Earthquake Geology: A tool for seismic Hazard Assessment
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Lecture – 54
Earthquake Geology: A tool for seismic Hazard Assessment

So, this is the part of our course, which is very important, other than what we have discussed about the act of forests and fluvial, landforms and coastal landforms now with the understanding of the coastal landforms let us see that how best we can interpret or identify the signature of Paleo earthquakes. And when I am talking about Paleo earthquakes along the coastal region signature of the Paleo earthquakes around the coastal region that means that we are talking about mega earthquakes and large earthquakes.

So mega earthquakes are those earthquakes which along the subduction zone which have the magnitude of more than 9 and less than 9.5. So and of course, the large earthquakes can range between 7.5 and 8.5. So we are talking about those earth signatures of those earthquakes. So I will also try to highlight here if time permits, the recent research which of our team got published in Nature scientific report, where we have been able to identify 7 tsunamis from the record of the past 8000 years from Andaman.

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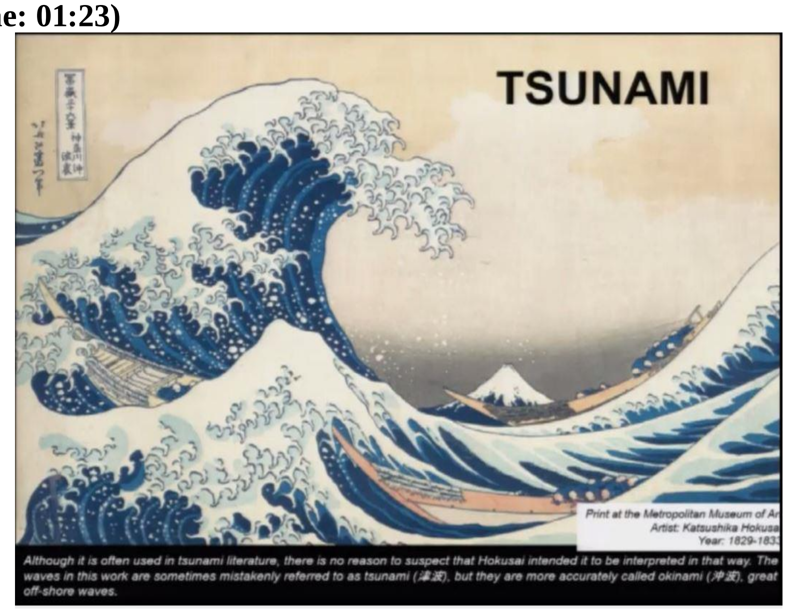

Now with the introduction of the tsunamis mostly in, the literature, you will find this picture from Japan. But this picture, it was, drawn or created by the Hokusai in years 1829 and 1833. And mostly this is getting like it is mistaken with the tsunami waves but of course, the tsunami waves are deadly, and some of them have interpreted that the tsunami waves are so deadly that they have the cloud here.

Which can eat away the landforms and the settlements and it could be much larger than Mount Fuji also. So although it is often used in tsunami, literature, there is no reason to suspect that Hokusai intended it to be and it to be interpreted in that way. The waves in this work are sometimes mistakenly referred the tsunami, but they are more accurately called Okinami great offshore waves. So, of course, the great offshore waves if we consider they have been product tsunami in the tsunami word itself comes from the from Japanese side, that is their harbor waves.

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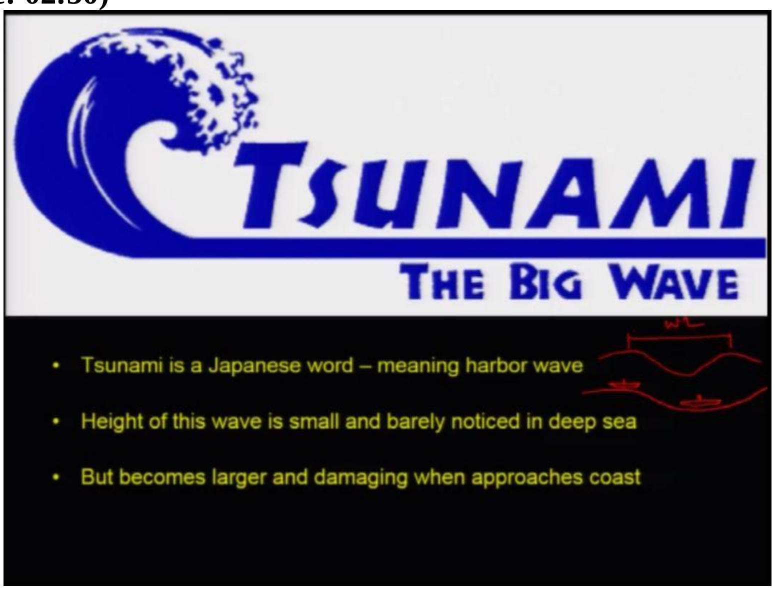

So, tsunami is Japanese word, meaning harbor wave or a giant wave or big wave you can say the height of this waves is small and merely barely noticed in the deep ocean and this is because of its larger wavelength but becomes larger and damaging when they approaches the coast and this is because of the stalking when they enter into the shallow waters we will see this one. So, please keep in mind that what we discussed about the, crust and the trough here so we will talk about the wavelength here like this.

So this wavelength will be extremely large in the ocean so you would not be able to even notice this so if you are having a very large wavelength and really shallow so even if you are having a ship or a boat, sailing on this, it will just sail very smoothly. No worries about that in the deep ocean but when it approaches the coast, it is extremely damaging.

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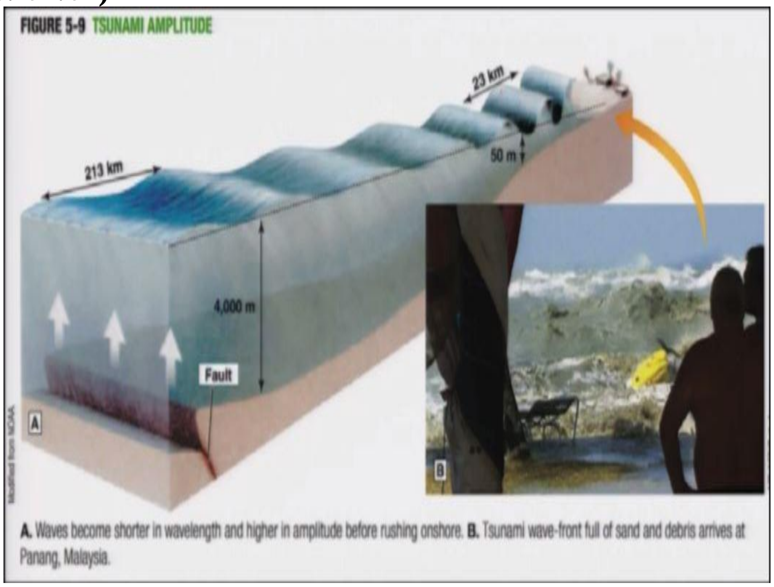

The wavelength could be more than 200 kilometers and very shallow, but it is the crust will not be so high and it will be barely noticeable in the ocean in the deeper waters, but when it comes to the shallower waters the wavelength decreases and the height increases.

