Earthquake Geology: A tool for seismic Hazard Assessment
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Lecture – 55
Earthquake Geology: A tool for seismic Hazard Assessment

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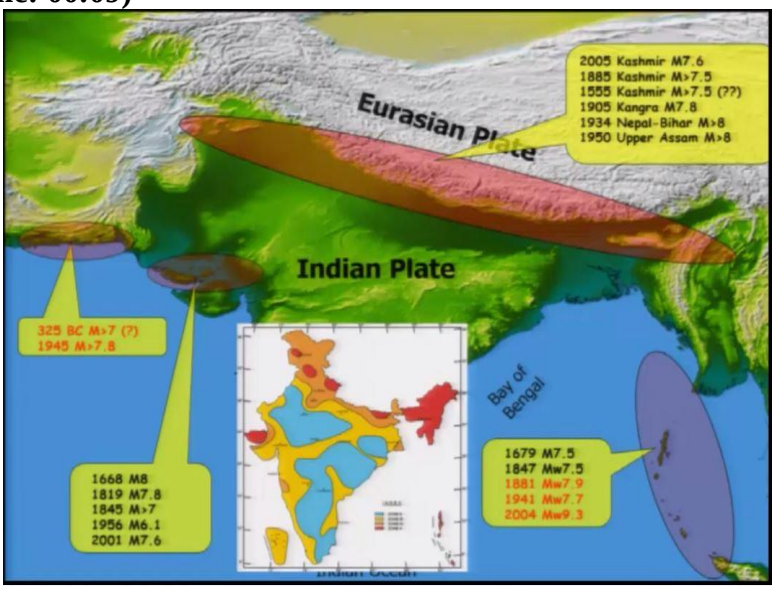

So welcome back as we were discussing about these tsunamis and so if we come back to the and look at the overall scenario of the Indian plate then what we have the seismic zones we have like Himalaya which we have already discussed and when we are talking about the active faults and all that along with that we have almost like more than 7500 kilometers long shoreline which is vulnerable to the tsunamis and the earthquakes triggered by subduction zone.

So one subduction zone we have over here and another one is over here. So other than that we have like earthquakes taking place and catch and based on that what we see is that we have the high risk zone and sitting in zone 5 is Andaman which is because of the and the subduction zone we have here and high seismic zone that is Sumatra Andaman subduction zone and we have few historical events.

Which have been documented in historical chronicals and other than that we have another subduction zone which is going to affect the Indian coast along the west side that is your Gujarat as well as the west coastal mainland India leaves your macron subduction zone which also talks about that there was 2 tsunamis in 325 BC another one 1945.

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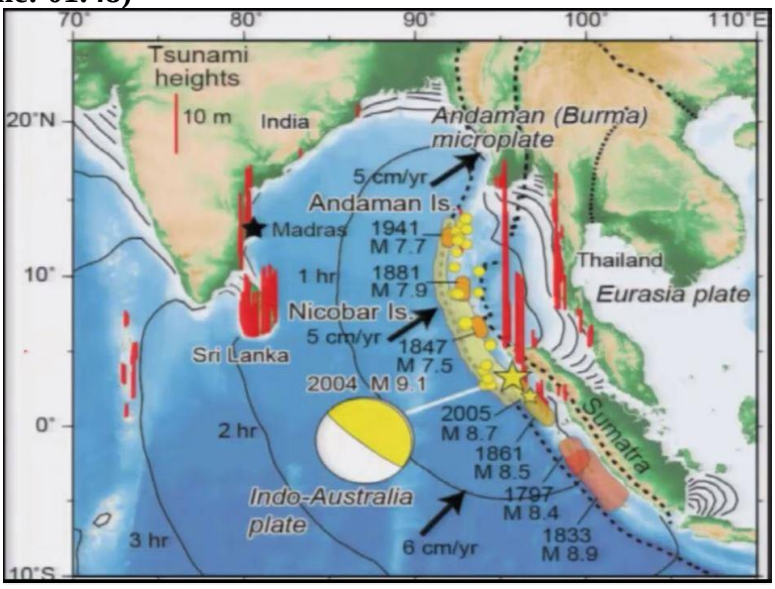

So with this if you look at then how what we observed an experienced in 2004 earthquake of 9.3 or 9.1 at this Andaman Sumatra Andaman earthquake these are all red bars which shows the wave heights which were been recorded, so this bar is 10 meter high. So you can understand that what is the height here.

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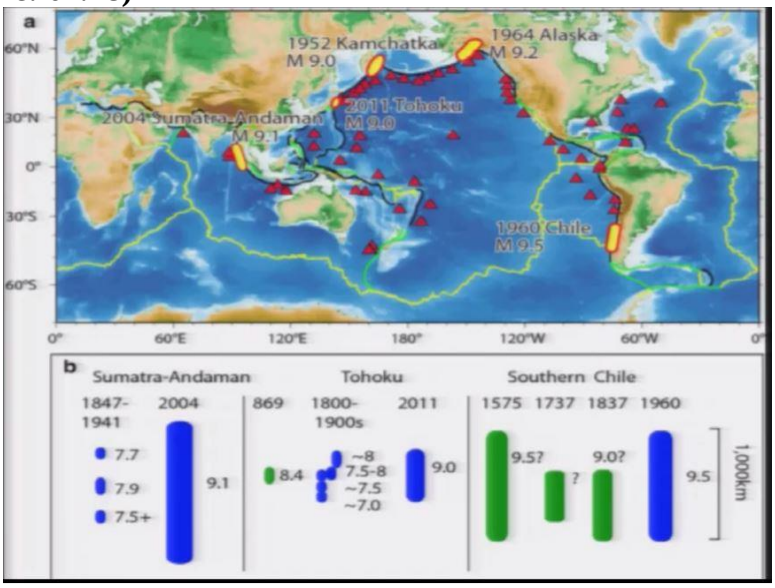

Now the points is that if we compare the rupture length and compare the 3 major or the mega earthquakes so far recorded like we had 1960 the Chilean earthquake 9.5 magnitude and Tohoku at around 9 and 9.3 or 9.1 Sumatra Andaman 2004. So the rupture length here was almost like 1000 kilometers or so but in the case of Tohoku though it was very damaging the rupture length was almost half of what we see here.

This was almost like 1300 kilometers this was 1000 kilometers Chilean earthquake 1960. So this whole area is vulnerable from the tsunamis as well as this zone and then what we have over here that is that your Makran subduction zone.

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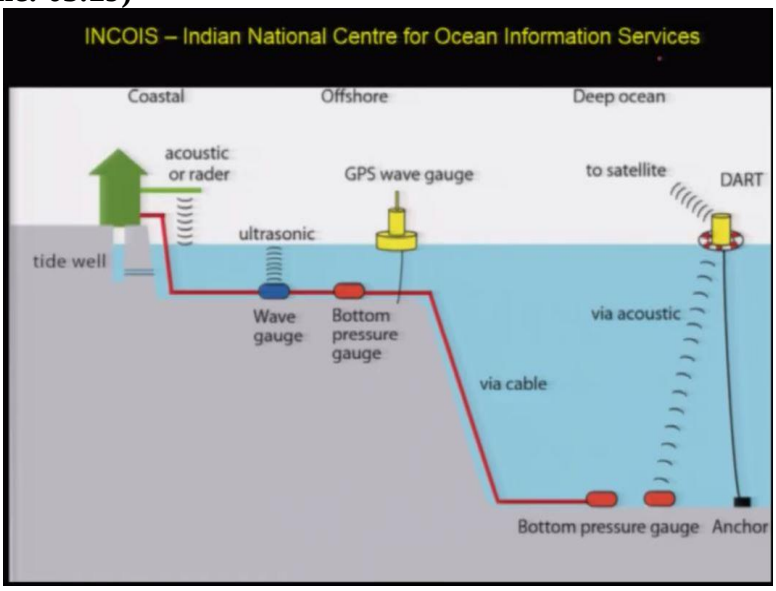

In India after 2004 tsunami ministry of our science and they came up with and the institution or organization known as INCOIS Indian National Center for Ocean Information Services which now gives the information that is early morning if we have a tsunami not only from the Andaman subduction zone or Sumatra Amdaman subduction zone are even from if the tsunami is triggered from Sumatra area. So this is an excellent initiative by the ministry of our science to set up the earth the organization INCOIS which is going to definitely safeguard all of us from by issuing the early warning of any such events.

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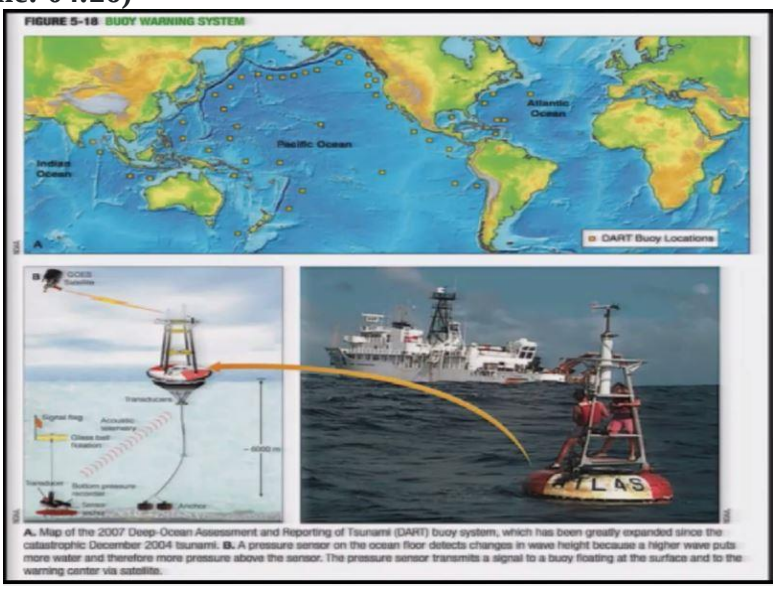

These are the locations of where we have the what we call the deep ocean assessment reporting tsunamis that is DART or Buoy system we have these are the locations of those which will take into consideration the wave heights and all that and they will transmit through the satellite and that will be collected and in particular organisation which will issue the warnings.

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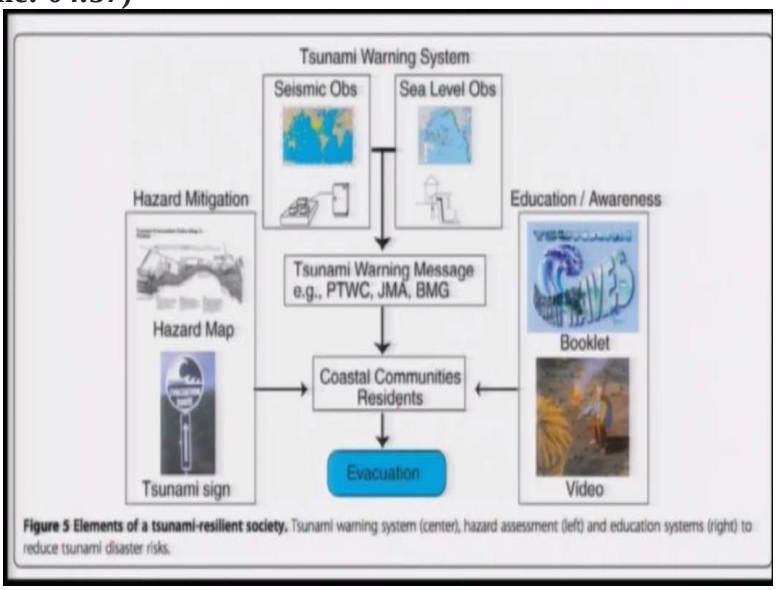

Figure 5 Elements of a tsunami-resilient society. Tsunami warning system (center), hazard assessment (left) and education systems (right) to reduce tsunami disaster risks.

So tsunami warning system how it works is that you have the seismic observations as well as the sea level observations which have been taken into consideration by the instalment of the gauges or the buoys and then with the help of that you issue the tsunami warning to the local agencies and the areas which are vulnerable to the tsunamis then the local this is extremely important.

Because the lot of area is been occupied by the people along the coast the coastal community should be informed and then you should have in proper evacuation plan other than that you need to have the proper tsunami hazard maps for mitigation purpose and also the tsunami signs which shows that which location you need to move on the high grounds to protect yourself.

And also in the in some countries and even now we have started in our own country that we have the education and awareness through the booklets and the native languages and Hindi or maybe in different languages depending on the which the state studying the coastline and then we have these small videos which with the cartoons which helps the local residents.

