Earthquake Geology: A tool for Seismic Hazard Assessment
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Lecture # 15
Interior of the Earth (Part II)

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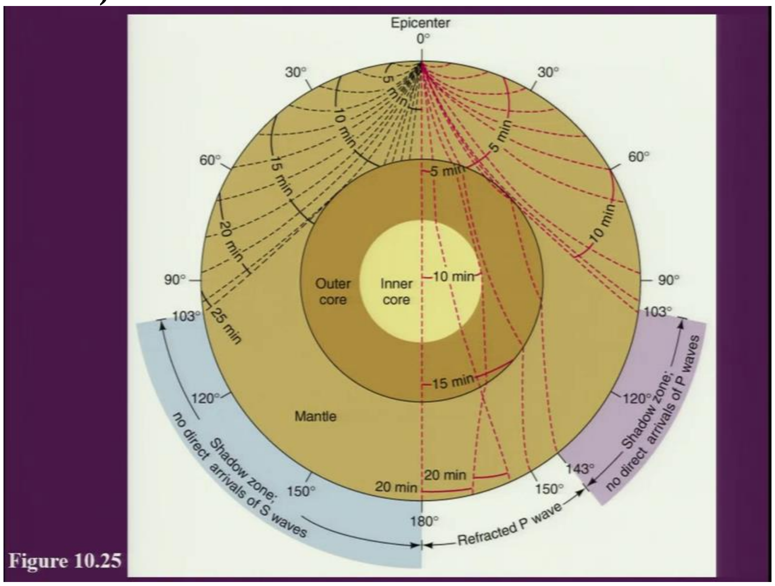

Welcome back. So, in previous lecture we discussed about mainly the body wave P wave in S wave. And we also discussed about that, why they are unable to 1 of the wave that is then you are S wave is unable to travel through the interior of earth because of its property.

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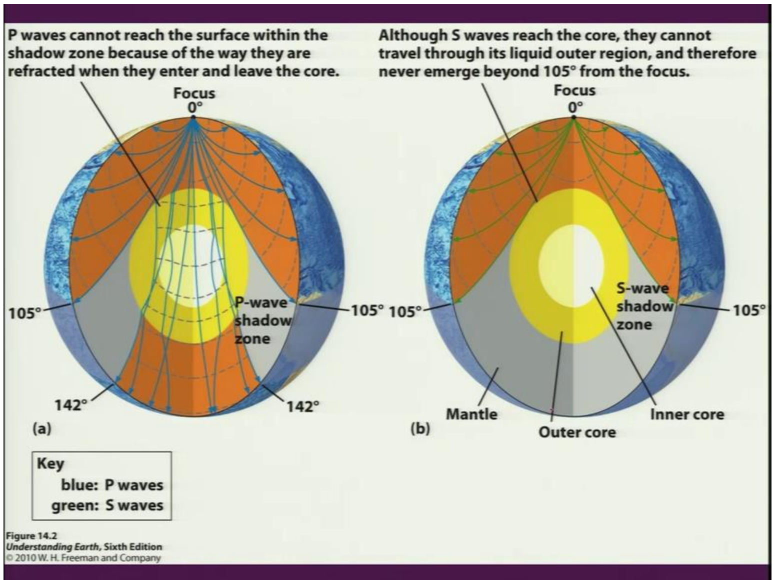

So, this is a similar diagram which explains the propagation of the P wave and the S wave. So, on the left hand side if you see if we trigger the earthquake here at this point, then you will have the P waves will not be recorded in this region because they are getting distracted P wave cannot reach the surface within the shadow zone, this was this 1 is the shadow zone for the P wave, because of the way they are reflected when they enter and leave the core area.

Because the inner core is solid is the outer core is liquid. So, from here they will be refracted and because of the change in the path wave of the propagation, they will not be able to reach this region. So, this portion will mark as a P wave shadow zone, whereas, the S wave pitches the core they cannot travel through its liquid outer region that is the outer core is liquid as they will not be able to travel through there.

And therefore, never emerge beyond 105 degree from the focus that is the point at where they are generating and this whole area will be here is wave shadow zone.