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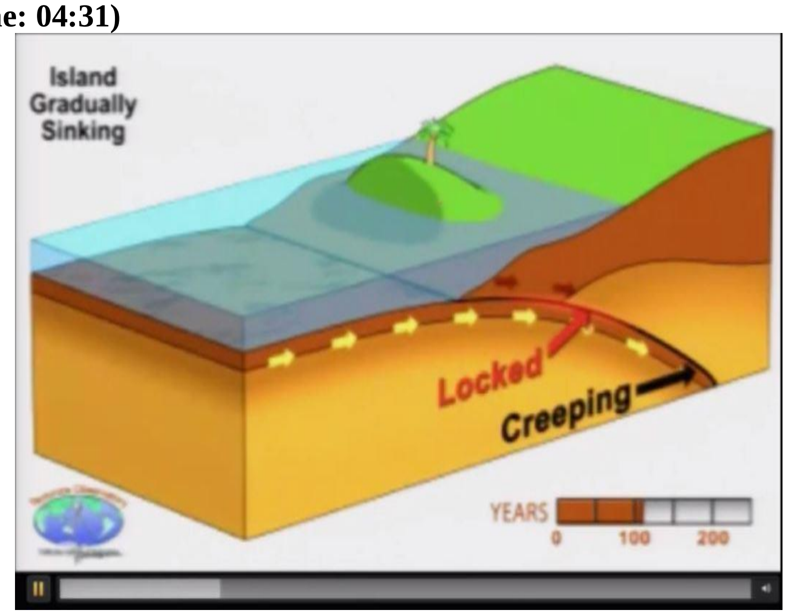

And it will be more deadly when we are talking in terms of the amplitude so I do not know whether it will work or not. But we will try. So now if you look at this small movie that shows that how usually the 2 plates, the one that is in along the subduction zone the oceanic plate is subducting below the continental plate or the oceanic plates subducting below the oceanic plate, then what will happen because this 2 plates when they are having the area of the interface will provide and create friction.

And they will keep having like an accumulation of strain and due to the accumulation of strain on the rocks will get deformed and it will result into the deformation of the landforms near the coast or along the trench area. So, and then when it slips, this will disturb the water column sitting at the top of the displacement here and that will result into the generation of tsunami waves.

So, tsunami waves are considered as an secondary phenomena related towards quick so, tsunami waves can also form because of the submarine landslide if you are there is an any slip or the landslip material is slip or pore down into the ocean along the coastline, then that can also generate the tsunamis but those tsunamis will be local tsunami will not have very wide affect in terms of the area.

But if you are having the tsunamis triggered along because of the earthquake and the displacement between the 2 plates, then it will have the wider effect covering or affecting larger areas. So, and sometimes it is so happened that the in displacement in terms of the length that is a source is less, but then if it is connected with the or it gets associated with the landslide or submarine landslide then the waves are much larger, which sometime is unexpected.

And the same thing happened during the 2011 Tohoku earthquake the rupture length was around 500 meter kilometers in terms of the length, but the waves which we have been experienced were much, much higher than what it was expected. And that was because of the submarine landslide. So let us see what you should not happen. So, just keep by over here and then what happens here and then what to shut off and land level change takes place here and after the slip here, how the waves are generated.

So, slowly the plate is moving down here, this is the portion of locked area. So this portion does not slip, but it will keep on dipping up like this this the area is getting down so it subsided and then it when it was unlocked or stepped. Then the area was uplifted. So you can see this portion the orange portion has been exposed. But earlier only this portion was exposed but this went down.

So I will play it again. And then you can find out now, one important point which I would like to mention here is that if you are having GPS stations across this one in this area, then you will be able to fix up that the area is subsiding over a period of time and that is also in case you can warn the people that this area can slip in future and will again have so, if you are having the subident period, which cores or uplift period in some area is much larger than we are accumulating more strain and we can have much larger earthquake in that region.

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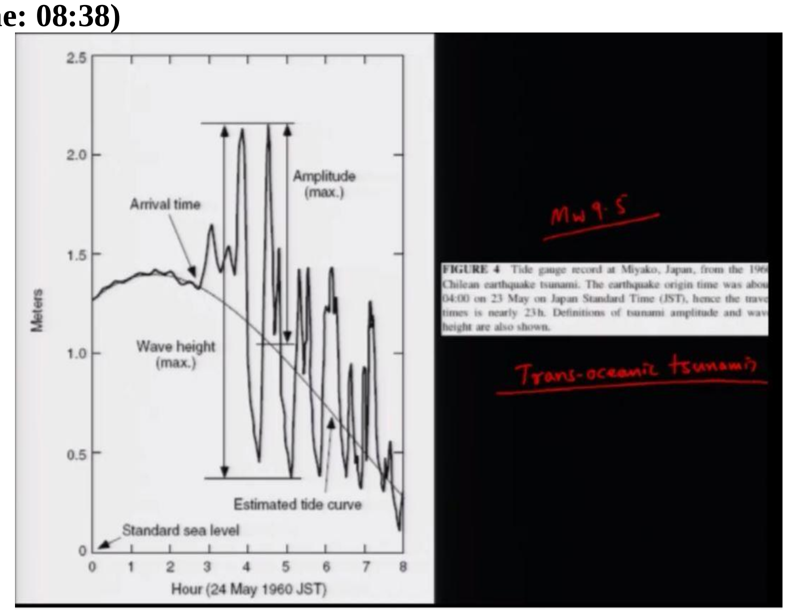

The early warning systems and all that they work based on the tidal gauge records and this is this tidal gauge record is from Japan. But the tides which have been unusual tides, which had been recorded was not an earthquake, which was triggered along the Japanese subduction zone. But this was because of the subduction zone which lies between the Nazca plate and the South American plate in Chile along Chile. So, this was the 1960 Chilean earthquake one of the largest so far recorded earthquakes on the earth and that was magnitude 9.5.

This was one of the largest recorded earthquakes and so, so, what it shows this tidal is that this is they have the curve which shows the mean tide level. So, you have the, the high tide low tide, high tide, low tide and all that, but suddenly they had something which is shooted up in this Nester, so, this portion of the unusual record of the tide tidal waves was because of the 1960s Chilean earthquake now one thing which one we can think of that the Chile or the subduction zone Chilean subduction zone lies much far from the Japanese coast.

But the effect of the tsunami was experienced in Japan which is sitting very far away. So this is this type of tsunamis we call this as an trans-oceanic tsunamis so they travel across the oceans and cover larger areas.

