**Earth Sciences for Civil Engineering Part-2**
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**Tsunami and related hazard (Part-2)**
**Module 3**
**Lecture No 13**

Welcome back.

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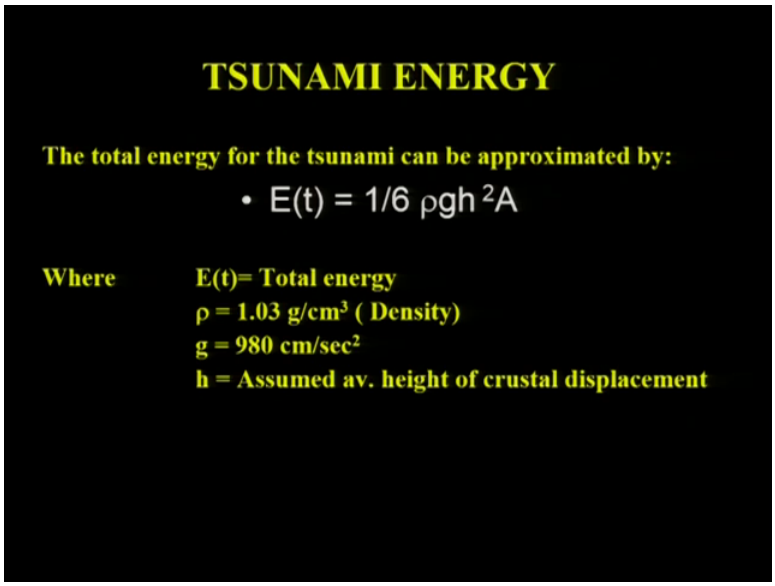


So during last lecture, we were talking about the the Tsunami and with a very simple equation you can calculate the energy which has been produced at that time of mega earthquakes so you have ETS your total energy and then you have the density of saline water or the ocean water and then you are having the gravity and then you are having the assumed height of the crustal displacement so if it is 25 meter displacement or 30 meter displacement, you can consider that. And based on that, you can calculate the energy which is been produced at the time of mega earthquake by Tsunami.

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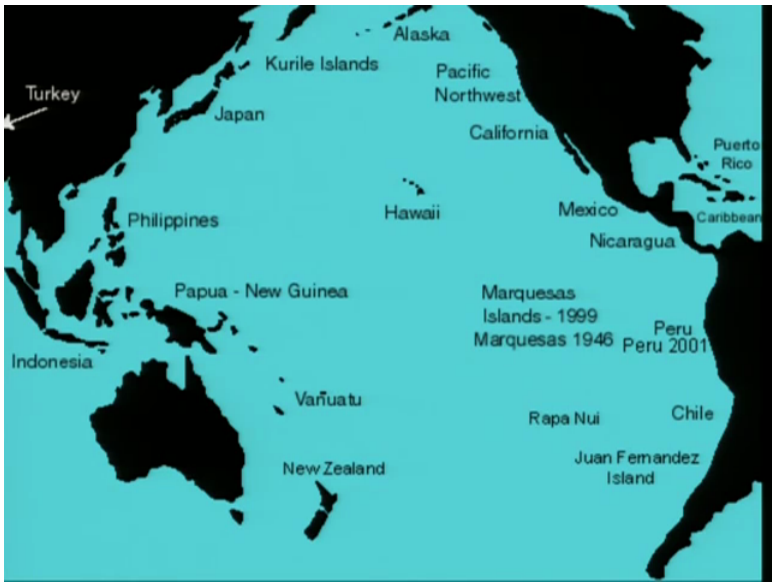


Now if you look around the globe, you have several locations which have produced mega Tsunamis and we can say the mega subduction zone earthquakes and the most vulnerable reason in the in the world is the in the pacific ocean or the countries which are around pacific ocean like this is south America and then you are having a north America here and then you are having Japan and then of course you come down here to the Sumatra part and all that. So these are the areas which are are capable of triggering a large magnitude subduction zone earthquakes and Tsunamis. Like for example this region produced a very huge Tsunami by an earthquake which had a magnitude of 9.5 in 1960 and then similarly we have couple of earthquakes which have been marked here but this was one of the largest over here so far recorded on the earth. And then of course the second largest which we had was around Sumatra, that is along Sumatra Andaman arc.

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These are few list of the major Tsunamis but apart from this, we have more in the last couple of years like the 2004 and 2011.

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Now coming to (sub) I will give a just a brief glimpse of what was been recorded and experienced in 1960 Chilean Tsunami and this had a magnitude of MW 9.5, so this was this is considered as one of the largest one so far recorded and then followed by this was so this is 1960

Chilean Tsunami and then we are having MW 9.3 or so, this is 2004. This is Sumatra Andaman earthquake so this was these are the 2 one and then finally we are having the the recent one 2011 Tohoku which was of 9.1.

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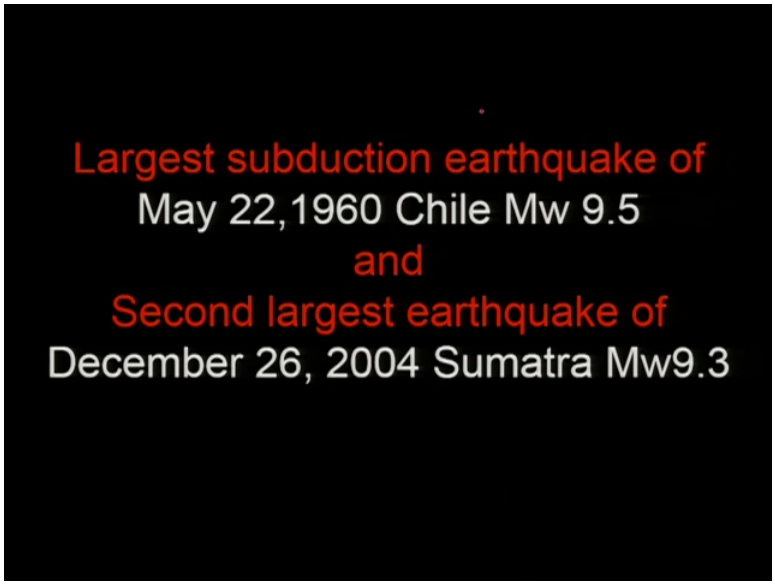


So the largest subduction zone earthquake occurred on May 22$^{nd}$ 1960 in Chile, magnitude was 9.2 and the second largest earthquake was so far recorded was December 26$^{th}$, 2004 Sumatra with 9.3 magnitude. In some literature, there was a mention that there was 1964 Alaskan earthquake was the second largest but it's just a matter of the decimals okay that that makes that probably that was the second largest. But in terms of the rupture and the damage, we had this was one of the largest magnitude earthquake recorded so far.