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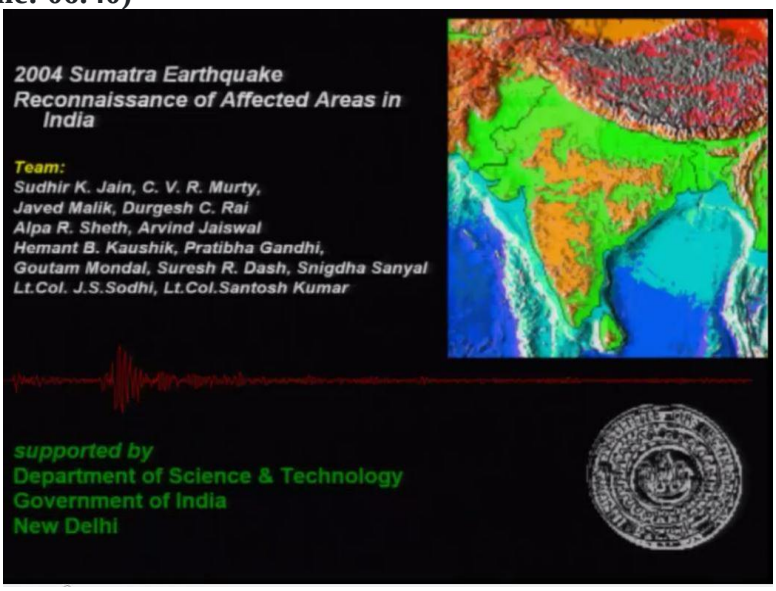

So this was the photograph which we took after the 2004 Sumatra Andaman earthquake and team which was consists was from Heidi Kanpur and 2 of our students who were in army have also joined us for the for this survey. So I will just quickly browse through that what signatures of the tsunami damage we observed after the 2004 Sumatra Andaman earthquake.

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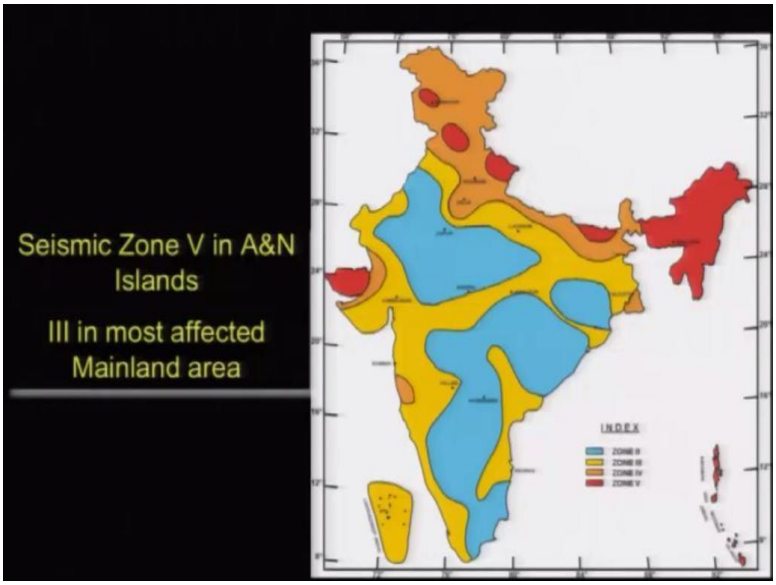

So as we know that our seismic zone vision map in that Andaman sets in zone 5 is highly vulnerable zone because of large magnitude earthquakes experienced in the past and having very active subduction zone which sets here.

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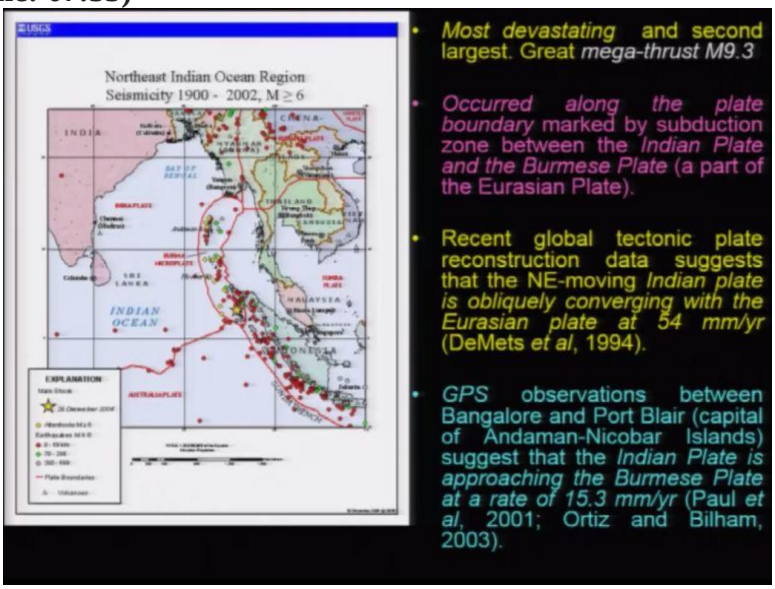

So one of the ideal location to experience or have tsunamis from this region. So this is the subduction zone in which I am talking about Sumatra either you call this is a Sumatra trench or Sumatra Andaman subduction zone.

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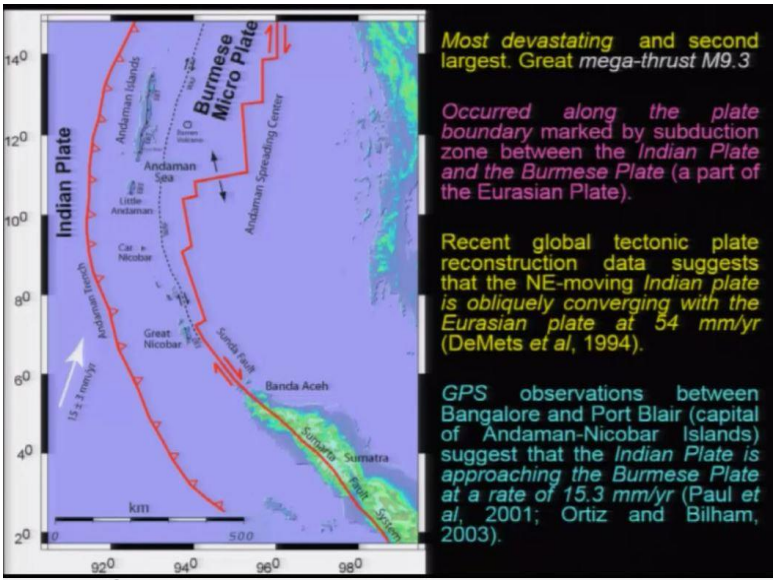

So location of the chain of islands of Andaman and Nicobar. So this is the southern move step. So I will show you what we collected the information moving from this that is South then we move towards north and so not only we are able to see the signature of land level change in terms of subsidence but only but we also looked at the uplift which was been experienced along the west coast of Andaman and subsidence in the east coast of Andaman.

And this locations we found a massive subsidence which ranges up to 3 meters somewhere over here that is the tip of the southern move step of the Andaman and Nicobar Islands and this location marks the Andaman Trench area. So 1300 kilometre was the rupture it started from here go went right to the tip of the northern tip of the Andaman Island.

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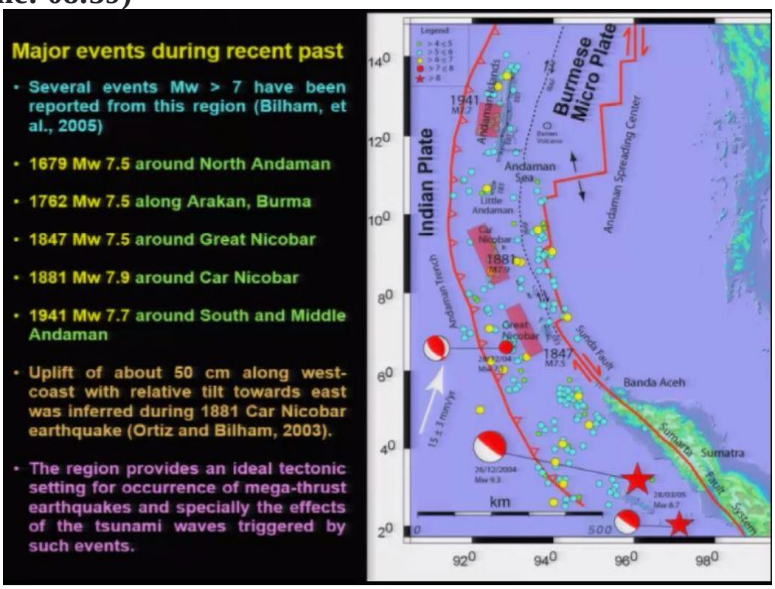

So major events during recent past if you get into the literature then you will find 1679 then 1762 was around Arakan and so Arakan is sitting somewhere over on the top of this over here this is the Arakan zone. So this portion is also quite vulnerable to trigger the tsunamis and which will affect of course the areas which are sitting along the coastline and also the beaches which are sitting touching the Indian Ocean.

So areas along the Indian Ocean are vulnerable to tsunamis not only from the Sumatra trench but also from Sumatra Arakan trench. So these are few earthquakes which are been listed or we have the records from the historical literature and but most of these earthquakes are 7.5. So what we have been able to emphasize in our recent research that we should not like ignore such large magnitude earthquakes also.

So we have these earthquakes from there and then some indications of the land level change was been given that was in 1881 and that was in Car Nicobar that around 50 centimeter uplift was been recorded now, this region is as I told that is one of the ideal region to triggers the mega earthquakes as well as large magnitude earthquakes as well as associated tsunamis.

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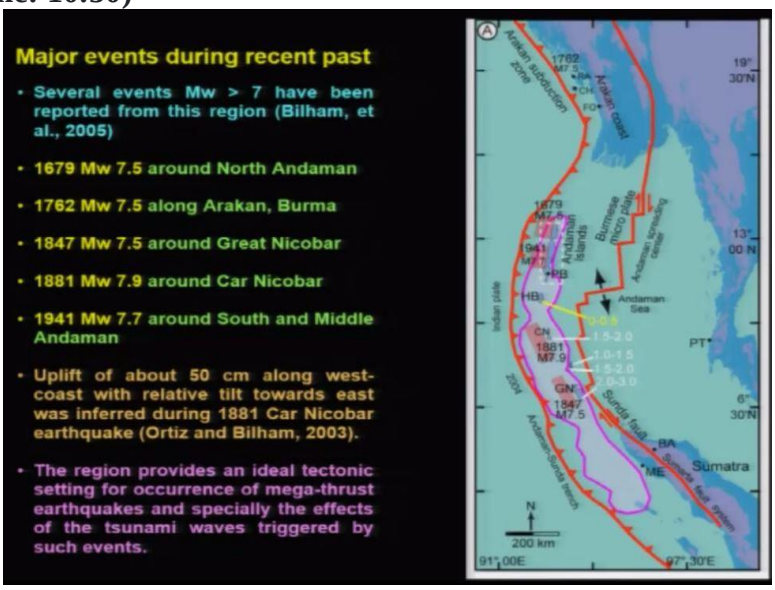

Now as this already I had discussed that we measured the areas in terms of the subsidence and the uplift and that what I would like to present here. So we have the coseismic land level changes along Andaman Nicobar or caused by 2004 Sumatra Andaman earthquake. So the blue letters you know the number shows your subsidence and the reds are indicating the uplift.

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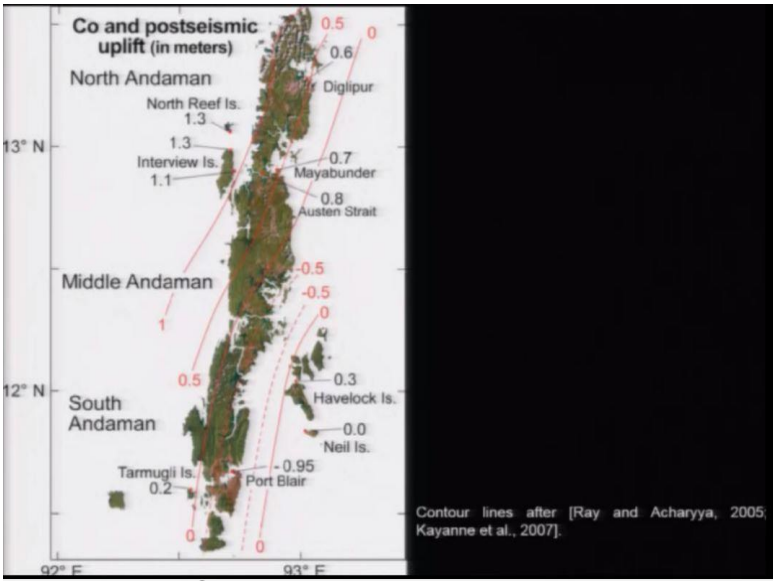

So in particularly the Andaman Island which is one of the largest one in the chain of Andaman Nicobar Island this was this 0 line that is pivot line which did not experience any land level change but so it was suggest sort of an X axis here this got uplifted and this got subsided.