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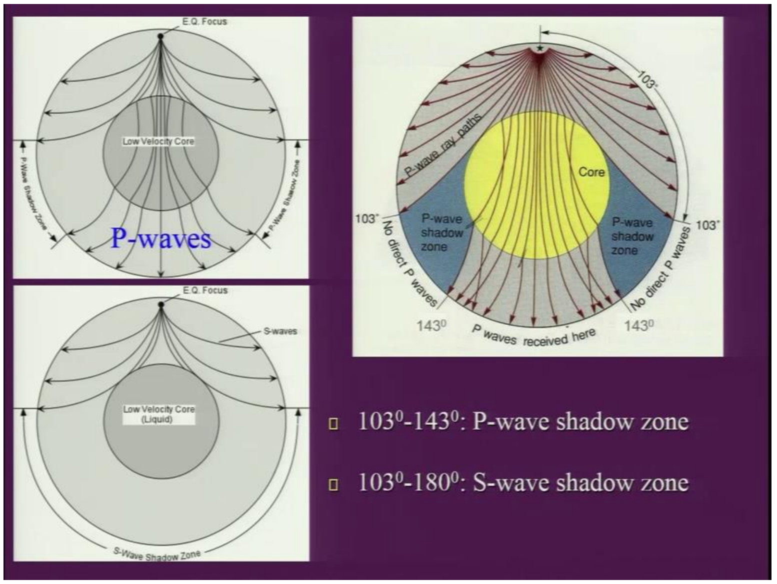

So, please know down this one that you have the if you are having triggering the earthquake at 0 degree then this region that is almost the variation of 40 degrees, you will not be able to receive any P wave and this zone has been termed as P wave shadow zone. So, P wave shadow zone is from 103 to 143 if you have triggered the earthquake at 0 degree and the S wave is from 103 to 180.

So, from this point to this point here, you will not be able to receive if you are dividing the whole earth into half and it will not be able to receive the and the S wave. So, S wave shadow zone is from 103 to 180 degrees.

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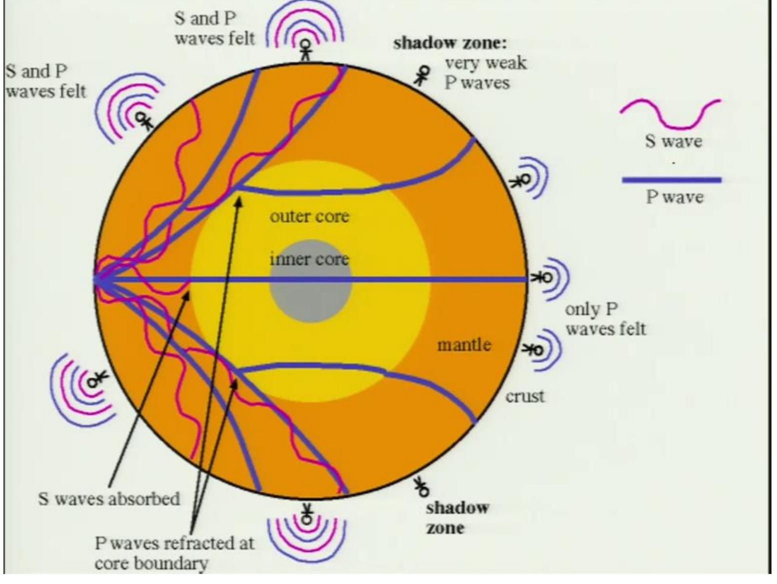

So, this is further to understand the propagation of the P and the S wave. So, S wave has been highlighted with the pink color and the P wave was with big blue color, and this all locations which are been shown here are these stations. So, suppose you are triggering the earthquake here, that is if you take this on 0, 90, 180 and 270, then in this region, you will not be able to receive any S waves, whereas, the refracted P waves will be received in this region.