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Now, as I told that along the plate boundaries, we are having the most vulnerable zones in the world. One is this one. This has produced the worlds' largest one and the second one is here that is Sumatra Andaman so these are the 2 plate boundaries which have triggered large magnitude earthquakes and giant Tsunamis during the 1960 and 2004 respectively.

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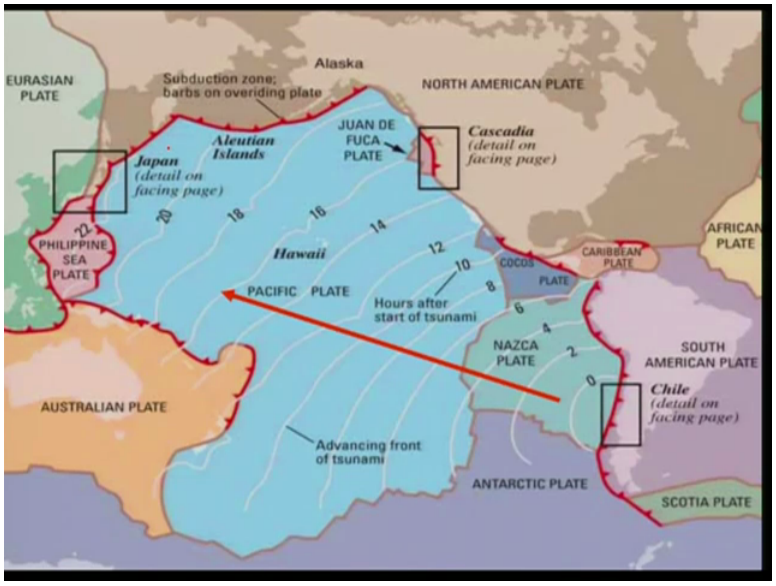

Now as we have been talking that if when when an earthquake, a large magnitude earthquake along the subduction zone occurs, it will be followed by giant Tsunamis or destructive Tsunamis. Now there is time where you can warn the people to evacuate and this figure it shows that 1960 Tunami started it (its) journey from here and it took almost like 22 hours to reach the coast along the Japan. So this is these are the hours which are been given so if you know the velocity and if you know the energy which has been released or the energy of the Tsunami, you can model the the time it will take to reach any particular region and based on that, you can issue the warning so this was like this Tsunami 1960, what people did over here, I will show couple of photographs of that region. So it took almost like 22 hours to reach the Philippine and Japan coast.

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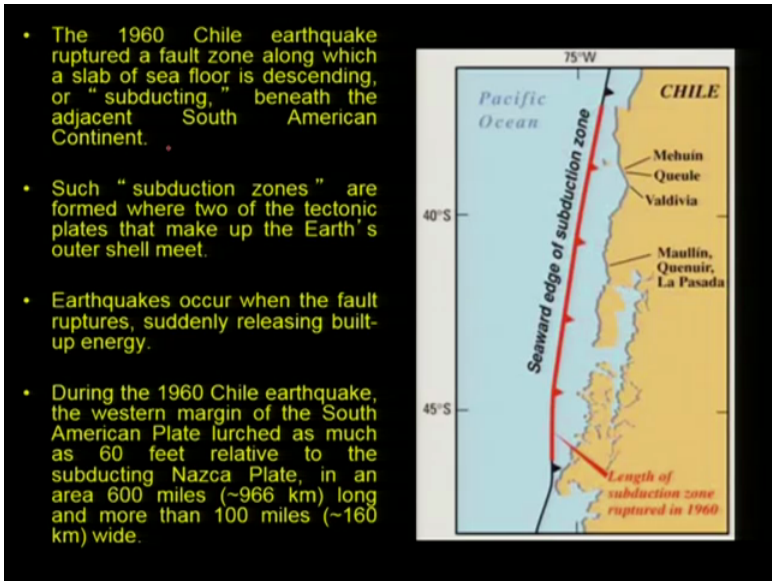


So the 1960 earthquake ruptured along a fault (where) which was almost like around 500 kilometers or so and it released a huge energy which triggered the mega Tsunami during that period.

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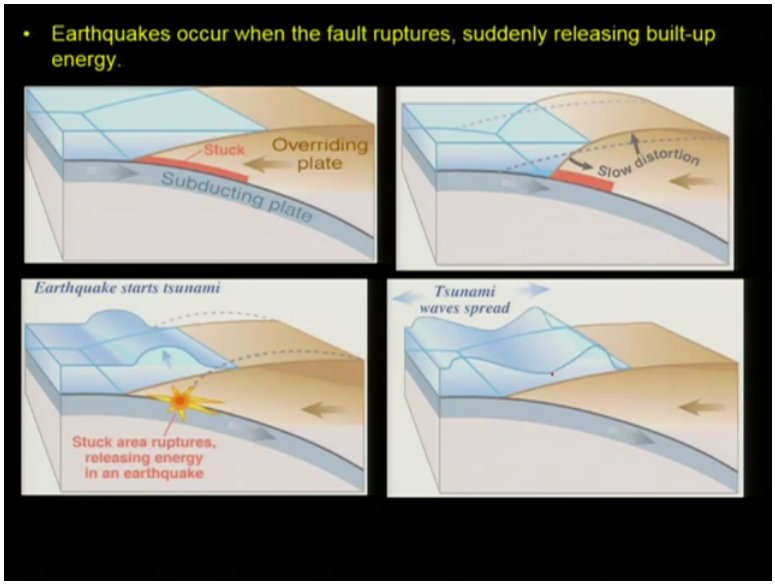


Now we we saw one small cartoon that how the the Tsunamis are been triggered okay so we have one like subducting plate, one plate, oceanic plate or either you are having an overriding plate is also oceanic so one plate is subducting below another one. There is some portion of the plate under great friction will be locked okay over the time and the strain will keep on accumulating so this will bulge so slowly there will there will be a distortion of this portion which is been shown here so the water depths will change but this will be barely noticeable but if you have GPS stations, that can at least capture this deformation okay over the time and we can understand and we can know that okay fine this area is getting deformed and will trigger a large magnitude earthquake.

So the previous boundary of the surface has been shown here by the dash line and this is the the bulge which has been developed because of the subducting plate and the overriding plate here and and finally what we see is an release of stored energy in form of mega earthquake okay so this release, the displacement so if you see this dotted line here is the previous slide here, this has been shown so what has happened is that over the time when this was locked, this area got uplifted and then finally during an earthquake, when the energy was released, this again was been flattened almost and it subsided okay.