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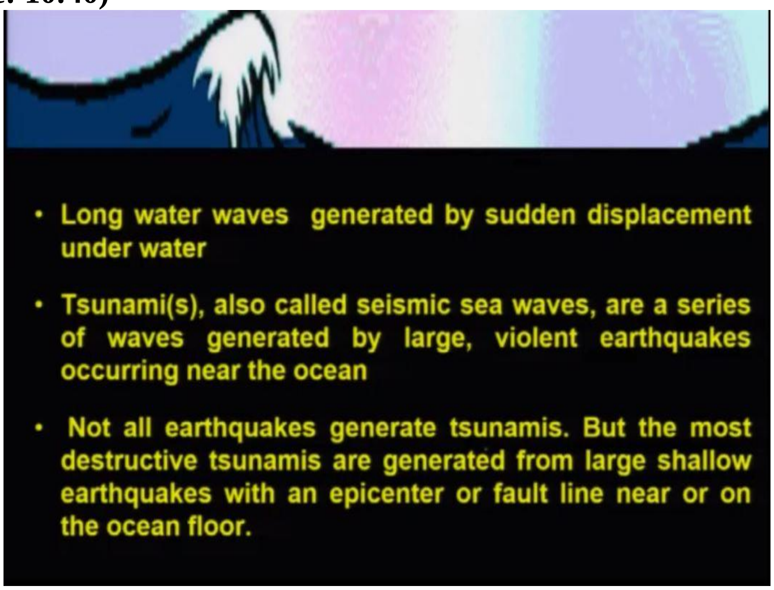

Tsunamis are basically the long water waves generated by sudden displacement underwater. Tsunamis always also termed as a seismic sea waves, and they are a series of waves generated by large violent earthquakes occurring near the ocean. Not all earthquakes will generate tsunamis because this again depends on the amount of displacement and displacement of the water column.

But, the most destructive tsunamis are generated from large shallow earthquakes, within epicenter of the fault line near or on the ocean floor. It depends on the displacement and also the depth at what depth it is been triggered again. So, if you are having shallow earthquakes, then you will have larger tsunamis.

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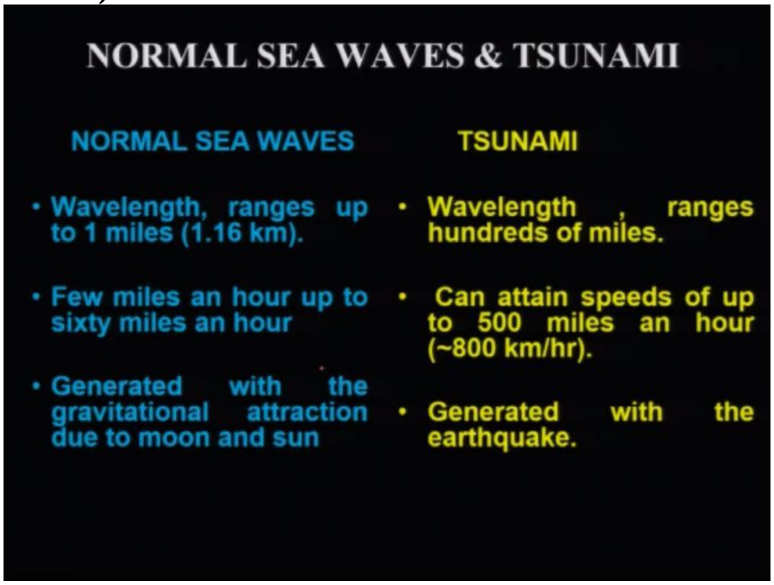

Now, if we compare this with the normal sea waves and the tsunami waves the normal sea wave the sea waves we call tidal waves, because of the attraction or the gravitation, activation of moon and sun, so, and they will have the wavelength which is ranging to 1.1 kilometers but whereas in this case the it can attain more than like the wavelengths maybe 100 miles or more. So, and also the speed at which it travels it will travel at the speed of jet almost like 800 kilometers per hour.

Whereas here it will have only few miles an hour or so, and this was generated because of the earthquake. So, these are the major difference between the normal sea waves or tidal waves and the tsunami waves.

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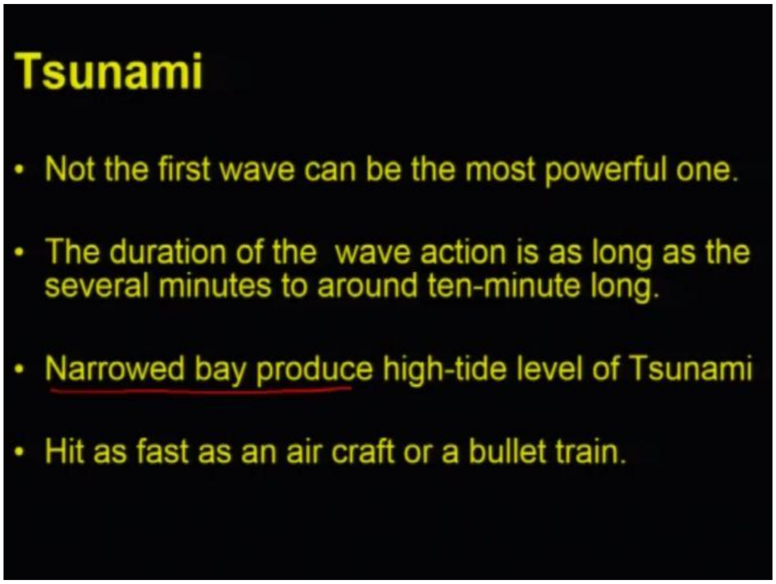

So, usually in tsunami what it has been experienced that not the first wave can be more powerful one because it may be the next wave which is coming in could be much more powerful than the first wave the duration of the wave action is as long as several minutes to around 10 minutes long? And this depends on the on its wavelength again that what is the wavelength of the tsunami wave which is generated.

And suppose sometime you have like people have experienced that and the reports are there that the first wave was not the positive wave when I see the positive wave then we usually talk about that this is your positive and this is your negative wave. So, the first wave if it is positive then it will inundate but if it is negative then it will expose the coastal region. So, in some cases the local people survivors the experience that the more the ocean floor for kilometers and then the it got inundated.

Because the arrival of the next wave now narrowed bay levels of tsunami. So, this configuration of the coastline will be will play an important role. So, when we try to prepare the inundation maps and all that, so, such features are the landforms are been targeted, where we can have the high tides, the high tide level of tsunami and because of the its topography, so it hits as fast as aircraft or bullet train. So, the energy the velocity is much higher as compared to the normal sea waves.

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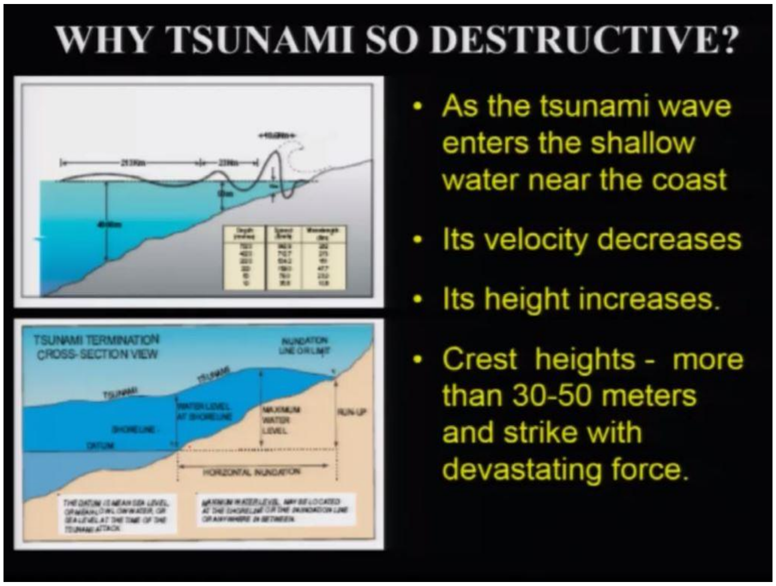

Why tsunami are so destructive, there is what we were talking about that it is barely noticeable the deeper portion of the ocean, whereas as it comes closer, then the wavelength reduces but the height increases because of the stacking. So as the tsunami waves enter the shallow waters near the coast, it is velocity decreases. Its height increases so, basically because of the striking and the height may go up to 30 to 50 meters depending on the topography, or the configuration of geomorphology setting of the coastline.