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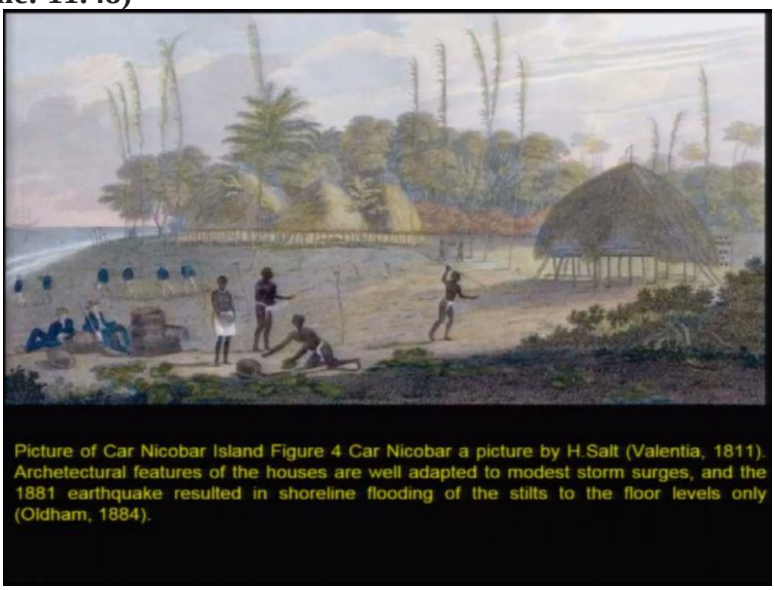

And literature also talks about that the local tribes they have and very good understanding of the tsunamis and usually that is reflected in their the construction of their houses. So they usually have the house is setting much high at higher level from the ground where this the over comes in and goes back but they are not disturb. So they will climb up and then they will sit on the upper floor where they have the main house.

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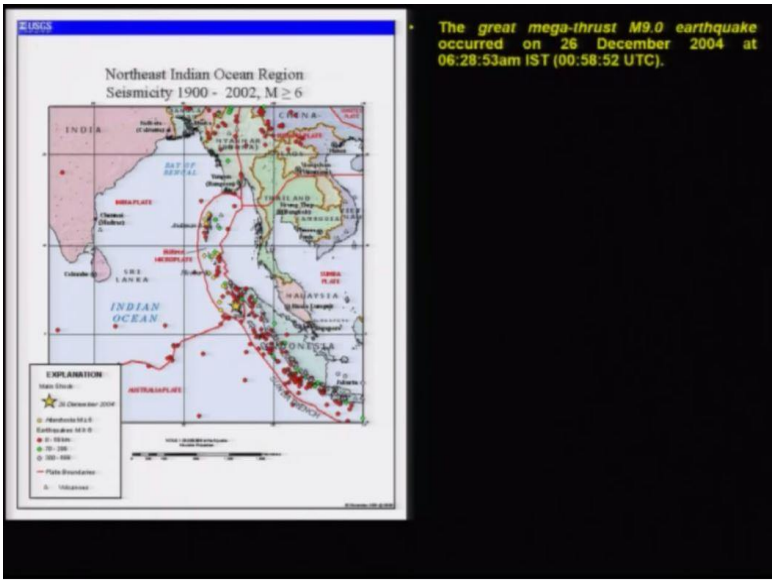

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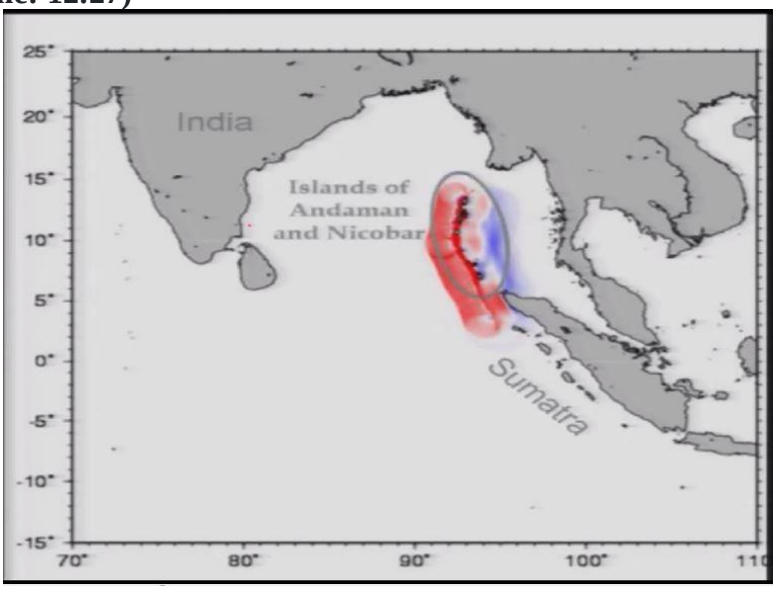

So as this this understanding they have better than the present local people staying the arable. So this was been generated by a model by Professor Kim G Satar key from earthquake Research Institute University of Tokyo and if you carefully watch this then you will be able to see that this is the time which was been given here then and then whole front ruptured and this was the source for the tsunami 1300 kilometers and it took almost like more than an hour to reach the Indian that is the east coast of mainland India.

So I will just play this again and then you can say that almost it took more than an hour almost 2 hours to reach. So we have if we had an understanding of such tsunamis then we could have evacuated people along the east coast where major devastation took place. So now look at looking at the subsidence and uplift in this region of Andaman what we found was

that we started from the great Nicobar that is the Indira point the southernmost tip of the Andaman we observed the subsidence of around 3 meters.

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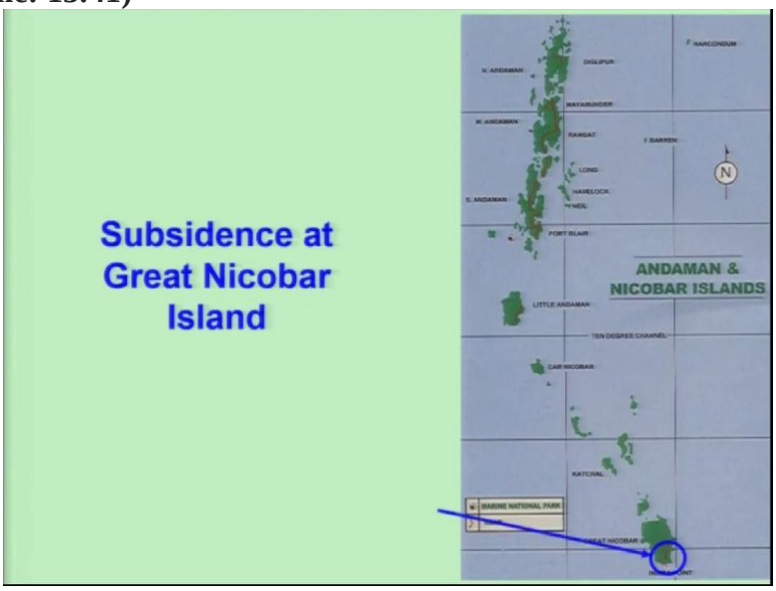

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And this photograph which was been provided to us by coast guard which shows in the beach here and then you have the some huts or the houses here and the watchtower and the next photograph you can see that the huts are been completely wiped off and the beach have started forming further inland as compared to what it used to have somewhere here in the previous photograph. So this suggests not the area subsided and the area of subsidence was almost around 3 meters here.

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And this was the case in that region the coastal regions were subsided and all that and this were the photographs which we the area we surveyed from the coastguard office in Campbell Bay that is great Nicobar where the toll that to informed us not the beach used to be almost like 50 meters from this part but now the area is getting inundated during even during the low tide. So this clearly indicates that there was an subsidence in this area. Now what to getting in even during the low tide?

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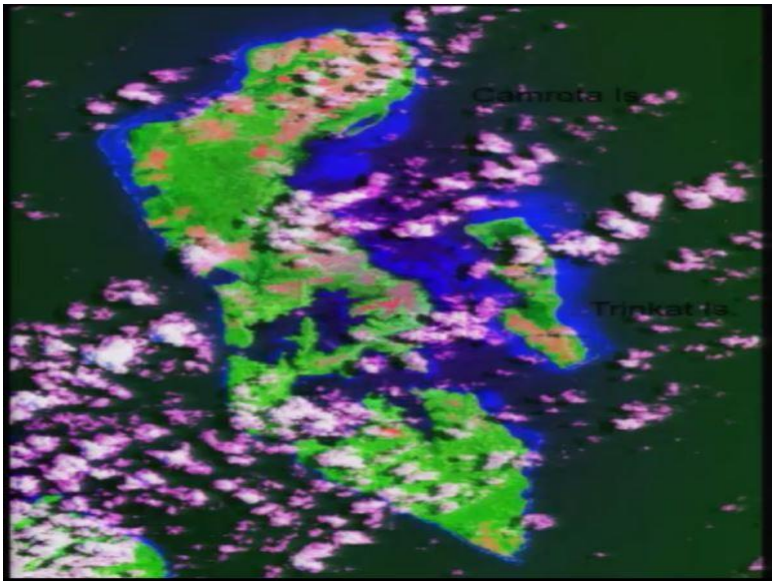

This was the case impact of this a tsunami waves inland and then we heard a story on our way to the Andaman Nicobar that the Trinket island got splitted in 2 islands and then we had a chance to fly over it and then what we identified was that that was merely because of the subsidence and the low-lying area and between the 2 islands where the water spilled over because of the during the tsunami wave and even after the area is get was getting inundated.

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So this is the photograph of the Camrota Island before we get into this one this is the portion here. So we were flying at this location and we found some signature of drowned beach also. So drown shore lines along the Camrota Island.

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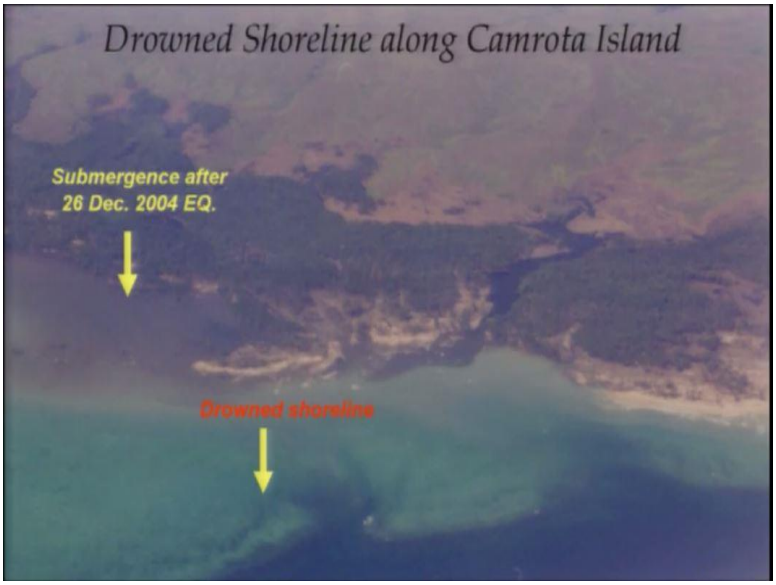

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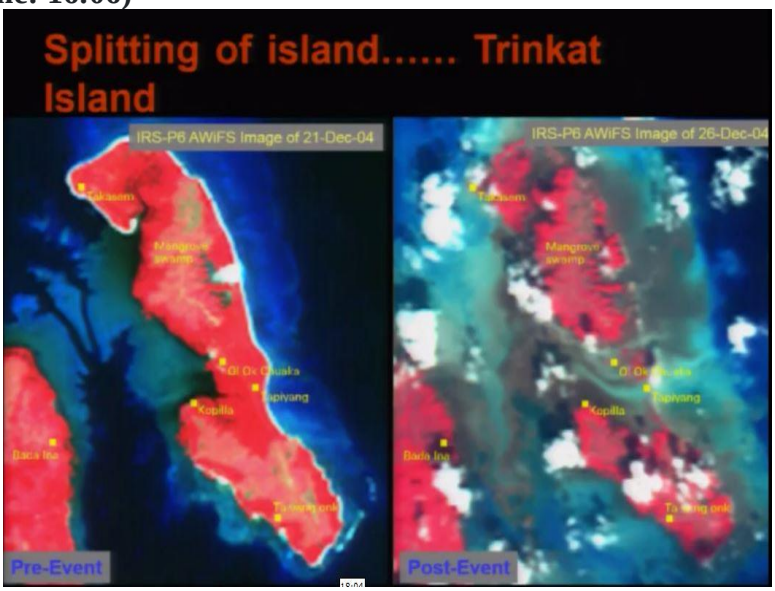

You can see here this is the drowned shoreline and this one which subsided during 2004 and then splitting of the islands if we this is what was been taken by the Indian satellite now it shows that this portion was like it looks like an they got split splitted in 2 but because this is because of the subsidence the area subsided and the low-lying areas were being inundated.