So over the time, the land level change will take place okay. So the earthquake which was triggered and the displacement between the 2 plates dislocated the water column at the at the in the ocean and this displacement resulted into the formation of the Tsunami so this explains the the formation of Tsunami which will inundate um the portion on land, far in land actually.

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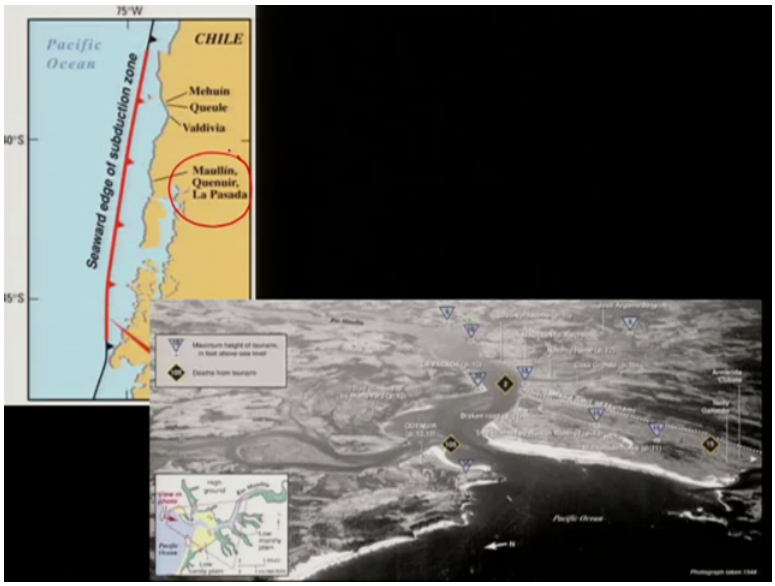


So let's move and see couple of more slides from this region what happened. Now this was the area which was extensively affected in 1960 and this what we found was Moulin or we can Moujine okay was the region which preserved the old signature of the Tsunami. So we did some feed in this region to identify the the older Tsunamis than 1960 and also we looked at the signatures of 1960 Tsunami which got was was affected the most during an earthquake.

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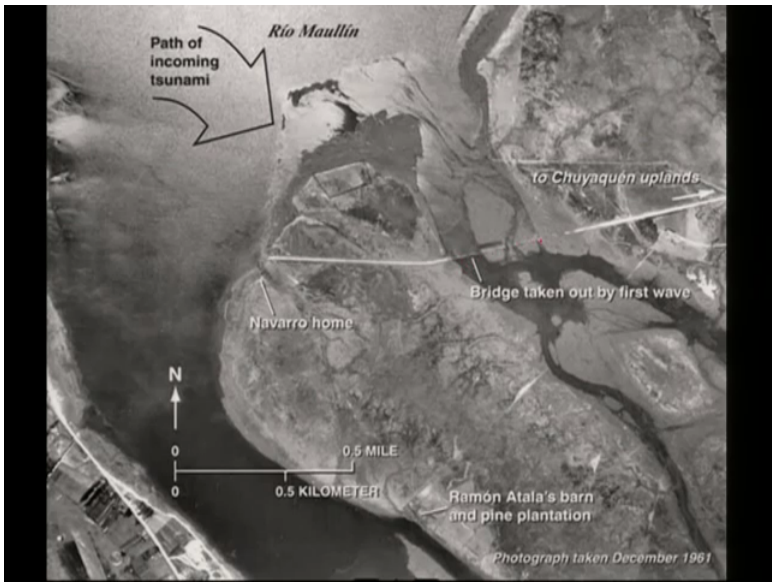


And if you can see here, what it shows is the path of the incoming Tsunami. It wiped off the bridge which was located here.

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So this was the conditions in the town in the Moudin.

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This shows photographs with couple of pictures couple of houses where this picture shows couple of houses here, you can see this one here and then so they had an very wide agricultural field with people staying there okay.

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But after if you notice okay, what happened, it was completely wiped off.

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So only couple of the trees which are been shown here survived, rest everything was been wiped off okay and during this earthquake, the land subsided so the level went down and then finally, this area was every time in high tide was inundated so these are the most common problems which one will face during subduction on earthquakes and after that okay.

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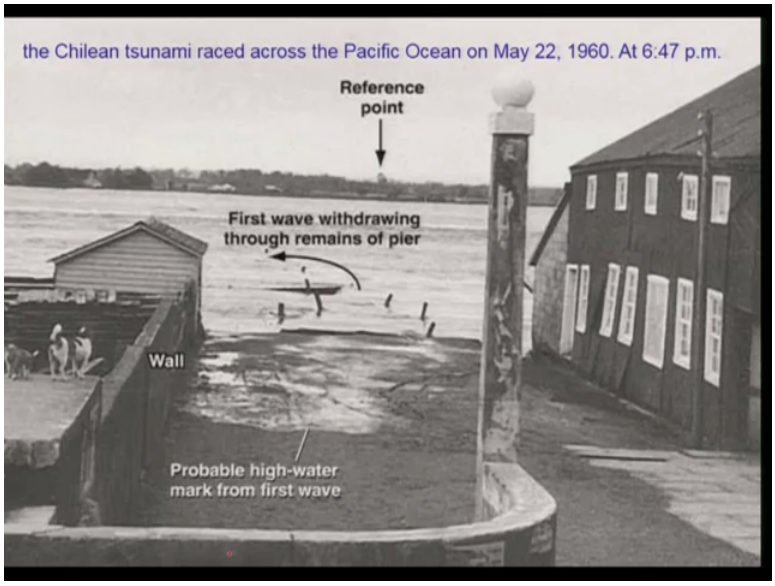


This is what they have shown that first wave came in…

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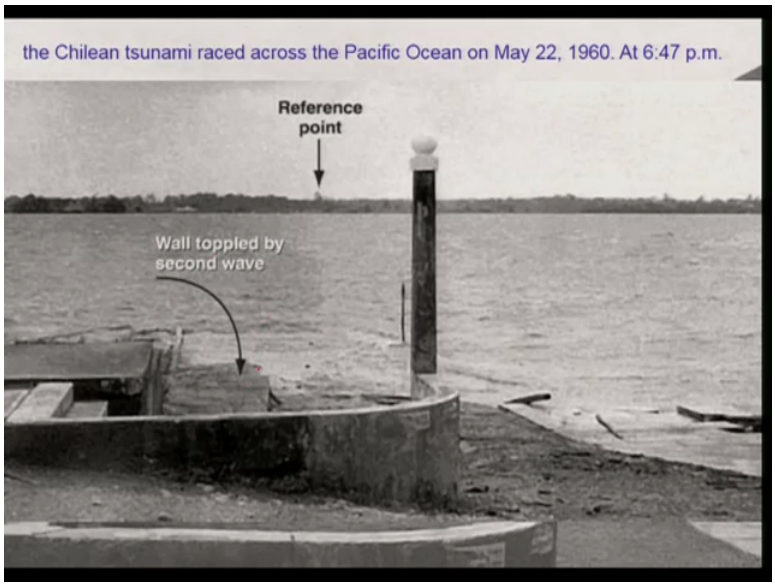


And the second wave wiped off this house here okay. The small hut which was been wiped off and the water level raised okay.