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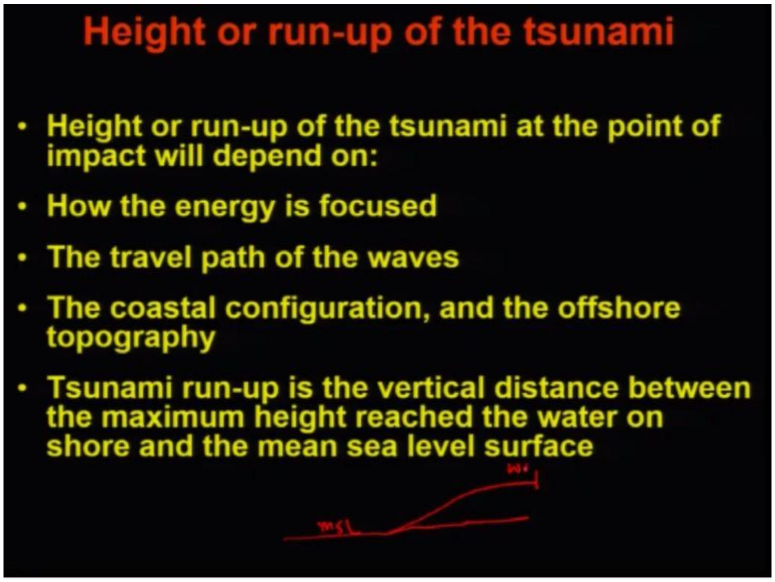

And there is the photograph, which shows wave height and the 2 waves coming in here, they during the after the 2004 earthquake in Thailand. So height and run up is another important factor which is been taken into consideration for modeling the simulation of tsunami waves as well as preparation of the inundation maps or hazard tsunami hazard maps. So the height or the run up of the tsunami at the point of impact will depend on one how the energy is focused.

So what is the alignment of your coast with respect to the tsunami waves coming here suppose we are having this here then it goes like that? So, the what we are talking about the relationship between the wave action so, we that whether the waves are deflected or reflected from the along the coastline then the travel path of the waves how they are traveling from which direction it is coming the coastal configuration.

That is the geomorphology of the coast and the offshore topography, tsunami run up is the vertical distance between the maximum heights reached the water on shore and the mean sea level surface. So, if you are having the mean sea level here MSL and the water which reached up to this point on the mainland, then this will be you are the run up maximum height, though of the run up between the mean sea level the wave of reach up to the point in land.

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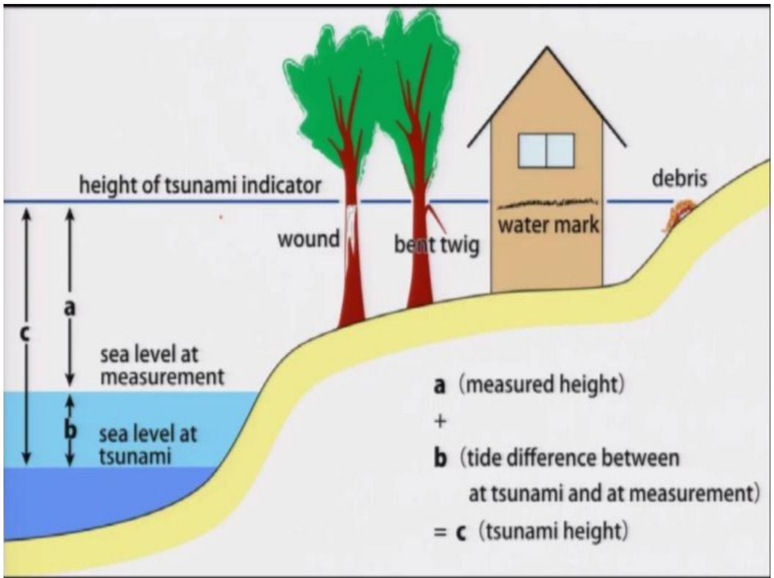

If you consider this then what it shows that you have the a is your measured height and b is your tide difference at tsunami or that is tidal difference between the time of the tsunami and a time of the measurement. So, at the time of the tsunami for example, you had the sea level was this one this is because of the tidal fluctuation not because of any other reason because the sea levels remain the same.

So, if you have you were having the, sea level at this point for example, there is a low tide and then at the time of the measurement and you will have to take into consideration this so, you will add this plus the height you have measured that is your a at the time of your survey that will give you the total height of the tsunami. This is an common practice which we do after the tsunami in any area to understand that how much area got affected or what was the run up height and all that.

So, we try to look at because when the tsunami wave comes, it will try to wound the trees along the coast and also leave the watermark if you are having any buildings and also because wave centers and run up will be up on the inland side then it will also leave some signatures of the material which is carried for example the Tabriz so plant Tabriz also can be seen sitting at very high level, depending on that what was the run up.

So, this type of signatures we try to collect and then we measure the we take the topographic heights and all that, and then we identify the mainly the height of the tsunami. So, these are been used as a height of tsunami indicators.

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▸ A. The coastal area of Meulaboh, Indonesia, before the tsunami. B. After the tsunami, nothing remains of most houses. Distinctive buildings in the upper right part of each image can be matched.

So, if you look at this 2 photographs from Indonesia, which was the photograph A on the left is before and B is after. So, you can just correlate these 2 houses which are which are left out here, but rest of all got destroyed and wiped off.

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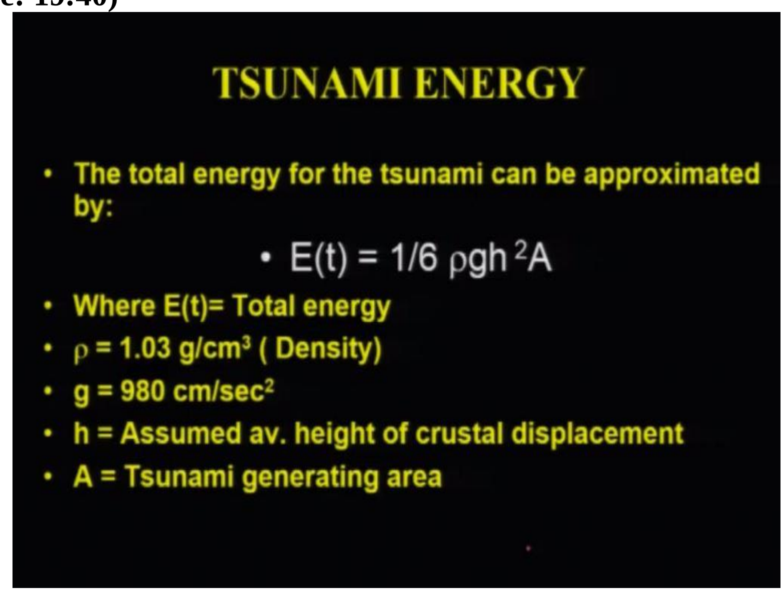

So, the, the inundation maps which when we are preparing we take into consideration the eternal heights from different tsunami all the lessons we learn from the past tsunamis. And so tsunami energy if you want to calculate it is very easy the total energy of the tsunami can be approximated by the equation which is given here, where E is the total energy. And then we have the density of the ocean waters, it should be taken at around 1.03 g per centimeter cube, and then you have the pixilation, we take.