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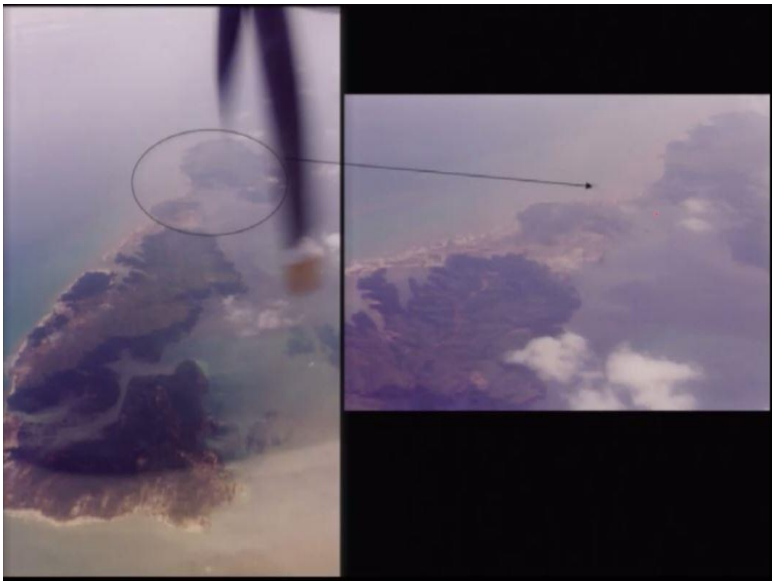

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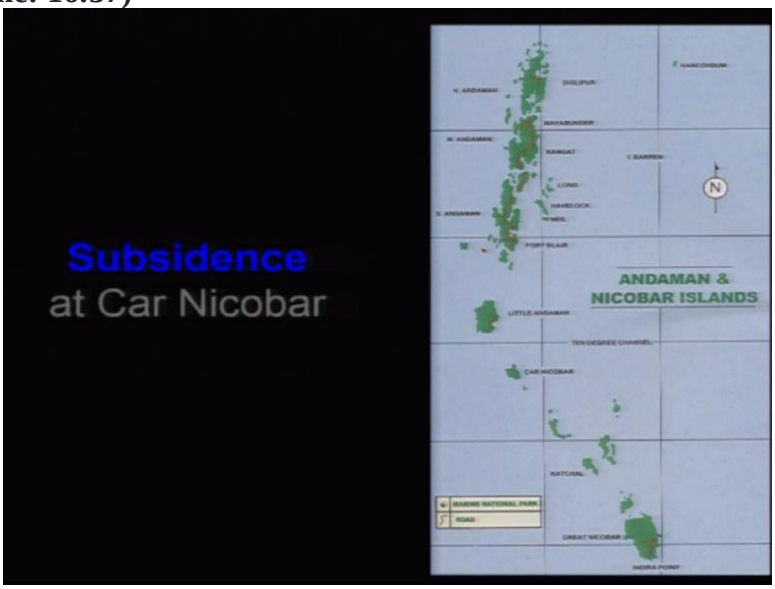

So this is where the photograph which we took aerial photographs which shows the inundation part in the central portion of that they are the Trinket Island now coming to the Car Nicobar here.

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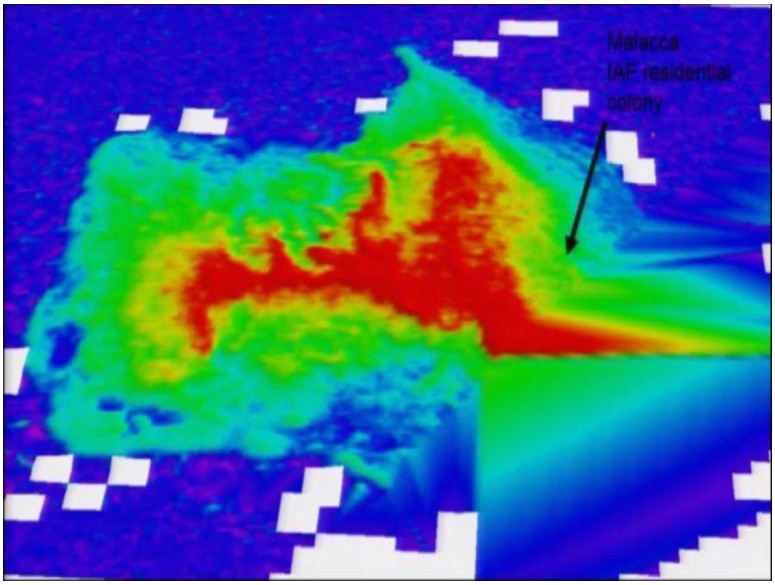

The subsidence was almost like 1.5 meters or so now this Island is extremely beautiful and the height is not much in terms of the elevation the hills are not very high and very flat topography here wonderful beach and this whole area is been occupied that is this is towards the east eastern coast this whole area has been occupied by the Indian air force residential colony and we have the air strippers also here.

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So this is what you see here is the air strip and this whole area is having an wonderful beach and the residential area but this whole portion was affected by the tsunami and devastated the in the region and this area got subsided by almost like 1 to 1.5 meter or 2 meters.

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At some places so a few structures survived like the water tank here because of its the structural pattern circular in shape you know, so the energy called disseminated here and this got survived but most of the houses were been swapped off one because of the earthquake ground shaking and then because of the tsunami.

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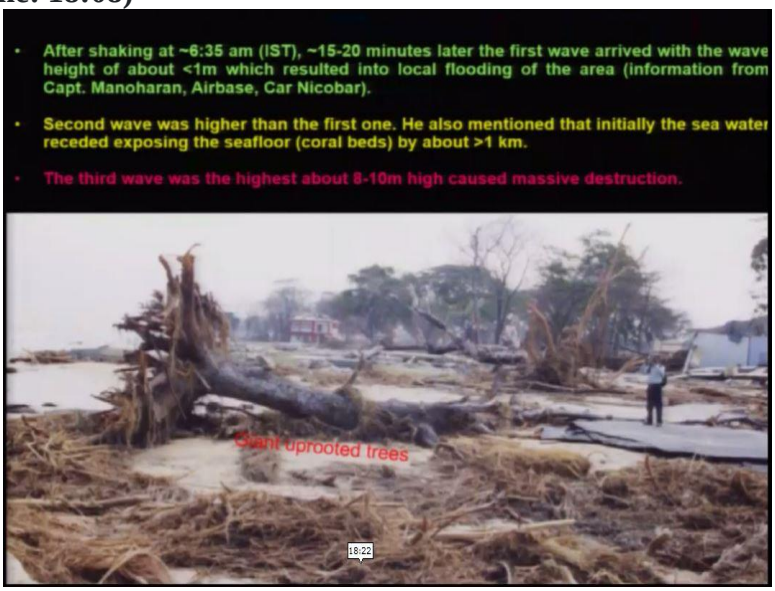

So the giant trees were not been uprooted and when we spoke to the survivors captain Monahan he told us that the half of the shaking was around at around 6:35 am. And after at 15 to 30 minutes later the first wave arrived with the wave height of around 1 meter but then we realized that this was the inundation was just because of the subsidence because the area subsided during an earthquake and the water inundated the region. So the second wave was higher and then that what he told but that the second wave was actually the tsunami wave.

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And then the third wave was much higher which was marked by the height almost like 8 to 10 meters and this we were able to observe record from the signatures of the water level and the cloths and the day breeze which were sitting upon the only four windows of the first floor. So it carried and deposited sand in this area and also the course at coral fragments you can see here the fish dead fish fresh lying on the floor of beach.

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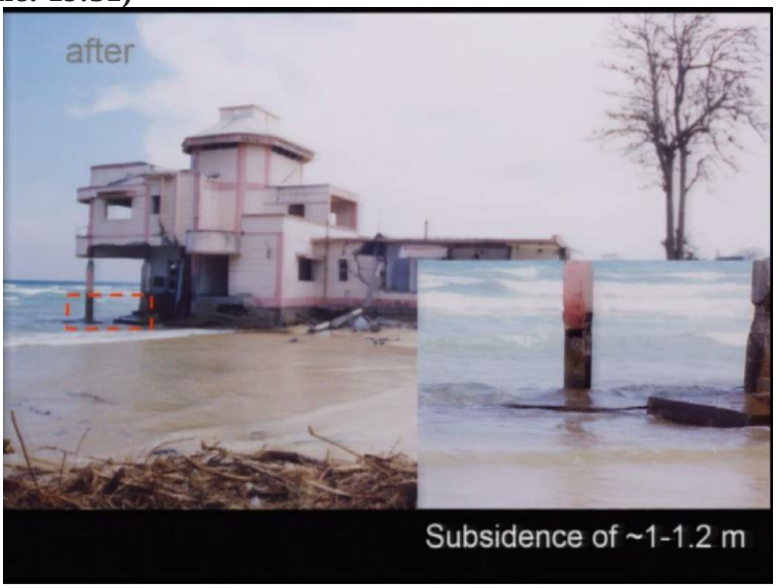

And this photograph which I was showing earlier so this used to have almost 100 meter wide beach here but now the sits and this is an inspection bungalow. So these 2 have meetings here and parties here but now the sets and water should not have been the ideal place no one will construct the and the inspection bungalow or a residential bungalow sitting in water. So the subsidence was almost like around 1 to 1.2 meters in this region.

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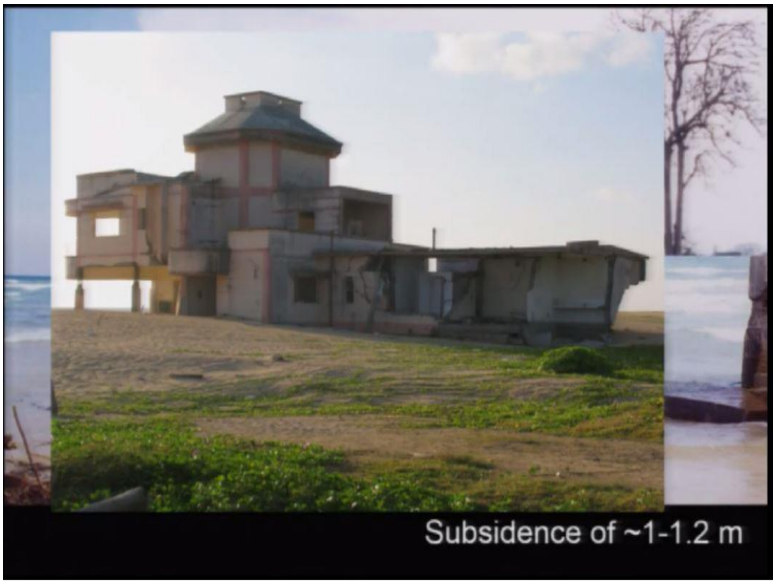

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And this is the feature which I have already discussed now what we have the formation of beach ridge and this photograph was taken in 2009-10 after the so the environment get changed because of the subsidence and some location the environment got change because of the uplift. So if you look at this window here of the first floor and the top 10 shed then you can easily make out and the wave height would have remained up to this which blown off the top of the of this apartment. And the windows shows the cloths which are hanging here at the top. So height was almost like we can make out and it was more than 7 meters.

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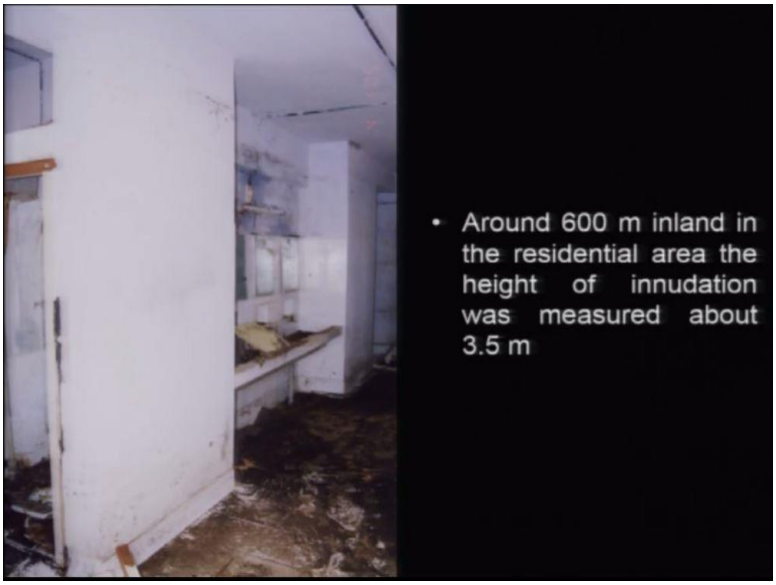

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Second markers we found was the inundation watermarks here in most of the houses and the height was almost like 3.5 meter here from round. What happened was the first wave when it came in of 1 meter then people moved on the first floor thinking that this is because of the inundation but, the tsunami wave was much higher than this one and then it wiped most of the people here and some of them the ran on the high grounds were and they survived.

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So this is because of the return wave which went back and the airport was also full of the day breeze and even can see the TV television here and the water tanks not water tanks these are all oil tanks which were quite heavy but we have been transported by the tsunami waves.