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Now this was an interesting which was noticed in Japan, the local people okay who were looking after the the tidal gate stations and all that, they understood or they caught that there is an water rise which was an unusual thing because there was no high tide during that period so they they

anticipated that there must be some Tsunami coming in and they warned the people and then asked them to go on high grounds.

And this is what has been done most of the time okay. In 2011 also, the people were been evacuated to the higher grounds to so that like they are they they will not experience the Tsunami or they are not been killed by the Tsunami, so this photograph was taken at 4:40 AM in the morning where people were been moved and you can still the people are over here, a group of people are moving towards the higher ground and then couple of people are already on the higher ground, so the first large wave reached up to this place, still these people are are moving on on within water.

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And then the second one, you can see here okay, the same house has been shown here. This is within 5 minutes of the time where the first wave arrived, second wave came in in 5 minutes and what you see here is the complete inundation of this region okay.

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And then it carried lot of debris in another 5 minutes okay.

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And then finally this was the situation okay and this was the water level rise up to this part in another 5 minutes, so this is what you you can do if you understand the process of Tsunami.

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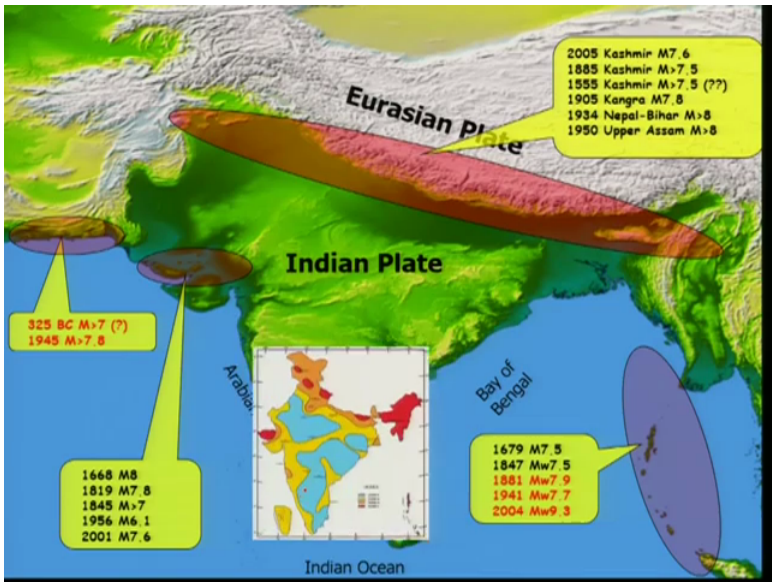


Now coming to the the other part that we we usually see okay, fine, apart from the Himalayan region, why it is so important for us to understand this process because we are not left out with any side from this type of hazard okay. In the south, we have the Andaman islands and this Andaman, Sumatra Andaman arc has triggered many large magnitude earthquakes and Tsunamis in the past okay so this was not the only one, that is 2004 was not the only one. It has also triggered more similar magnitude earthquakes and associated Tsunami, associated giant Tsunamis in the past also okay and if you come to the the west side, so if the Tsunami is being triggered here along this portion, this whole area will be affected. Not only the Andaman iseland but this whole area will be affected and also this region okay. This is the region of Sundar Bun area which is very flat area.

So this also will be affected if the Tsunami is been triggered along this zone. What we have been talking about that we have the collision zone here, we have another active zone in Kachchh, there is in some, in the west, we have Makran Subduction zone which has also reported events in the past like 325 BC, there was a major earthquake and then 1945 another earthquake which triggered the Tsunami so of the Tsunami is been triggered here okay of with the large magnitude, this whole area like Gujarat coast and right coming up to the Mumbai and Kerala and all that,

that whole area will be affected by such Tsunamis if is comparatively large as we have experienced in 2004.

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Now this was like again going back into the Chile part. What happens after that okay so if the area is subsided or if the area is up lift the environmental changes will be seen along the coastlines okay and this is mostly for the regions which are close to the subduction zones.

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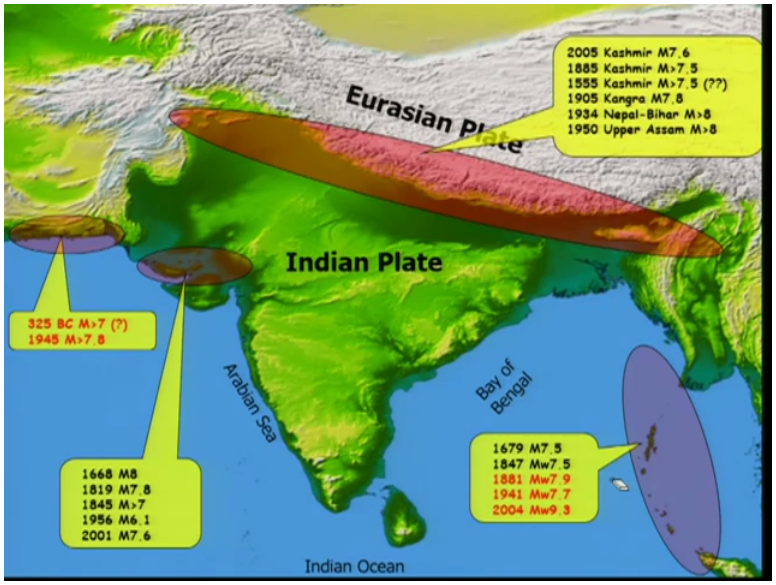

Like in India, we will not have that much of problem in terms of the land level change along this coast but there will be a massive change of land level where are having the islands sitting close to the arc okay so arc is not very far from here, it is somewhere over here, it goes like this so this will be this area will have more of land level change problem.

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So in 1960 after that, as I told that large area was been subsided so which area the area which was used for agricultural purposes now sitting in as in tidal floods okay.