And then we have the assumed height. So if you have the height, it is the height of the area where that is an average height of the custom displacement, then you can easily calculate the energy conditions of the tsunami and A is the tsunami generated area. So how much area was involved in generating this tsunami that is we take the so this you can get from the seismic data which helps in fixing up the total area of rupture.

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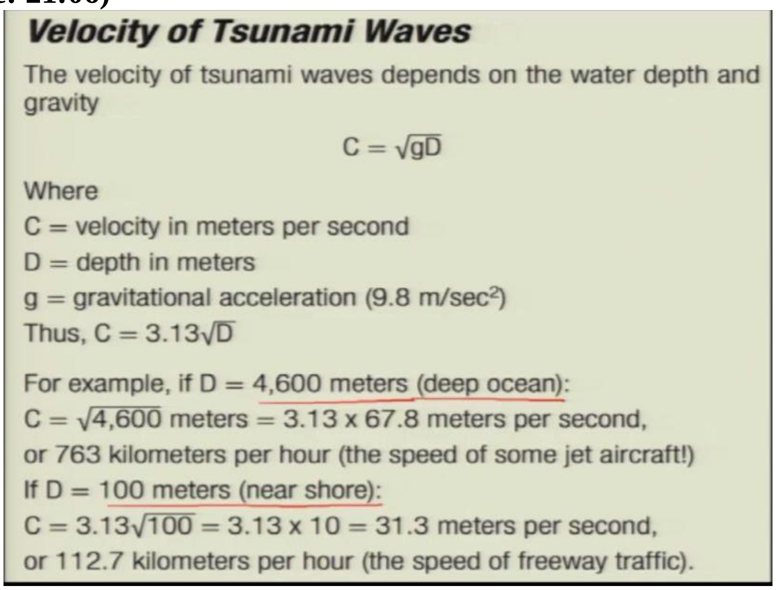

So, velocity of the tsunami wave can be calculated which depends on the water depth and the gravity. So, you have gravitational acceleration which we are talking in the previous slide also and we see is the velocity in meters per second D is the depth of the water. So, for example, what you have is that if the D that is a depth is 4600 kilometers in the deeper ocean, then you can have the C is equal to the velocity in meter per second.

So, it will be all you can say that this is around 763 kilometers per second. So, this is almost equivalent to the sum of the jet aircraft. Now, if you having shallow water that is near the shore, so, this is the deepest portion. Whereas if you are having the shallow water then the energy conditions like the energy reduces here. So, statics the velocity reduces but in depth will be high but the height increases. So, this is the main difference here we are having it on the deeper waters the velocity is high but here the velocity decreases.

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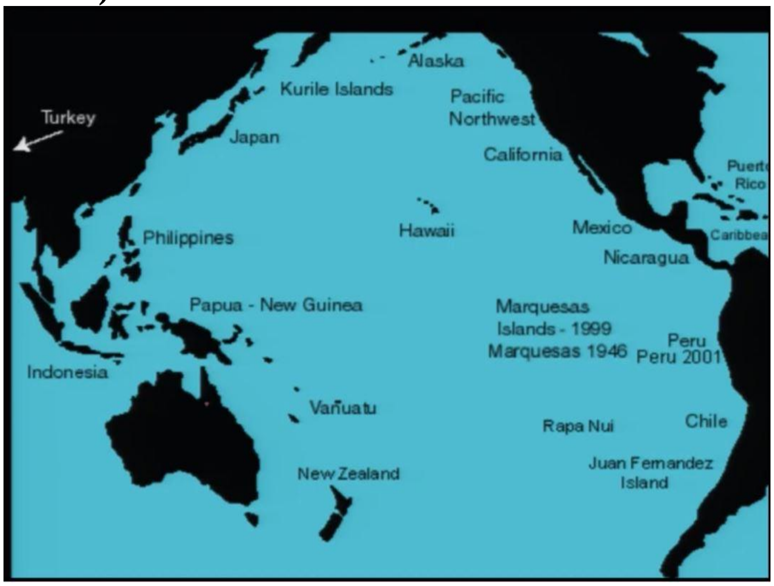

Now, this is an example, which we will quickly look at that what happened along the Chilean coast here during the earthquake which was triggered along the trench the subduction zone between the Nazca plate and the South American plate here and how it affected and what were the signatures which they found. We part of a play why in Japan area of course, it also affected this whole ocean that is the Pacific area got affected because of the 1960 earthquake.

Now, this areas are very sensitive in terms because these are all subduction zones and these areas are very sensitive and triggering this the large or mega tsunami and then we are sitting here we have the Sumatra and then further up, if we go towards northern we get into the Andaman region. So the tsunami is triggered here in North America will also affect the coastal regions which are sitting in the Pacific rain here. And if the tsunamis are triggered here, they will also affect this region.

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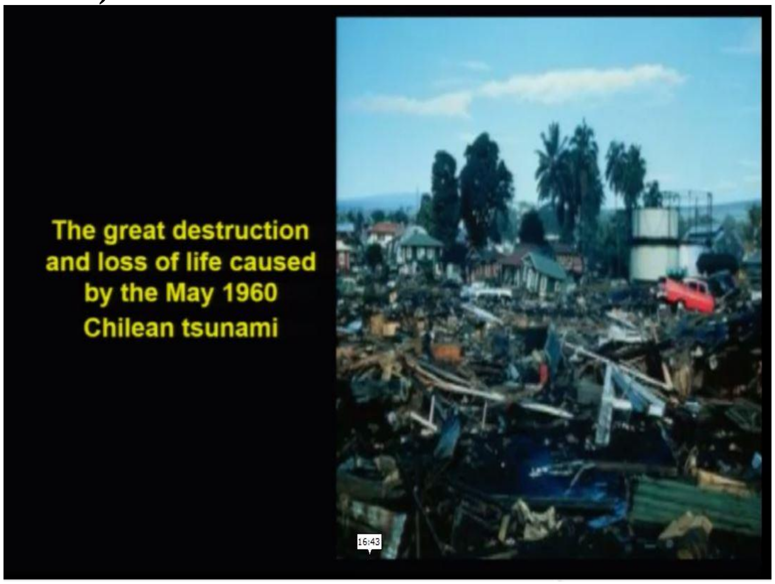

So these are few listed tsunamis. 2004 is not listed in this 2011 is not listed in this and few more which were recently experienced. So this was the great tsunami of 1960 Chilean earthquake of magnitude 9.5.