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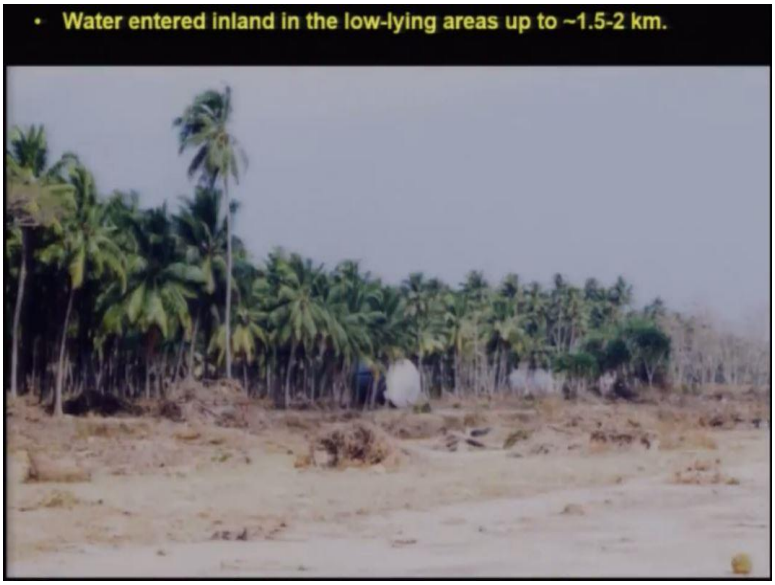

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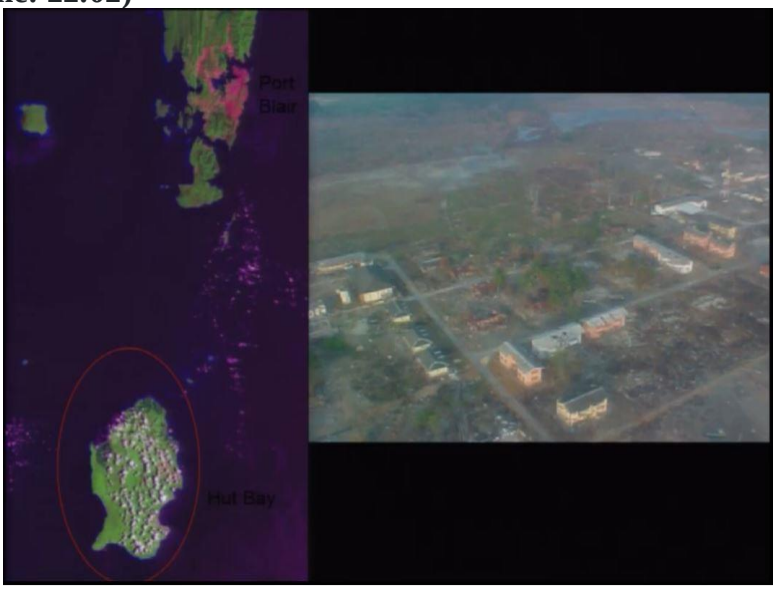

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Way inland from the coast now another this is a hot day so we are slowly moving from south to north it was extensive damage was experienced in this region also and again similar features of bending of the fan wings because of the return wave and most of the walls were had been broken. So you can understand that amount of energy and to say because of the tsunami and then we also looked at the signatures of the waves which came in multiple waves.

So we can judge the height of different waves from this so for 1 wave is around 1.5 meter from this floor. So if you calculate from the mean sea level then it will be much higher than this one and second one is around 2 meters or so from the floor of the house.

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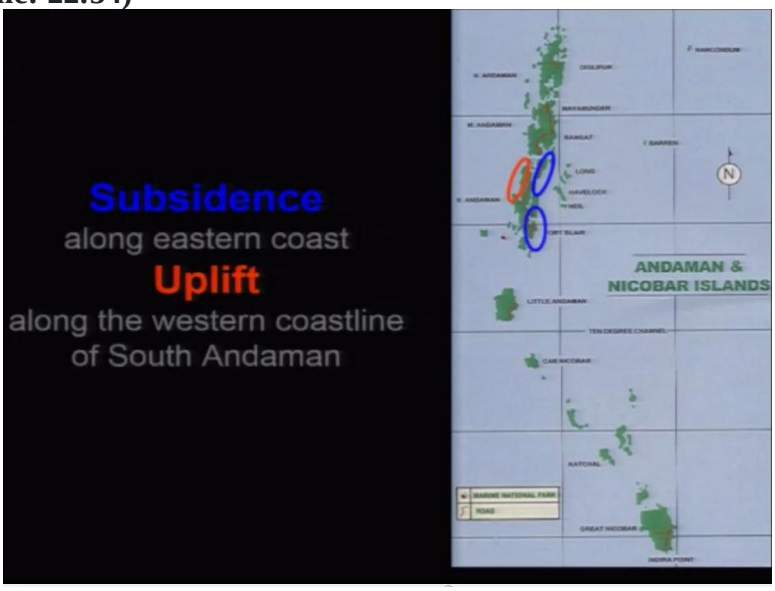

And then coming to another one here what we found the uplift and then and the subsidence on the east coast and the uplift on the west coast. So I will just quickly show you some aerial photographs and the ground photographs from this region.

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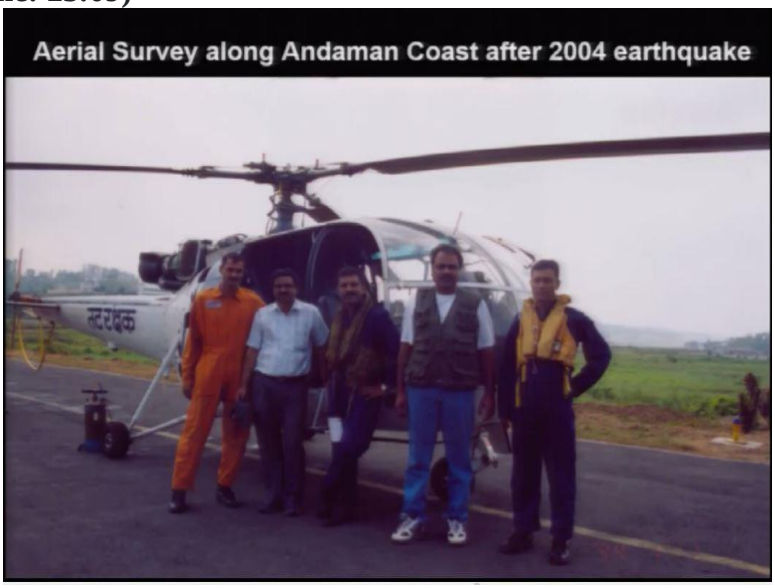

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So we took help of the coast guard and we flew in the helicopter as well as we also use an small airplane to conduct this survey so this what we found along the west coast. So this was before and this is after so the area got uplifted here and got exposed.

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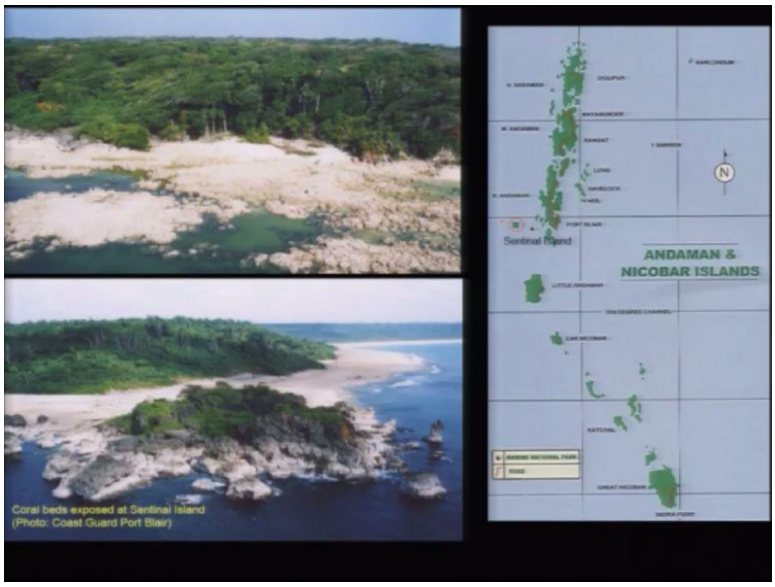

And coming to this portion here that is the Sentinel island no one tries to go here because this whole island is been occupied by the tribes local tribes and the photographs which have been provided to us we have from coast guard so what we found here is that there are many coral platforms for the terraces which are indicative of past uplift during major earthquakes.

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So Sentinel Islands no one tried to goes and this photograph again was been taken by coast guard at the local tribe holding in bow and almost like 2 meters and trying to aim the helicopter here.

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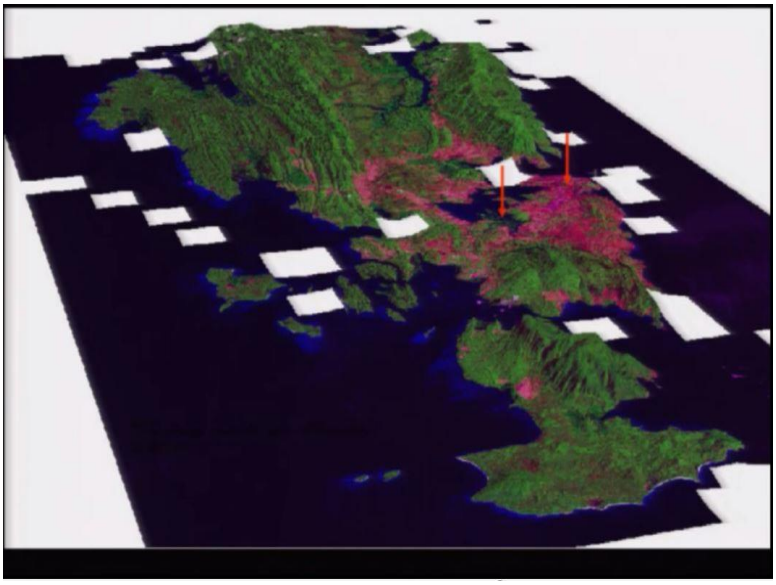

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Then coming to this portion that is your Port Blair and Sipcot the Port Blair area and the Sipcot area close to that subsided but during so this is this falls on the on the east coast of Andaman island the subsidence was almost around 1 meter this area was famous for the its yield for paddy man.

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And how on the settlement so now nobody is interested in buying houses here because the area is getting inundated because of the subsidence in this region so this is an (())(24:58). So if you look at this one here. So this whole plantation now sits in water and then local administration they understood that this is not the temporary solution or the temporary inundation for initially they thought of that the tsunami wave came in and got inundated the area but now, they later on they realize that this is the permanent thing which is going to happen. So they raise that what the road heights to provide the proper transport to local people.

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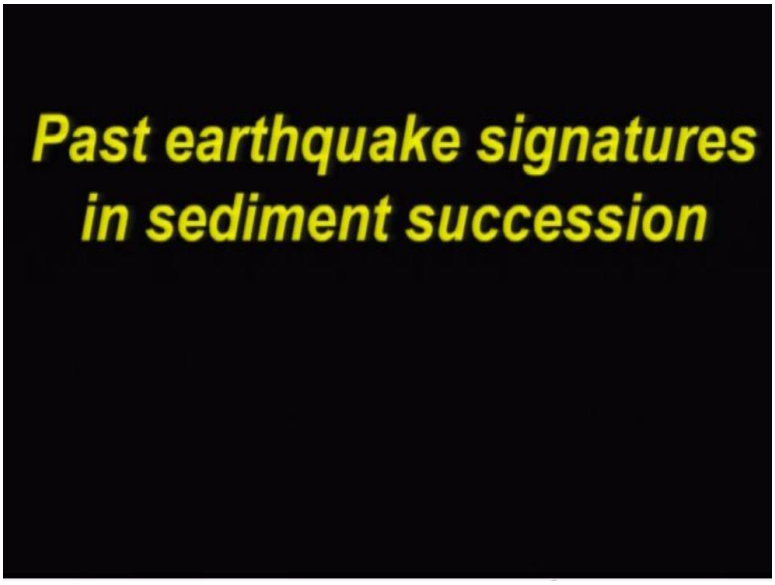

So this is what it should be shown here so this was been raised by almost 1.5 to 2 meters. So subsidence was observed at different other places also along the east coast now past earthquake signatures and sediment succession usually we tried to look for that.