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So you have high tides coming in and inundating the areas so it is you are you in short you lost the land from the in that area.

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So this is the situation you will come across a lot of dead forest because of the the inundation and erosion of the tidal waters.

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These are all the examples of the dead forest and that similar thing we we also observed in Andaman after 2004 Sumatra Andaman earthquake.

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So this is the high ground now so people who used to stay here have shifted, those who survived from this event, they have shifted on the higher grounds here and some of the remnants of the soil is have is been shown here still exist okay and this in the old soil which was before the 1960 event.

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So still we have some remnants of old soil there but now it is subjected to erosion because of the tidal inundation.

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So what we did was, this is the best way to identify the earlier events because all such events, either it is earthquake or Tsunamis, they will some signatures in the sediments.

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So we looked at that stratigraphy and this our team. We both were from India and the the team was been headed by professor Brian Atwater from USGS, US geological survey and this guy is from Chile and 2 guys here. One and the here one, another one, they are from Indonesia so a very small think worked in this areas extensively and looked at the signatures of the Tsunamis.

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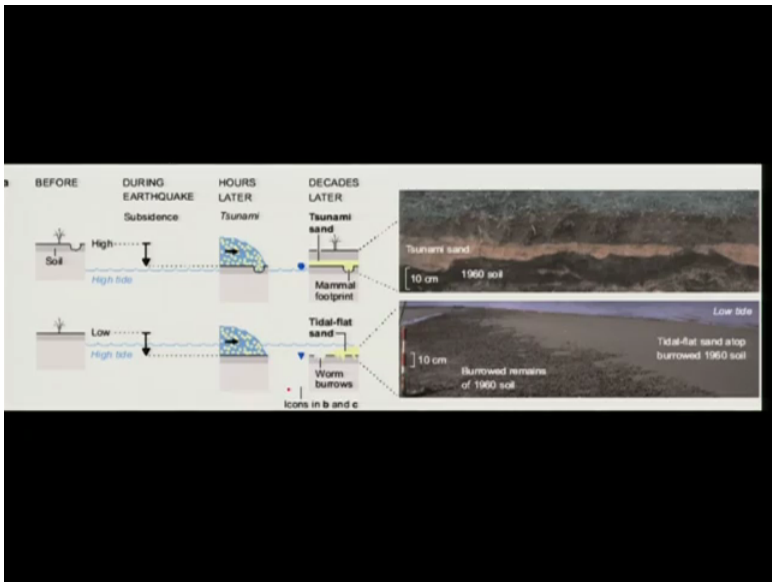


Now what has been shown here is a very simple process okay so we have like soil before earthquake and then during earthquake, there is the land subsidence is there so what will happen, when the Tsunami comes, it will deposit the sediments here and these sediments will get preserved over the time and we will see the soil is kept the the previous Tsunami signatures okay. And this is what we exactly in the the stratigraphy here, so this is small trench, section which we see, there is a vertical face of that where we see the Tsunami over here, where is (lo) yellowish, reddish yellow color and the below one, the dark one is your 1960 soil. And then further process goes on and we are having deposition of another soil here. So if this crosses this phenomena occurred in the past also, we should see similar type of stacking of material okay.

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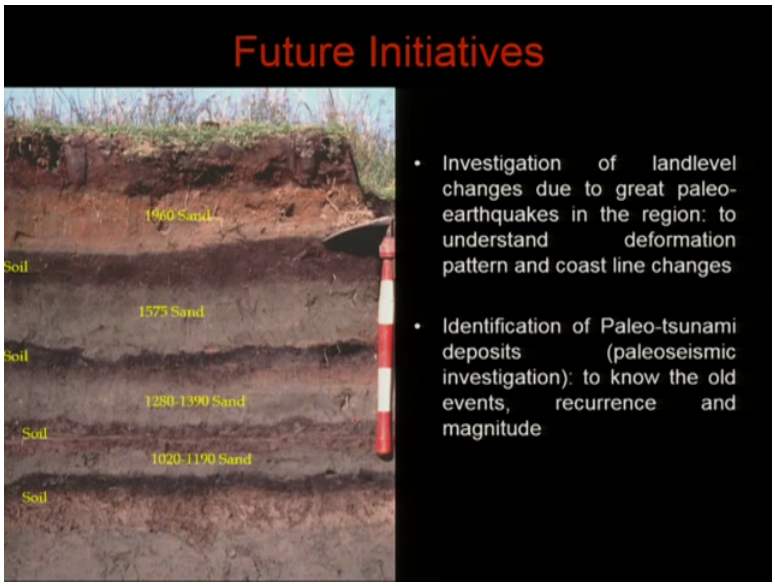


This is what we got there okay so we have like in the top which I was showing in the previous slide, we have this in present soil here and then we are having in 1960 sand that is deposited by Tsunami, 1960 Tsunami. Then we are having another, this is the the soil of 1960 which was the which marked the surface during 1960 and then we are having another sand layer which was dated at around 1575 so what we do is, we collect the charcoal samples and then we tried to date is, how old the sample know that okay so we can at least bracket the events during at when when exactly it took place okay and then we are having another soil here and that and another sand layer which is older than this one so this is around 1200 to 1300 A.D. and then we are having around 1000 A.D okay so we have series of similar events and the stratigraphy shows that this area experience many more similar type of events in the past okay.

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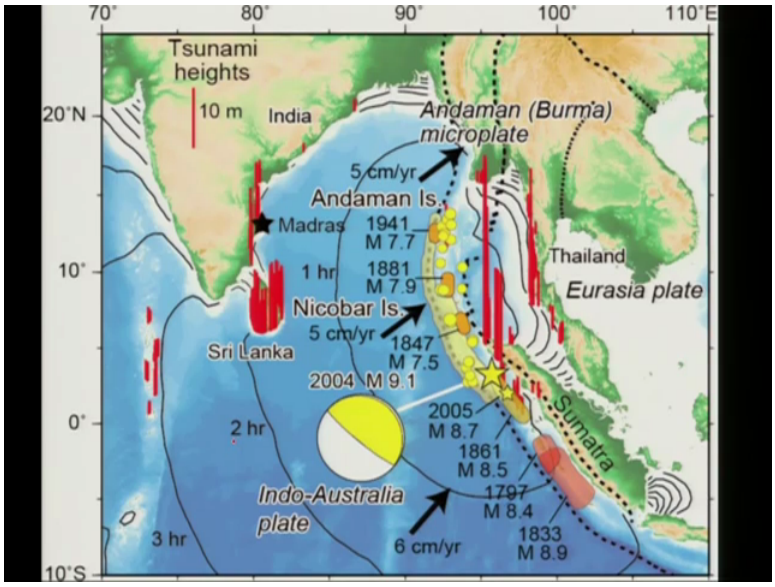


So if you come to Indian part, the the subduction zone part, what we see is that in 2004, a very large area got ruptured okay so this whole area was fractured or faulted during an earthquake, so there is an displacement along this area which was almost like 1300 kilometers, so very large source was available for the Tsunami to be triggered and it resulted into a huge Tsunami which an very like large waves okay which engulfed many locations in the region. So this has been shown here, the wave heights and this is the the bar which marks the 10 meter height here okay so it was quite large in some places okay.