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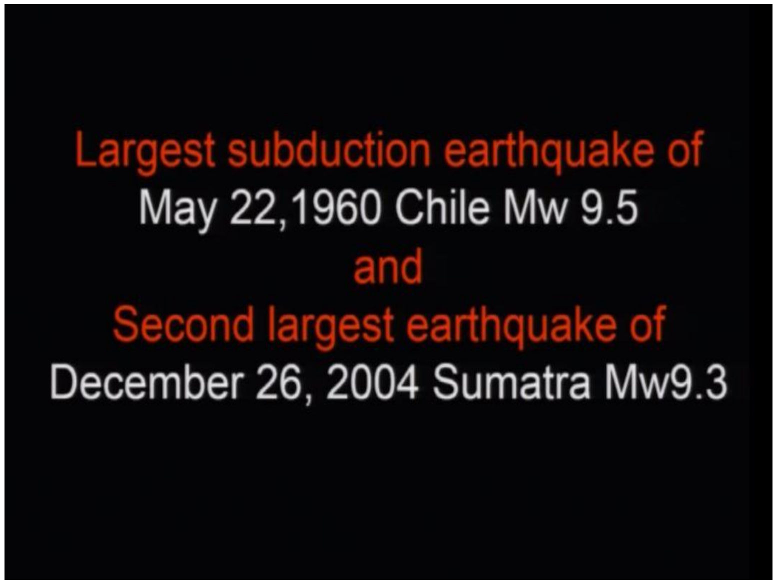

So the largest subduction zone earthquake of May 22 1960, Chilean earthquake magnitude was 9.5. And then second largest we consider this as a 9.3. But in some literature, you will find that the second largest earthquake has been listed as an Alaskan earthquake and from North America and that was around 9.4 or so. So, anyway coming with considering this, this was for us it was the second largest one, the 2004 as compared to the 9.5 trillion earthquakes, the largest 1.

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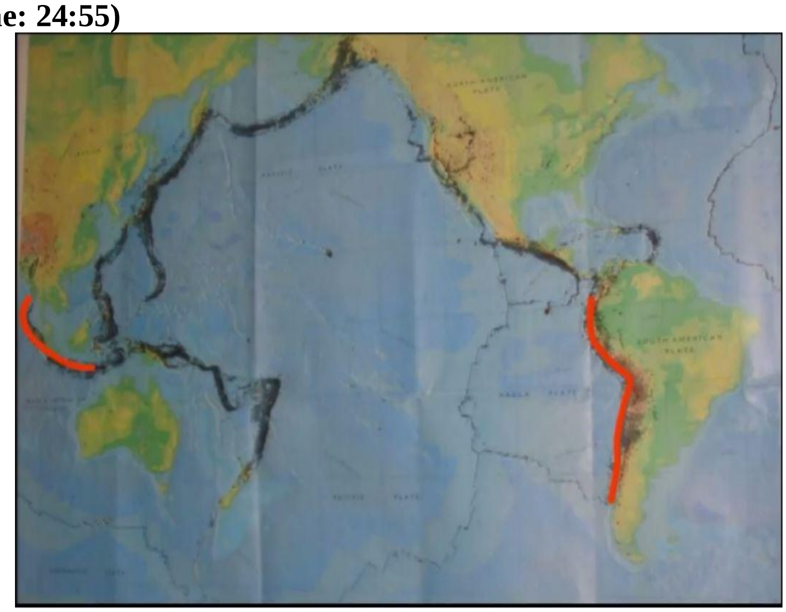

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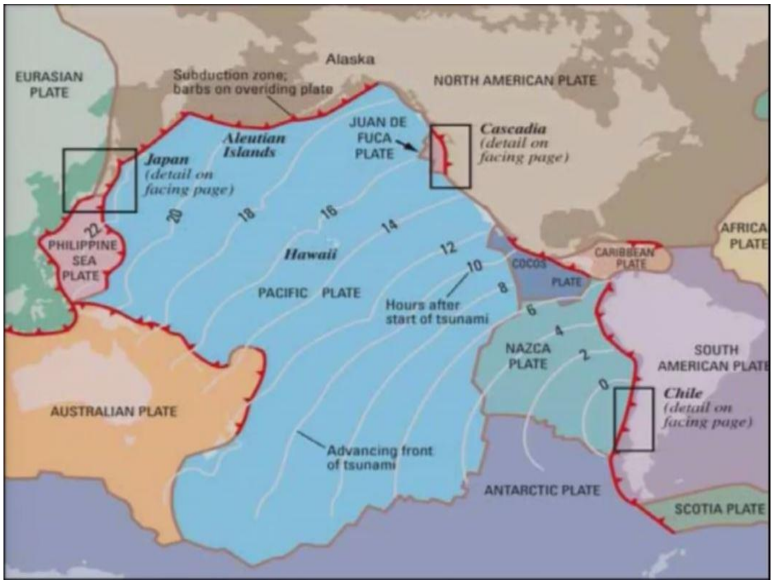

So, this is the subduction zone here and what we are going to discuss more further is from the Andaman Sumatra Andaman subduction zone. So, the numbers which are which are shown here and with the white controls the ours which took that tsunami from this point 0 hours it took us almost 22 hours to reach the Japanese coastal. So, in some locations you have like ample of time available to issue the warning so you can evacuate the people from the coastline and all that. Look at this one then it almost took 22 hours.

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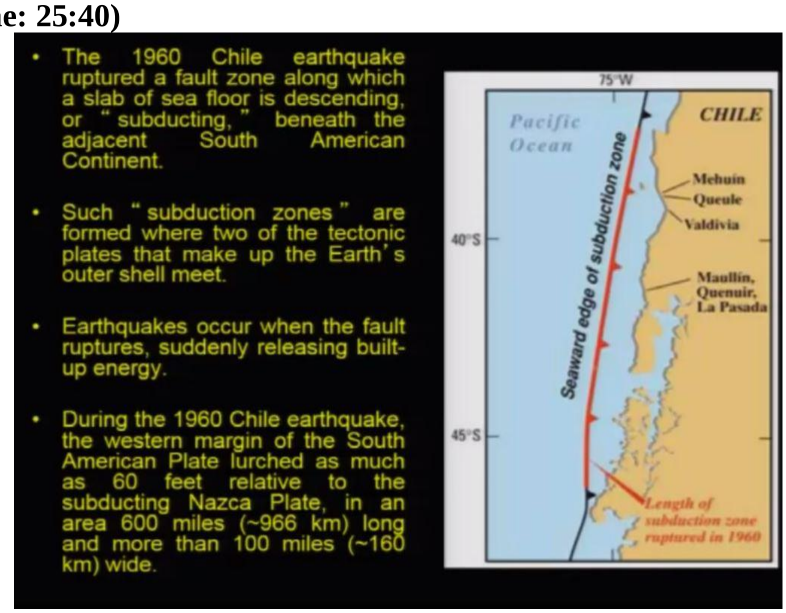

So the Chilean subduction zone is, of course and very one of the deadly subduction zone which has triggered many more tsunami not just in the 1960 but even comparatively, so smaller tsunamis along this one.