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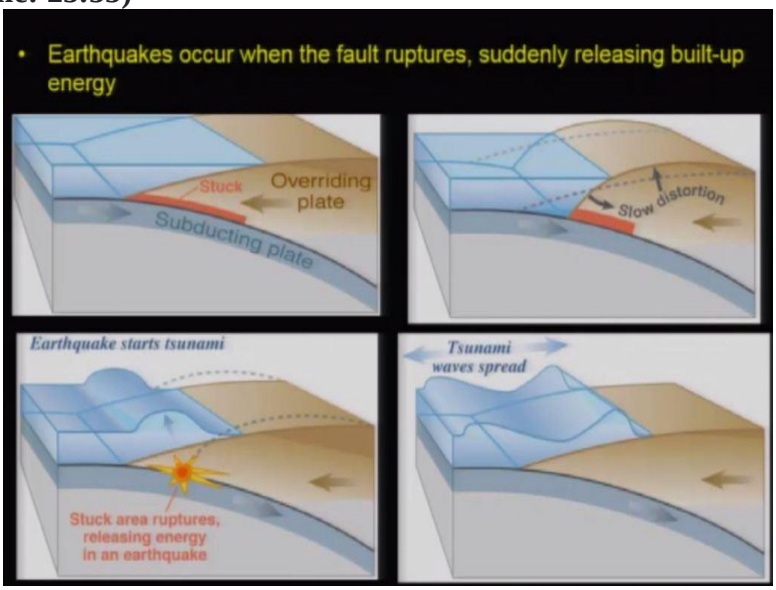

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So the earthquake occurs when this we have already discussed so we will just move ahead so keeping this in mind we started hunting for tsunamis preserved in sediment sections around Badabalu this one of the best signatures the location where we found the signatures of at least 7 tsunamis from south east coast of Andaman. So Badabalu is a wonderful beach located south of Port Blair who had not many people visit.

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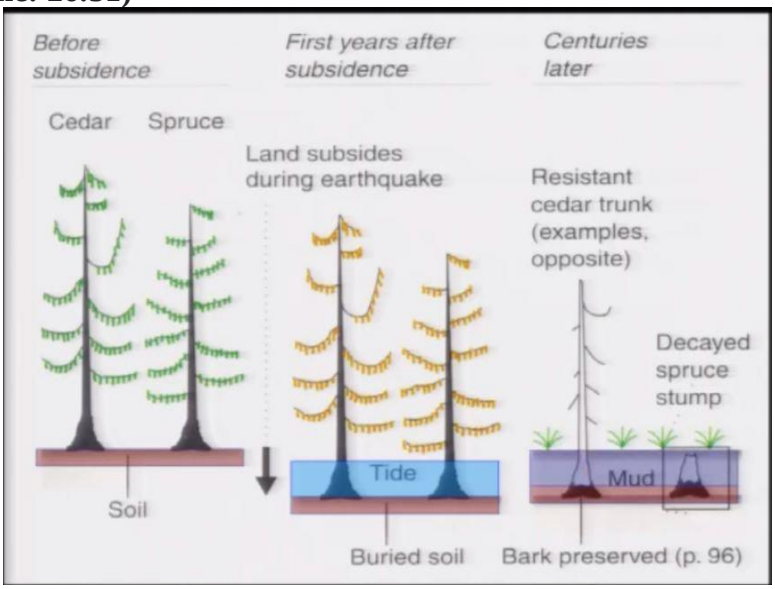

But now people have started visiting it after the event so if we reconsider this and then that if you have a soil and then earlier you had in the vegetation here and during subsidence the land level went down and this whole area started getting inundated and because of the increase in salinity from because of the inundation of the ocean water this will die and so we will see some remnants of the trunks of the trees and or we can say that the dead forest appear. So this

is because of the inundation and further we have the deposition coming in and then new surface evolves here.

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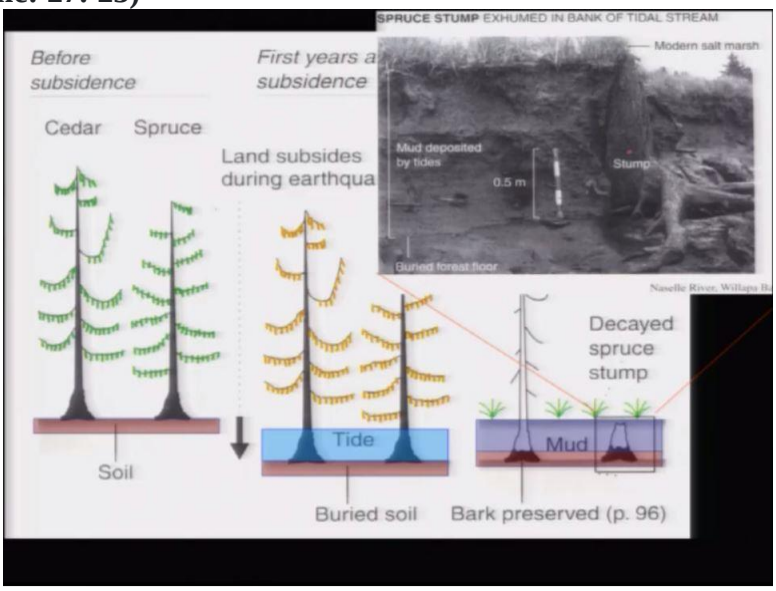

So if you look at this signature how it looks like this is from Phillipa Bay from US which shows the preservation of the trunk of the tree which died because of the subsidence in this region. So such examples of the signatures we try to look at if possible if they are preserved they remain result in the disagreement succession.

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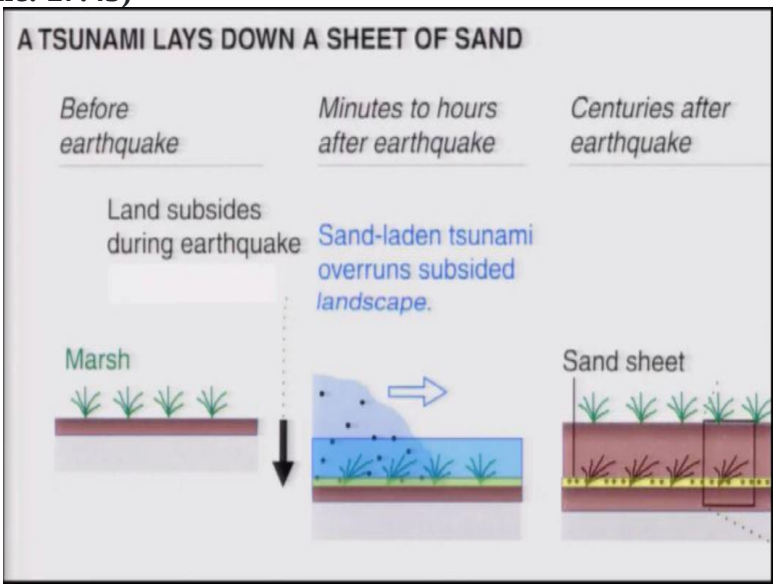

Another part is that we look at if we see the sediments getting preserved which we have been drought or transported during the tsunami for this part which we were talking about in the previous one of the previous slide that we are having the marsh area and then it gets subside then the sediments which were in drought or transported during the tsunami will get

preserved I mean dick this section you will be able to see the deposits that is your sand sheets.

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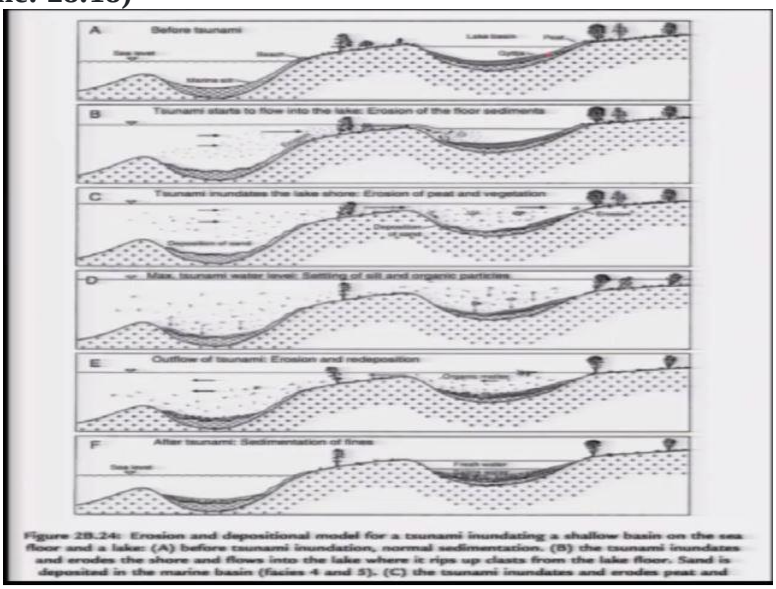

Figure 28.24: Erosion and depositional model for a tsunami inundating a shallow basin on the sea floor and a lake: (A) before tsunami inundation, normal sedimentation. (B) the tsunami inundates and erodes the shore and flows into the lake where it rips up clasts from the lake floor. Sand is deposited in the marine basin (facies 4 and 5). (C) the tsunami inundates and erodes peat and

Most of the big areas will be before we start looking hunting for the tsunami we try to look at the areas which are having a topography which is shown here like we have this the beach ridge and then we have swell beach ridge well so most of the time. What happens that if you have not tsunami then this portion or the sediments from this will get it ordered of course the tsunami will also carry that the power sediments from the deeper portion of the ocean and along with that it will also carry the organisms.

So the fossils which we find in the deposits are also an good indicator of the sediments we have been deposited by tsunami because otherwise in case of the storm also the strong can carry the sediments and deposit tunnel along the coastline so to differentiate that we use and one of the proxy like the valiant logical studies of micro fossils and mainly for many far are we use to understand because they grow or they live at the deeper ocean depths. So that helps and then since we have we see the depression here see so most of the sediments which are eroded from this one will fail will get deposited in this area.

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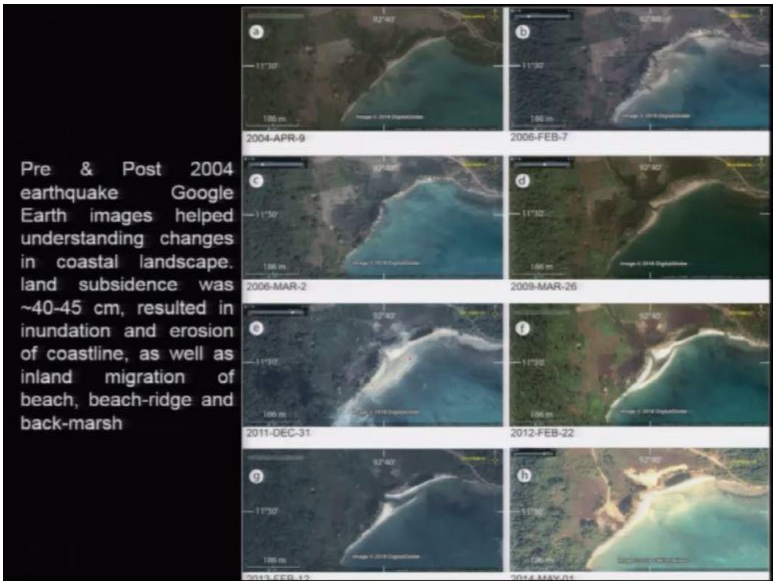

So we were lucky enough to look at the previous images that we from different time before 2004 and then after 2004 and then we were able to pick up from Badabalu at how the landscape got affected because of the subsidence and the wave action from the tsunami which was triggered by 2004 Sumatra Andaman earthquake.

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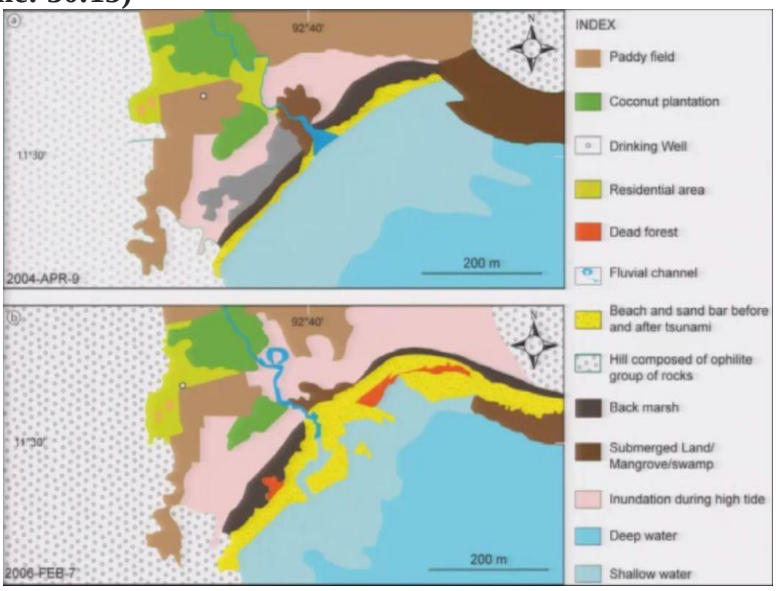

And this is the comparison here so because of the subsidence so before that the beach used to be here which is marked in yellow but after subsidence it inundated the whole area were here was affected because of the subsidence and then what we found was that the back mark back marsh behind the beach which used to be here but now it is seen further inland so if there is a change in the environment in past events also we can be able to pick up this.