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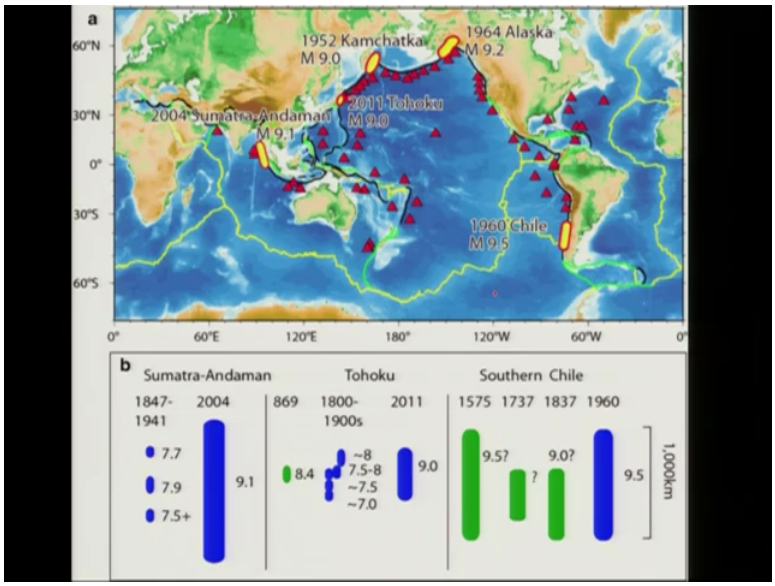


Now this just the comparison which has been given between earthquakes like Sumatra Andaman earthquake and then are having the 2011 Tohoku earthquake and then we are having the 1960 and few more earthquakes from Chile okay so which were been identified from the stratigraphic signatures. So here it has been shown that what is the the comparatively ruptured areas okay, that was around 1000 kilometers, this was very small, it's almost half of this. It's 500 kilometers of area ruptured and here it was around 1300 kilometers okay but what recent finding suggest that because there was a question that why even a small area of 500 kilometer which was ruptured but the Tsunami heights which was experienced and during that during 2011 earthquake, why it was so, why it was so high actually okay.

So the reason so what they found was that this earthquake not only rupture the 500 kilometers area but also resulted into submarine landslide which added up the the energy to the the Tsunami okay and that what resulted into the higher waves height okay in this region.

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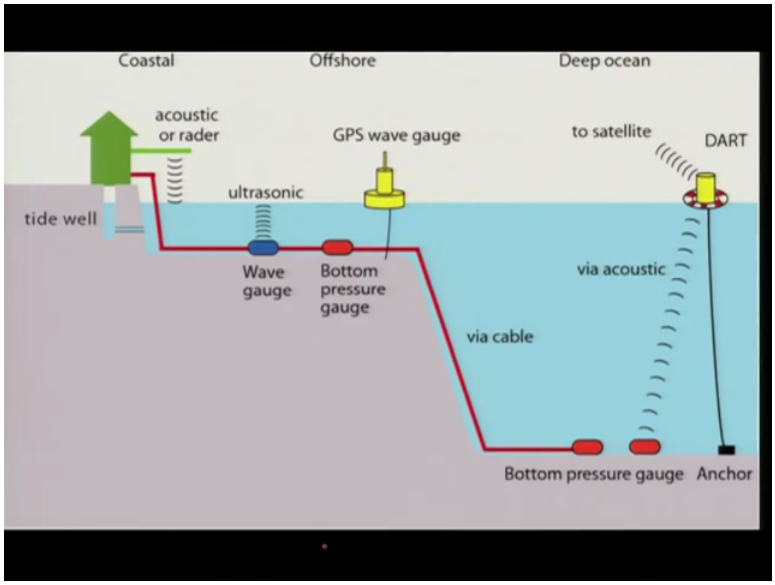


So now with the advancement of science, what we can do it, we have the sensors which are been left out in the the ocean okay which will keep on sending the signals through satellite and of course we also have the floating gauges, GPS gauges which will also talk about that if there is a sudden change in the water level okay so this will help us in sending the information in terms of the warning okay before it reaches the particular location of interest.

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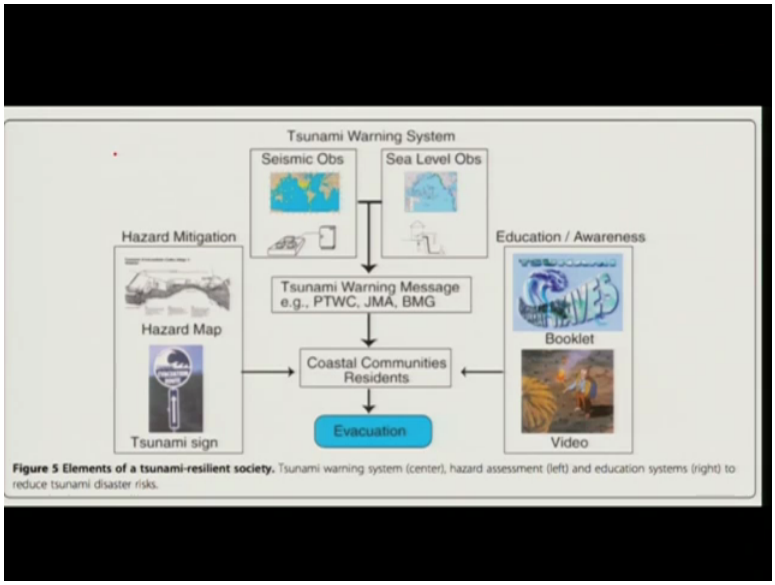

And apart from this, there are ways to to create an awareness amongst the people okay and the ways people are still working on on this that how best we can reach people before time to minimize the hazard and risk okay so if you understand the from the part experience that how much area got inundated in mega earthquakes or the giant Tsunamis, you can come up with hazard maps and then at the same time, you can also identify the areas which we say the high grounds okay, so in US and Japan, what they have (so) done is that they have marked the, they have put the signboards okay which that okay fine, in which direction you have to if a warning has been issued okay.