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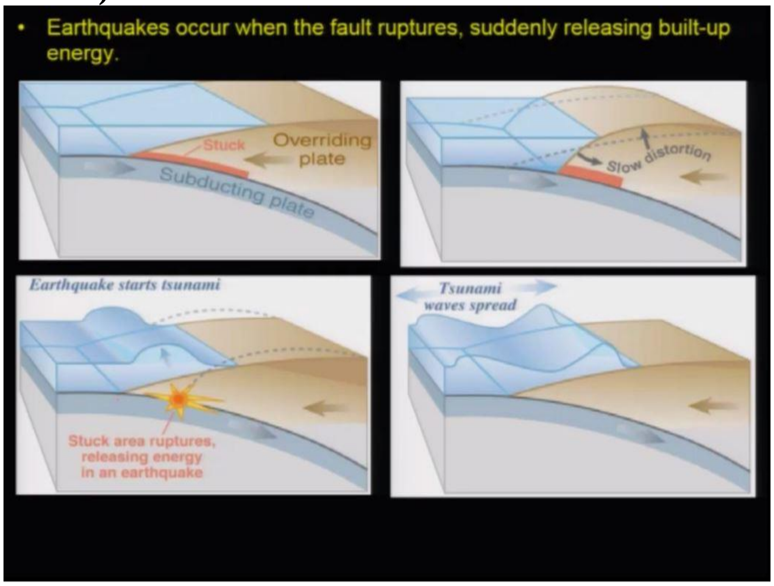

As we have discussed in the beginning that the earthquakes occurs when the fault ruptures and sudden release of the energy houses getting cumulate over the time is released. And if they the water column has been displaced sitting on that rupture, then it will result into the tsunami. So, this the sketches also shows the, the similar part which we saw in the beginning, one small cartoon, but here it shows that the area because of the locking here will get uplifted. And then finally, when it is released, it will result into the, that is the energies release to cause the slip here, and then our result into the slip displacement cause the formation of the tsunami waves.

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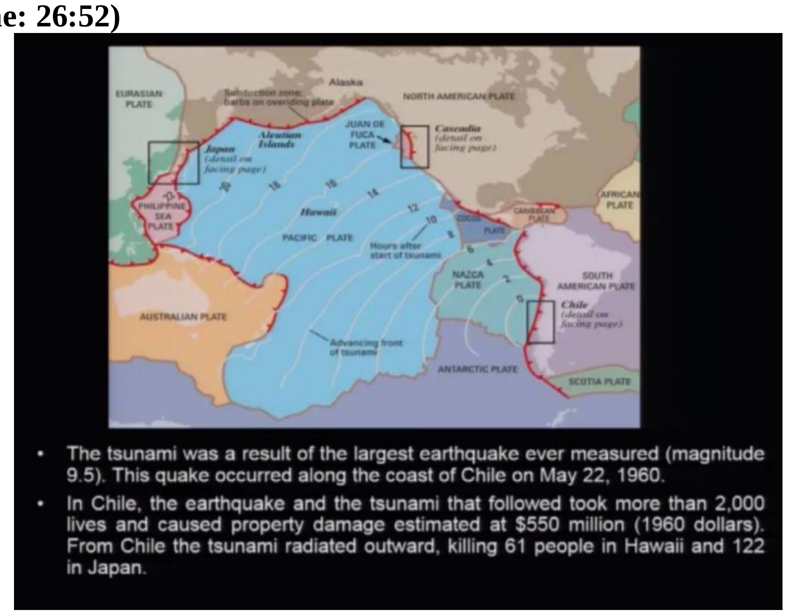

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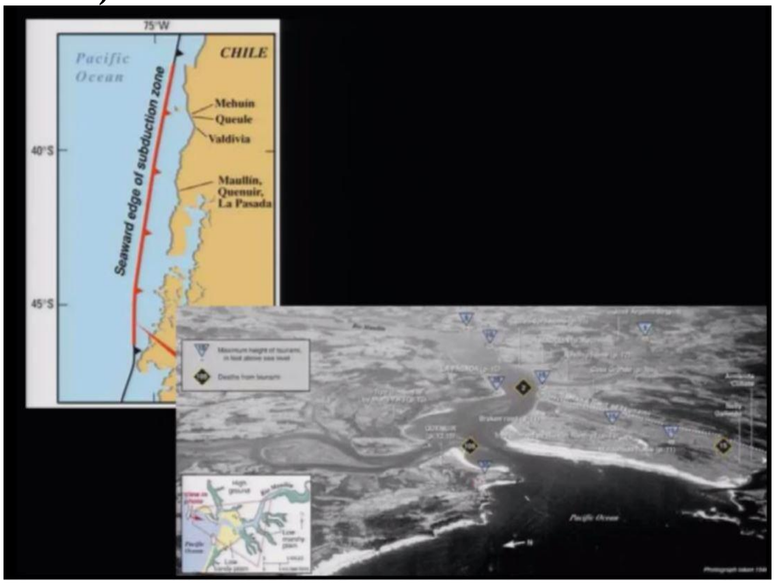

So, let us look at a few examples from Japan and Chile, which indicated that what happened during the 1960s in earthquake so this was the area where we did a detailed survey. And this paper was published in Nature long back. So we did joint field with the USGS scientists and 2 of us work for way from India and then 2 from Indonesia. So we had a big team and then we worked in Maullin here.

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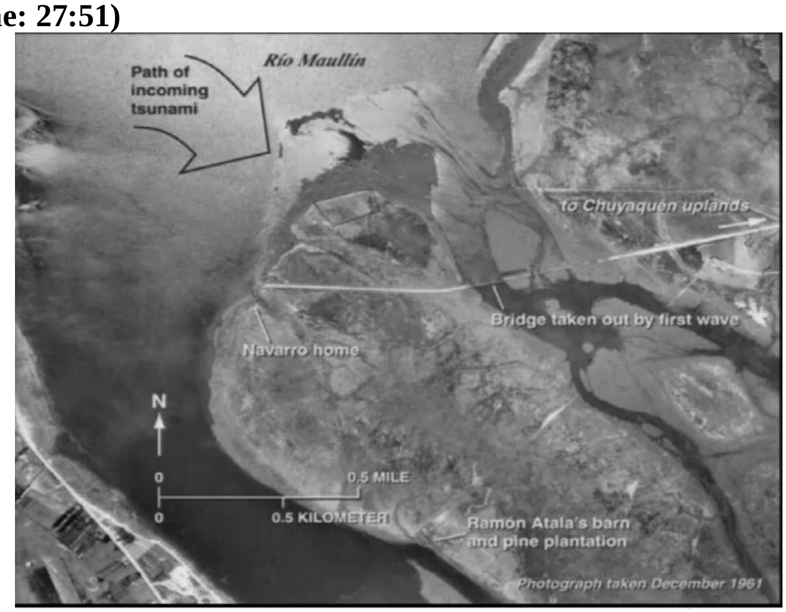

So this photograph is from this area here, which got affected during this earthquake, and the area subsided during the 2019 60 Chilean earthquake. And the bridge which was sitting here was blown up still it is not constructed. We used to travel through this area and reach this portion to identify the values and signatures.

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So this was the situation in the city of Denver after the 2000. After 1960 Chilean earthquake, the houses were been destroyed completely. And this photograph was been taken where we did our survey. This was this was before 1960 event. So, this would be the end and there is a river which flows here. And this whole area was very good agricultural field. And you can see the houses and the boundaries here the agricultural fields, so people used to stay here. So that means that even during the high tide the water never used to get into this one this region.