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So we also found some dead trees and dead forest and uprooted trees due to subsidence and due to the massive erosion by 2004 tsunami and all indication of that so beach used to be here but now the beach and the beach resist moved towards land. So local people have artificially filled the area to protect the inundation and safeguard their agricultural features. So this is what it shows that the landfill was almost like 1 meter they did in this area.

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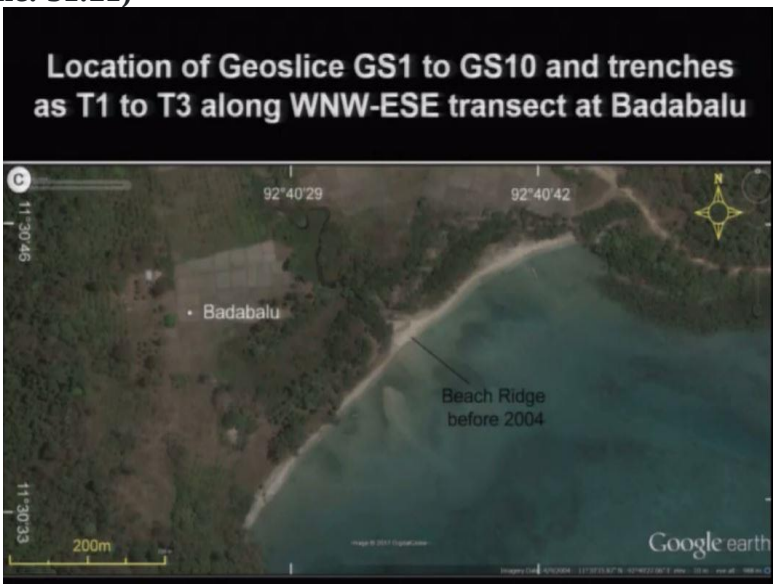

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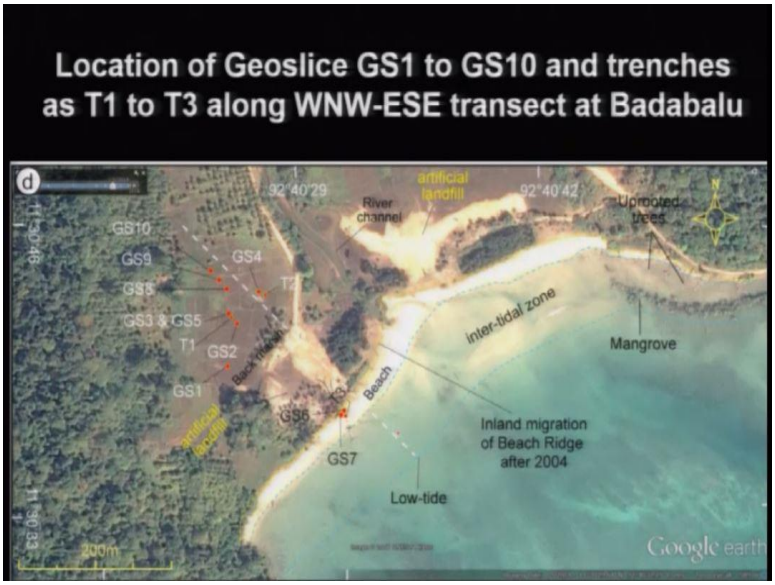

So location of the Geoslices we took these sections from this area we also open up small pits and then we also took the topographic profile to mark the and how much amount of land level change has taken place in our took place along this because of 2004 earthquake.

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So we used pits and then if you carefully see this part here this is the 2004 tsunami sand preserved in the sediment section. So these are the trench photographs which will be taken from the area around Badabalu. So we based on the grain size the colour and the contact we demarcated the units. So these are the different units which we marked this soft sediment layers and we also collected samples for sand and charcoal to be dated which helps us in bracketing the events.

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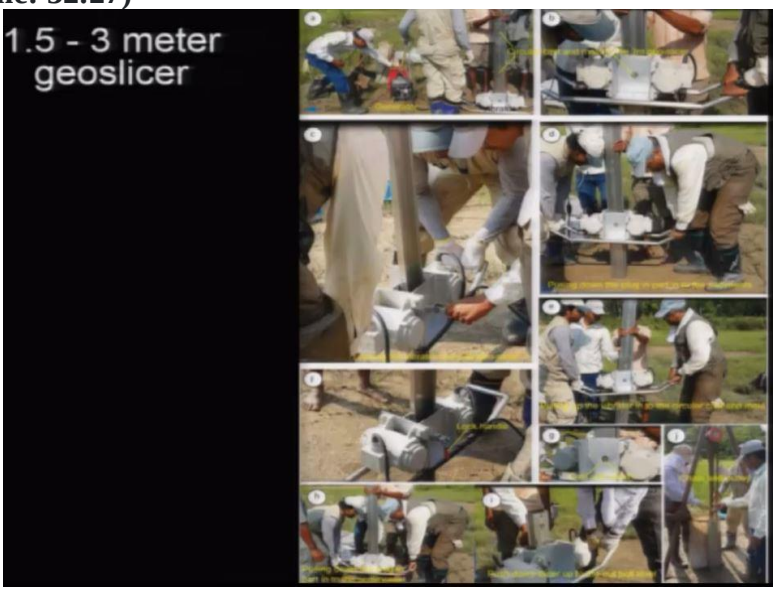

And this was the geo slice which geo slicer which we use to take this section up to 3 meters. So these are this is well connected with the generator here and that is we are putting inside the surface and then and finally collecting the section here.

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So a lot of hard work and then finally what we see is the section coming in and then we also peel up this and preserve in our lab to have the library of the sections. So this is how it looks like and this is 2004 here and this was the previous soil of 2004 and on the tsunami sands at here.

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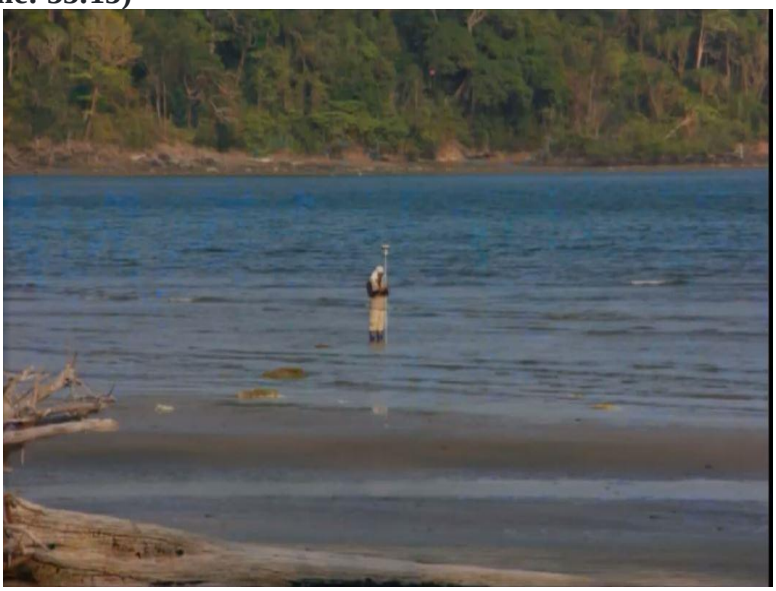

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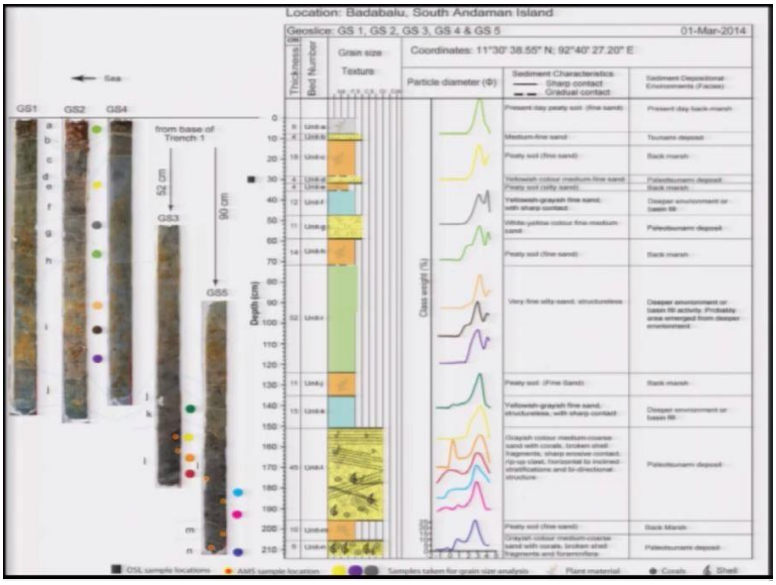

This we are doing total station studies took the topography profile and then and detail logging and then in lab we also did particle size the grain size analysis and most of the tsunami shows by distribution by modern distribution because they are not well sorted they show the mixing of the difference in size.

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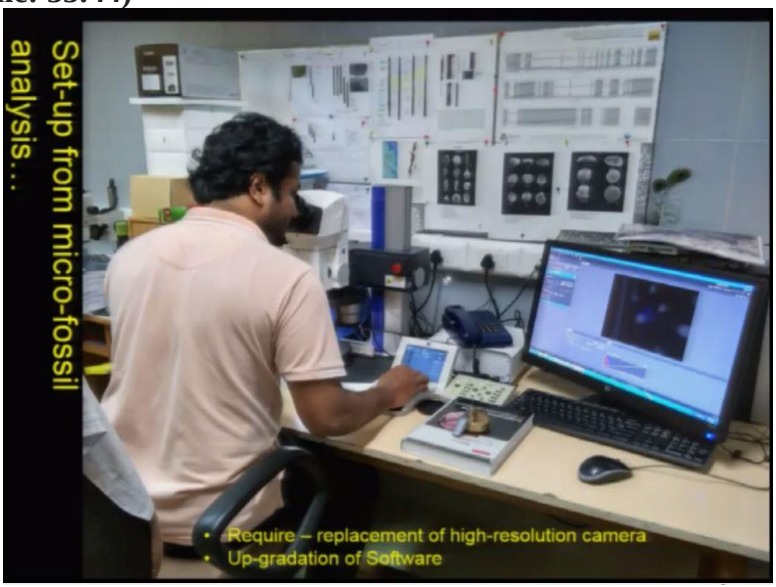

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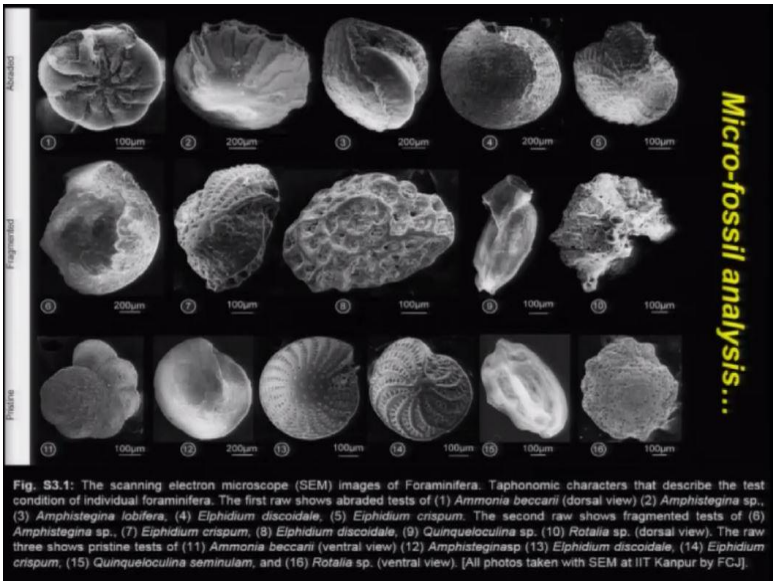

Fig. S3.1: The scanning electron microscope (SEM) images of Foraminifera. Taphonomic characters that describe the test condition of individual foraminifera. The first raw shows abraded tests of (1) *Ammonia beccarii* (dorsal view) (2) *Amphistegina* sp., (3) *Amphistegina lobifera*, (4) *Elphidium discoidale*, (5) *Eiphidium crispum*. The second raw shows fragmented tests of (6) *Amphistegina* sp., (7) *Eiphidium crispum*, (8) *Elphidium discoidale*, (9) *Quinqueloculina* sp. (10) *Rotalia* sp. (dorsal view). The raw three shows pristine tests of (11) *Ammonia beccarii* (ventral view) (12) *Amphisteginasp* (13) *Elphidium discoidale*, (14) *Eiphidium crispum*, (15) *Quinqueloculina seminulam*, and (16) *Rotalia* sp. (ventral view). [All photos taken with SEM at IIT Kanpur by FCJ].