So this shows that evacuation way were you to move okay so this shows so should say is evacuation route okay so which part you have to move so it will guide you and then you can reach the closest one as early as possible. Other than, you have an education and awareness part where you can keep on like what we are doing right now but what they have done is, not they have created some cartoons okay or videos which are been shown and they have come up with some booklets which are given to the school kids okay so that they can understand what best they have to do at that time of Tsunami when the the warning has been issued okay. So finally what we see is the Tsunami warning is been issued, it will go to the the local agencies and then coastal residents are been informed and then finally they will go for an evacuation okay.

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This is the picture which took after the earthquake of 2004 which shows that so this area is in the northern side of Andaman, northern part of the Andaman which clearly shows and there was an uplift here so this photograph was taken after like almost an after a month or so or may be a week okay if I am not wrong, which shows that the water used to come up to this level and there is a beach here okay but later on, because of the uplift, that water has never reached up to place, it used to restrict the inundation up to this okay so this area got uplifted or exposed to the the surface okay.

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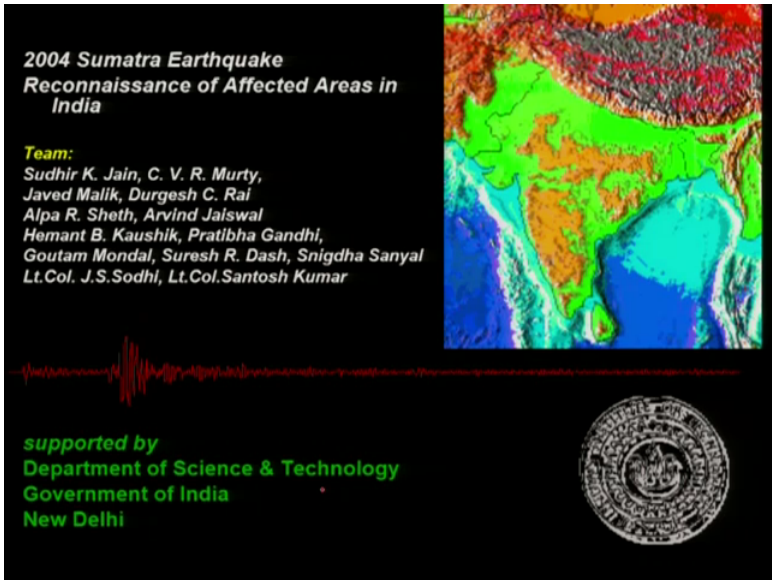


So we had a very good team from here, from IIT Kanpur, we did the survey and we also involved a couple of army officers who were the students with us at Civil engineering department okay.

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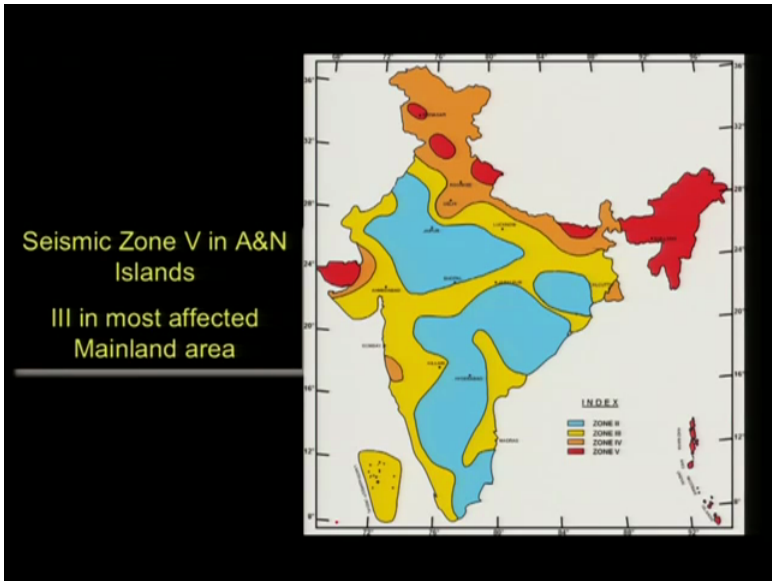


So we conducted a very (regress) reconnaissance survey and looked at the affected area so I will just share couple of slides from there, what we did so we know that this area that is the Andaman region falls under the seismic zone 5, so we had that understanding but we never had an experience of mega Tsunami in recent past okay.

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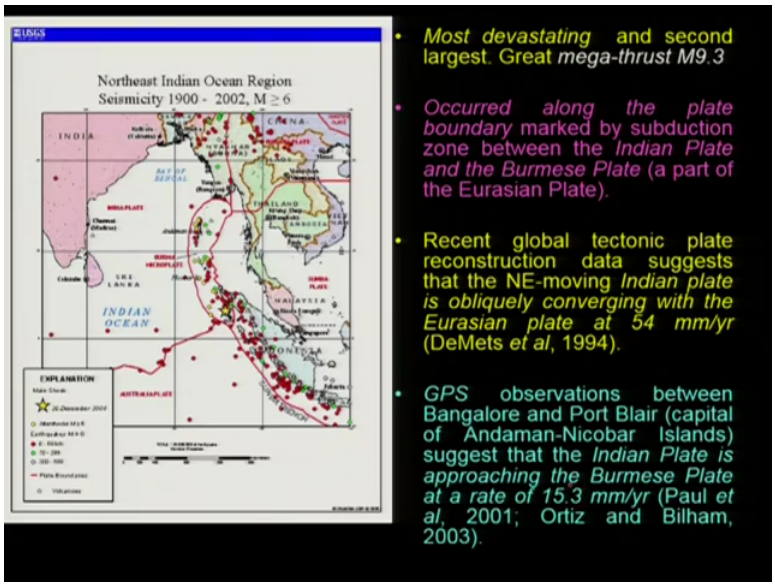

So if you look at the the tectonic setting of Andaman and and Sumatra areas and with respect to the Australian plate or we say the Indian plate, so what we we see is that the Australian Indian plate is subducting or the Burma's micro plate is subducting below the Eurasian plate here okay and that is what has been was responsible for the formation of this and the Andaman, for Sumatra Andaman arc here. So most devastating and second largest earthquake was been triggered with 9.3.

It occurred along the plate boundary marked by subduction zone between Indian plate and Burma's micro plate, a part of the Eurasian plate, a recent global tectonic plate reconstruction data suggest that this area or the plate moves in north, east direction with an velocity of 54 millimeter per year so it is quite fast here okay in this region and GPS observations between Bangalore okay over here and the Andaman islands suggest that the Indian plate is approaching the Burma's plate at the rate of around 53 millimeter per year okay.