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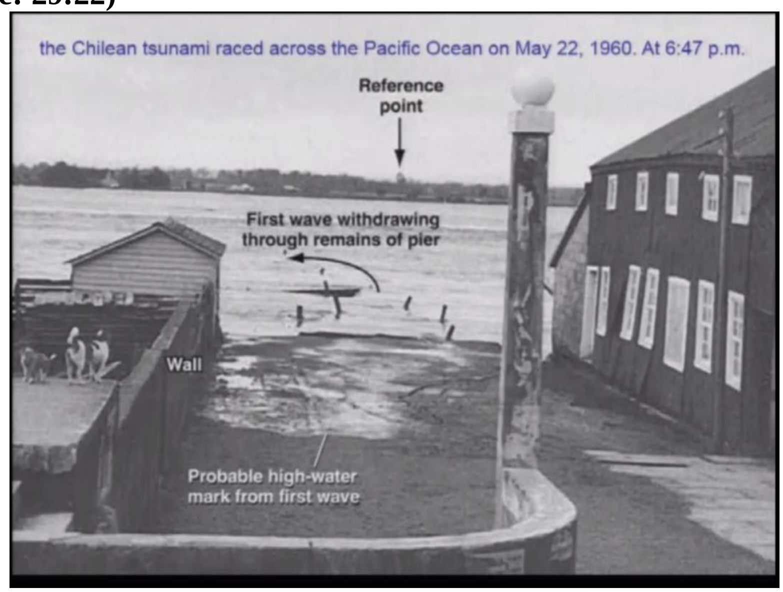

But after the 1960 earthquake, this was the situation so; you can compare this tree here. So, few trees were been left out whereas, whole area was swept away and this shows the first wave which came in which was which only removed some structure from here. But the second wave took away the heart which was sitting here. So, this is what one can learn from the multiple waves will come, so, this was first wave and then this is the second wave.

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Now, in Japan, what they found was that came, the tidal gauge chart which I have shown in the beginning, it was an unusual recording of the tidal height and the tidal gate station. So, this was at 4:40am the front of the first large wave which came in so, the warning was been issued people moved on high ground.

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And then you can see the second fight for that was 440. This is 445 still the window is here and the train station and was also intact, but later on the window was pushed and then they got lot out of (())(30:34)coming in.

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So, this was at 4:55 when the photograph was been taken at 7:30am and this left the watermark here. So such features are the signatures we try to take into consideration when we are talking about the run up or the tsunami heights.

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So this was the area which now is subjected to inundation in Chile and the area which was occupied earlier is under erosion and we see the signature of the dead forest there. So, we tried to look at some signatures of the dead forest as well as we looked at the preservation of the deposits tsunami deposits, if at all they are present indicating the past events.

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So, this was the area which was occupied earlier, but now the certs under erosions people have moved on the high ground and they have started settling down on the higher elevation, because this area is affected after the site.

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So, this is under the ocean. So, what we did was that we studied the, the sections here, which helped us in identifying the signature or the of the previous earthquakes or tsunamis. So, we use the back hole or what we call the JCB in India and we open up the trenches and studied the stratigraphy.

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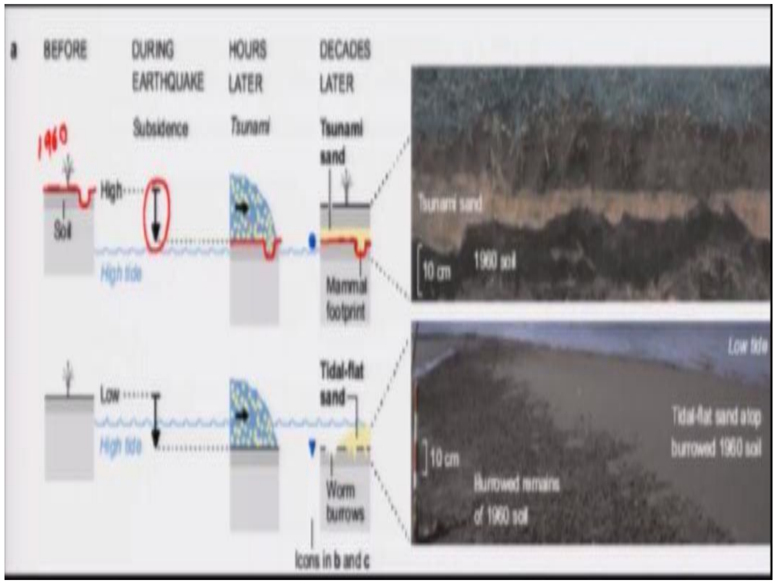

So, this is the team here we have. So, usually what happens is that when there is an that before this is for example, this is the surface here. So, you have in soil and you have vegetation like what we see here in this photograph, and then if the event results into subsistence, then the area has been subsided. So, this level has gone up, so, water will inundate and when the tsunami were comes, it will carry a lot of sediments. And, that is the sediments; those sediments will get deposited and then get preserved.

So after decades, you will find that there is a very prominent sand layer, which is getting preserved in the stratigraphy. So this is what we see in the section. So the soil was 1960 soil so, this was the surface during 1960 and then the area was subsided. So, this 1960 soil course here and then this was the sediments which were been brought by the tsunami waves got preserved here and this what we find the tsunami sand.

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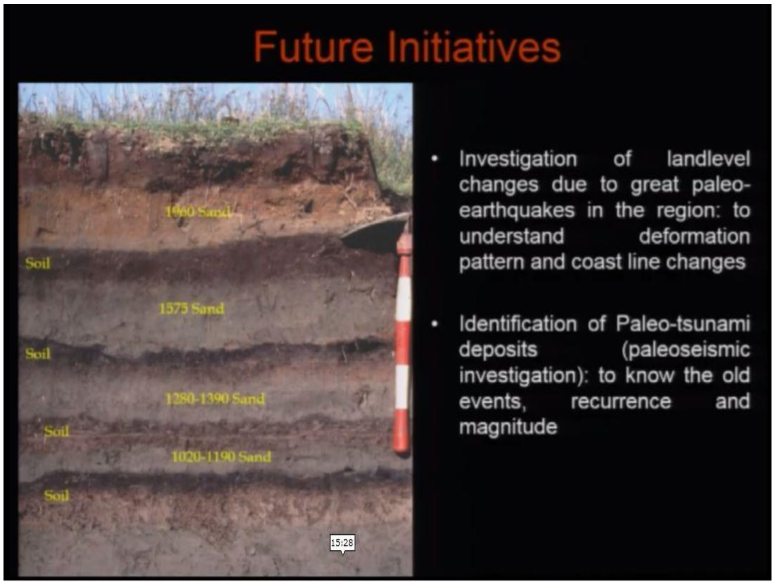

This is one of the way to identify the previous, the older tsunamis and what we found here was that multiple tsunami sand layers from this so we have the soil here, which is you must rich because along the coast will have very rich organic material. So you will have numerous rich soils and then then we are having kept the sand layers which are capping those sides. So when if you have the ages of this, the sediment ages, then all ages from the charcoal found in this then we can bracket the events.

And that helps us in identifying the, ancient tsunamis. So this was like around 1000 years, and its 12,000, this 1280 to 1390 and 1500 and 1960. So this also can help us in and in bracketing the events as well as we can talk about the recurrence interval. So I will stop here, and we will continue in the next lecture, talking about the part from the Indian side. Thank you so much.