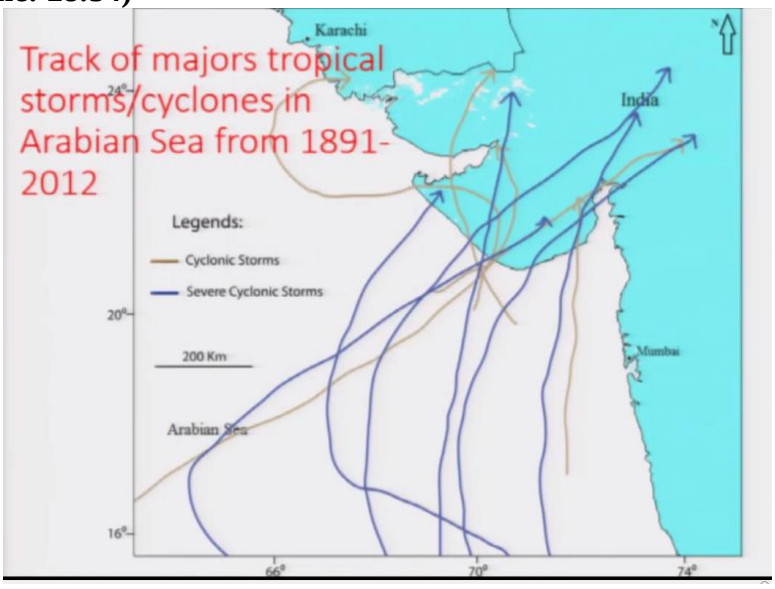

So this other tracks which shows the this storms tracks of the cyclones since 1891 to 2012 so most of the areas along this course that is Gujarat southern Gujarat when the west coast of Gujarat and got affected because of the storms.

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Fault parameter for tsunami simulation for Makran Subduction Zone

Modelling Parameters for Tsunami Simulation		
Moment Magnitude	9	8.1(Makran Tsunami 1945)
Longitude	64.50E	63.48E
Latitude	24.70N	25.15N
Fault Length	575	150
Fault Width	120	70
Focal Depth	15	15
Dip Angle	7	7
Strike Angle	268	246
Rake Angle	90	90
Displacement	17	6.6

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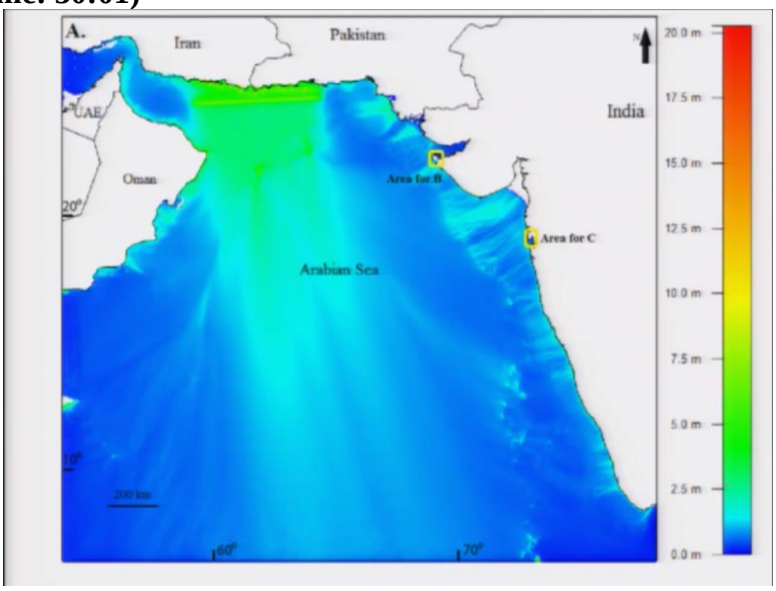

But at the same time we also looked at that what would have been the inundation using the simulation putting the parameters of the 1945 Makran earthquake. And what we found was the huge pigments of the rocky platform wet eroded and deposited are you can eroded transported of flit up in the area and that showed us very clear indication of probable tsunami deposits so this is the tsunami generation which we did and the height which we in we observed here based on the simulation was ranging around 2.5 meter so the wave heights were 2.5 meters.

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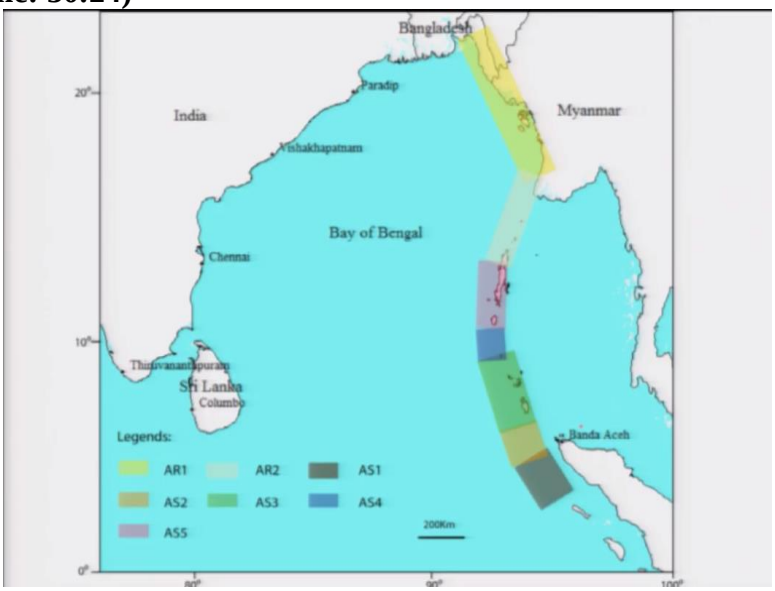

So similarly we are planning to do this work along the Andaman using different sources not only based on the historical record but also based on the Paleo seismic studies which we have carried out from this region and hopefully this will help us in understanding that the 2004 was not only the it is let us type like for the 2 powerful earthquakes or the tsunami but also other tsunamis.

Which would have been generated from this region had a different effect along the east coast as well as along the west coast off Indian the mainland and also the its effect on the other adjoining countries but with the Indian ocean. So I will stop here and we will continue if possible a few more lectures in this course. Thank you so much.