And we also took help from the (())(33:47) studies mainly we did micro fossils lab and we and these are the micro forces which helped us and justifying that the sediments will been carried from the deeper part of the ocean and deposited along the coast.

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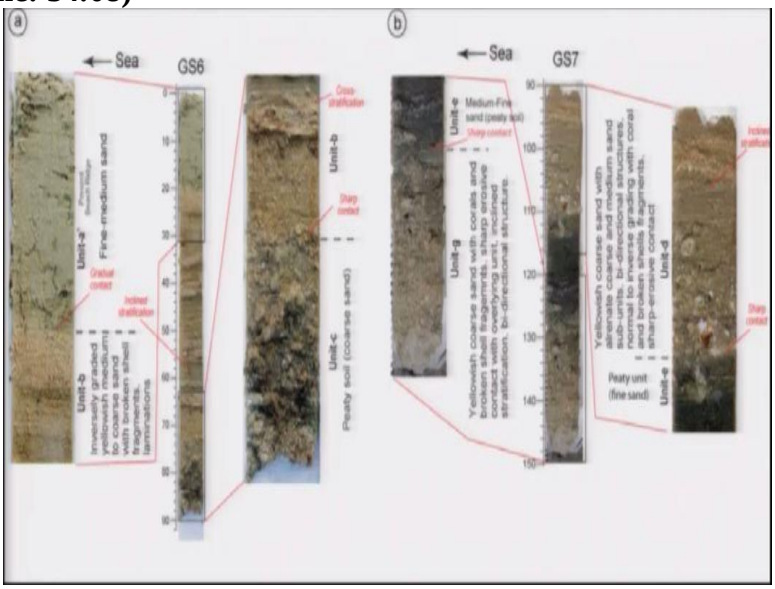

So if you look at the close-up of this then what we see here is the blackish layer that is your peat and on the top of this we see the tsunami sand and tsunamis and also the deposits also we are not very well sorted they are poorly sorted and shows the inclination or the incline stratification sharp contact with the underlying units and all that. So those things we took into consideration to identify the tsunami deposits the normal storm deposits again.

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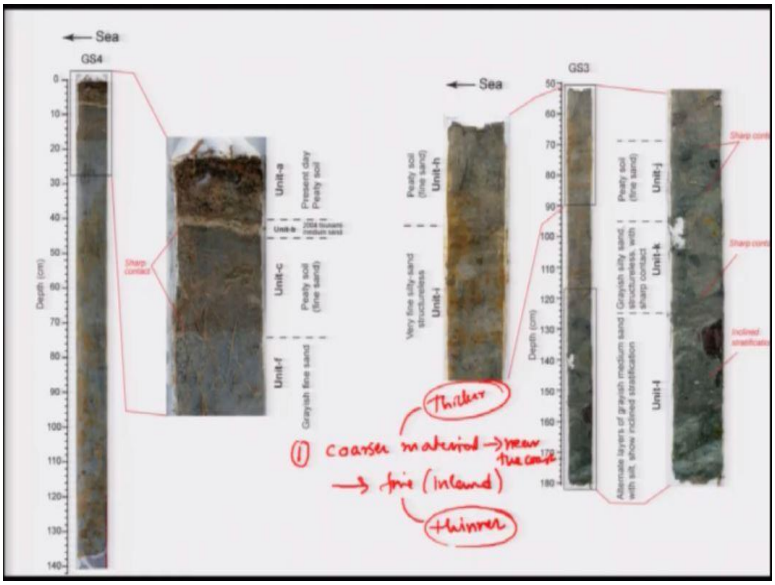

The very sharp contact here and the very thin sediment layer here of medium sand and one thing which you should remember is that the grain size of the tsunamis and will reduce us. So you will have the coarser material near the coast and if you move further inland then you will it will become finer. So this will be near the coast it will be have coarser and thicker and inland it will become finer and thinner.

So this is we are talking about the thickness so it will be we will see a thicker section here so this is close to the coast. So we see coarser and thicker and as we move inland then we found that they are becoming thinner. So they will the sediments will pinch out because the carrying capacity or the energy conditions changes.

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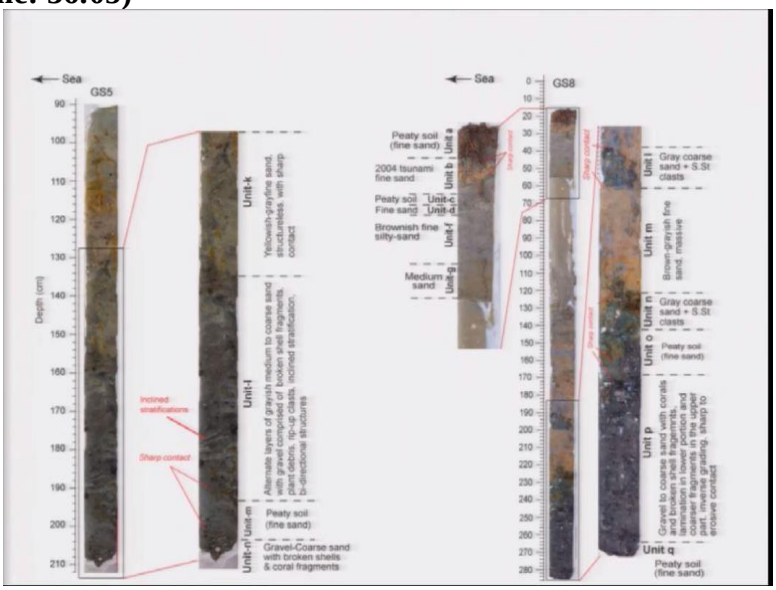

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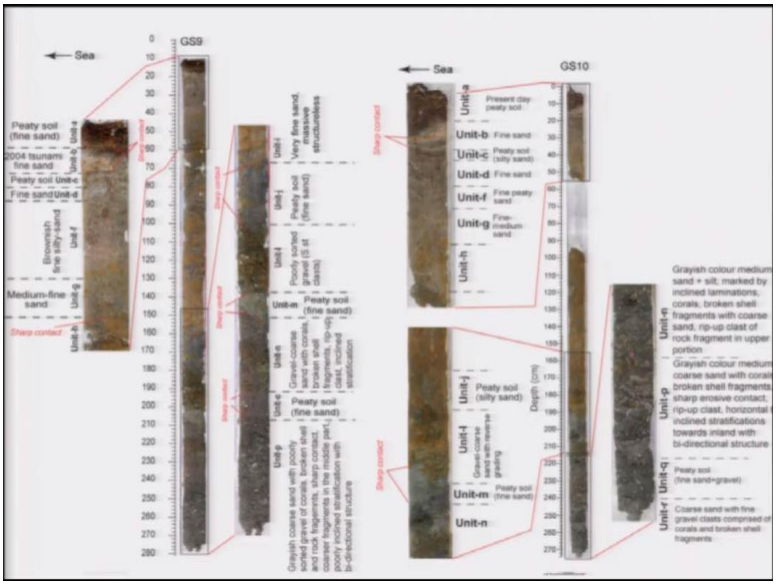

So these are a few more examples and based on this what we did was we collected the different samples from different units and we tried to bracket it and interpreted our whole sections.

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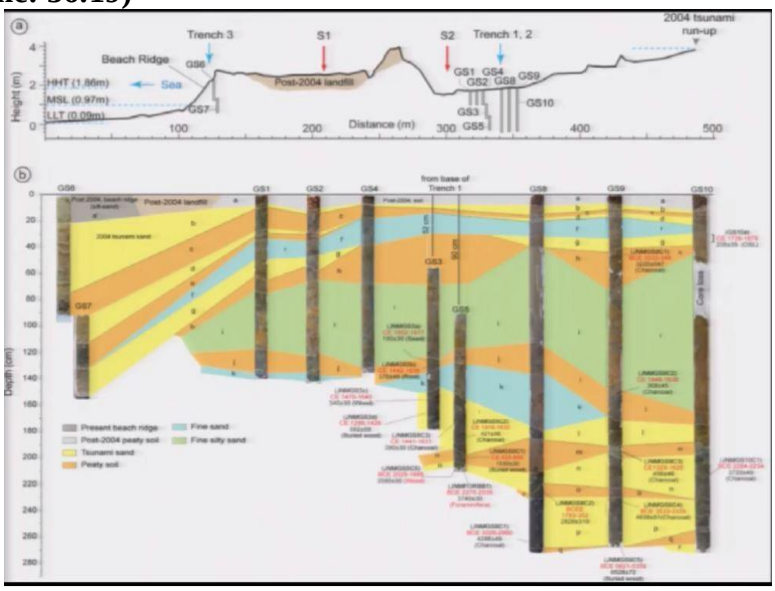

And in terms of the tsunami events so all yellow this diagram in yellow colour shows the tsunami sand and we put the this the importance of the topographic profile which we took and then we also looked at that what was the low-level tide and mean sea level and high higher high tide levels. And based on this we identified that the area subsided by around 45 to 50 centimeters in this area.

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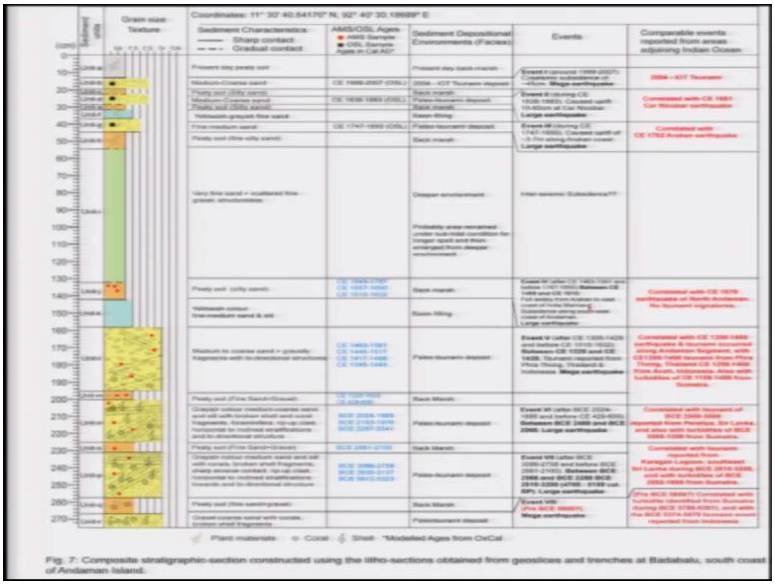

Now with the ages which you see here and we use charcoal and did the EMS ages as with the OSL dating we did of course cream that is from sand and that helped us in bracketing the events and based on that we were able to identify the 7 tsunamis here. So this is how we can reconstruct the history of tsunamis and the mega earthquakes because the weather we have the tsunami deposited by the mega earthquakes.

A large earthquake that also can be differentiated based on the thickness as well as the sediment size that can help us and then we can also talk about the recurrence. So what we found that from our present study as well as the previous one that they were at least 3 mega earthquakes from this region which were responsible for triggering large magnitude like large magnitude tsunami.

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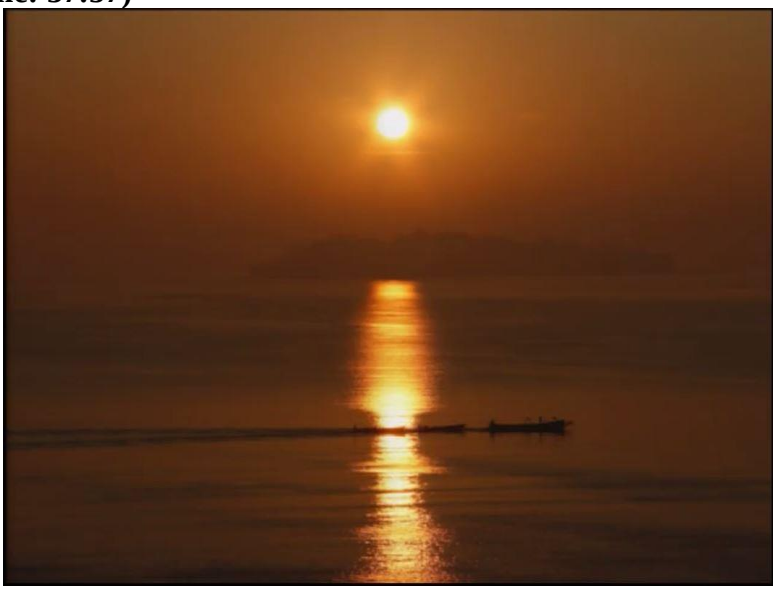

And the interval was around 400 between 420 to 750 years for the mega earthquakes and giant tsunamis and the large earthquakes which were triggered in between for example if you look at so those were the large earthquakes which were ticket and for example 1762 and then 1881 and so and this one also was I was the larger earthquake that is in 1679. So those earthquakes were the large earthquakes in between little shorter interval of around 80 to 200 meters that years. So with this I end my lecture here thank you so much for your attention best luck.