So this an total conversions between the 2 plates but if you look at between the 2 micro plates and all that, it is something like 15.3 millimeter still it is quite fast okay.

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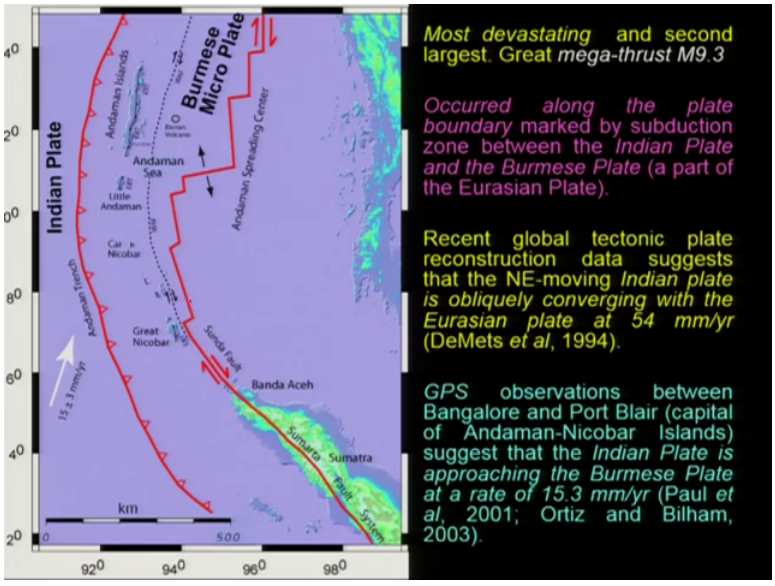


So this the the tectonic configuration of the plate margin, we are having the Andaman trench here and and we have another what we call the Sumatra fault which is at the back on this all area is

the back arc extension which is going on and since we had configuration like one plate is subducting below the another one okay, we have some volcanic eruption so this Barren volcano which is the active volcano in the Indian side so this whole area which is around 1300, 1200 to 1300 kilometers ruptured during 2004 earthquake okay.

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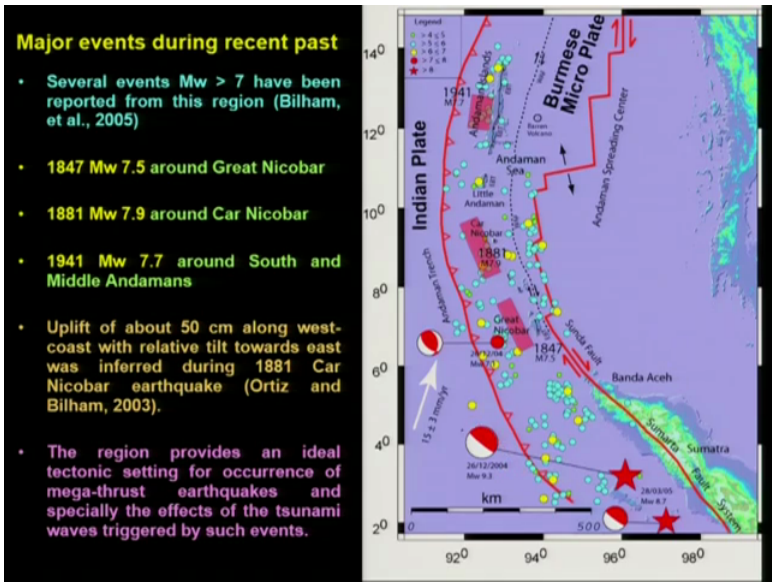


So what happened was that there was this was 2004 earthquake which triggered on the subducting plate or the overriding plate, the epicenter was just on that and then it triggered the complete area and at during that period itself, on the same, after few seconds or may be minutes, there was another earthquake of 7.1 magnitude and then the rupture propagated in this direction and fractured the whole area okay covering 1300 kilometers. Now if you look at this map, it clearly shows that there were couple of large magnitude earthquakes which occurred in 1941, 1881, 1847 within surface area which is marked by pink boxes here okay so this was the only small surface areas or the surface ruptures okay which resulted by which were (resu) ruptured by this earthquakes okay. But compared to this, they were very small but there were signatures of such earthquakes okay.

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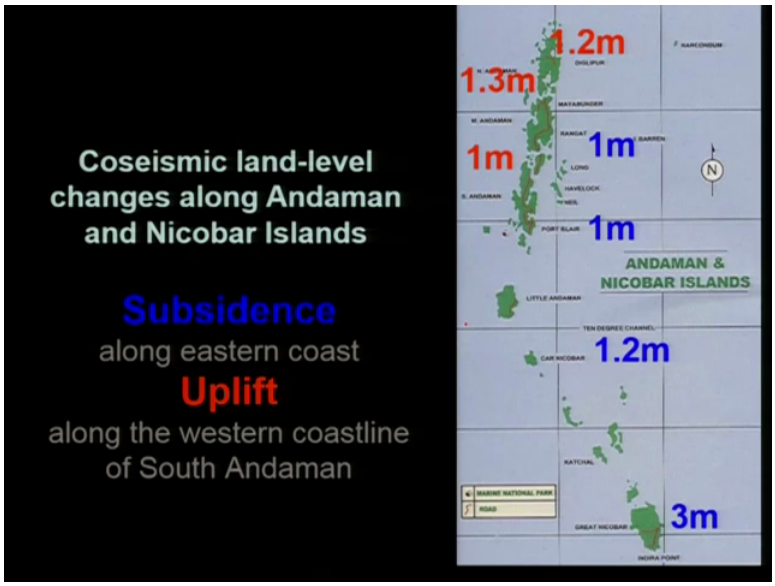


Now what happened in 2001, 2004 if you look at the I will I will start presenting some observations which we made from south and then we will move towards north okay so dramatic land level change took place and what we say co seismic land level changes at the time of seismic event okay so we say co seismic land level changes along Andaman and Nicobar islands okay. So blue ones are shown are here, this numbers are showing the area subsided okay and then this part shows with the shown with the red one, this area uplifted so there was an very typical a tilt which took place okay so there was an the force was from here so this area got tilted okay so there was an tilt here so close to the epicenter, the subsidence was much larger, almost like this is not very close but almost like 300 to 400 kilometers from the epicentral part that is Bandhachi. The area was around subsided by 3 meters and then as we moved further north, the subsidence reduced okay.

So we will stop here and we will continue in the next lecture, thank you so much.