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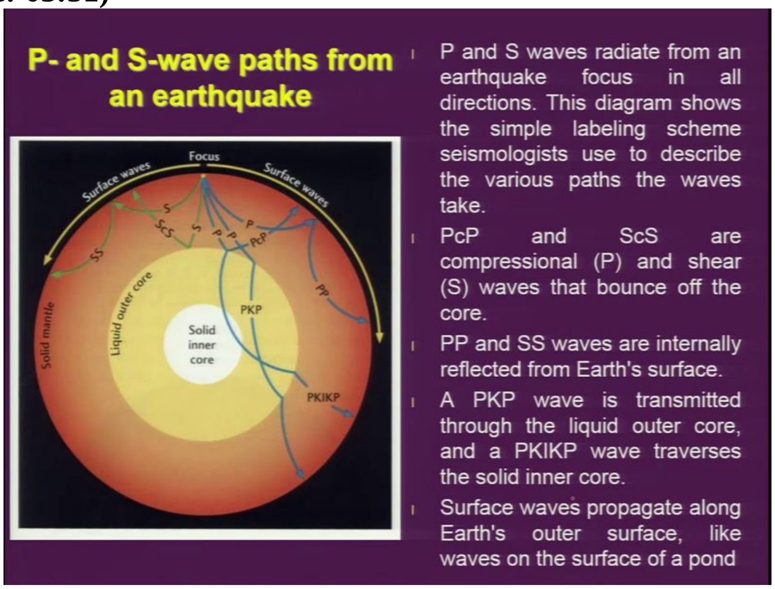

So, P wave and S wave paths from an earthquake we take then what has been shown here is that you have some reflected waves which are coming from the of the surf and the contact between the mantle and the outer core. And you have and then some which passes through and then this are the refracted waves of P and then we have also they reflected S waves which have been received by the stations which are sitting here.

So, different terminology has been used. So, P and S waves radiates from an earthquake focus in all directions. So, the diagram simply enabling this scheme, the seismologist uses are to describe the various part of the waves they take. So, PcP is here, this 1 is the PcP and ScS is over here. So, this are like are compressional P waves we have S waves and this shear S waves that bounces of the core. So, they are just reflected back and they are received by the stations PP are over here, SS waves are internal reflected from the Earth is crust.

And were further we have PKP so, here is that is transmitted through the liquid core and a PKIKP is this 1 which is further urban different reflected from the inner core so, when it enters here and then when it goes out of that so surface waves propagate along got out of surface like waves on the surface of pond. So, this is another category of waves that is the surface waves as compared to what we have learned about the body waves.

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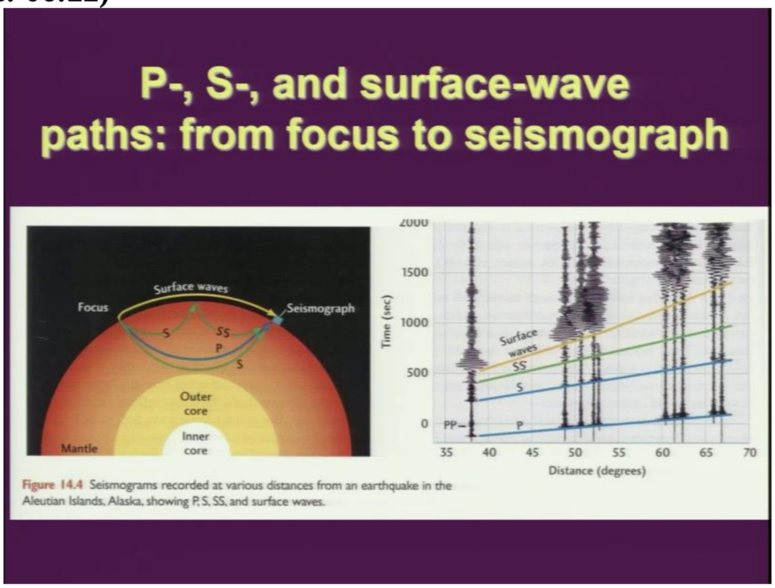

So, P and S waves and the surface wave paths from focus to seismograph. So, seismogram is the as the instrument which records the P and S waves and are we can say that body wave and surface waves. So, on so, the instrument which records the seismic waves is termed as, seismograph and the data which we will get is termed as, seismogram. So, these are all what it is been shown here as the seismogram recorded at various distances. So, there is a seismograph is the instrument and the recorded one is this 1 is here seismograms.

So, depending on the velocity, it reaches a different time this has been shown as the time and the y exists and you have the distance or where different seismographs are located which shows the arrival of the other the P wave and the S wave and here partition shown here you are having the P wave and the S wave so P wave was arrive first than the S wave and then SS which is again shown here, which are reflected from the surface of the earth and you are having the surface waves.

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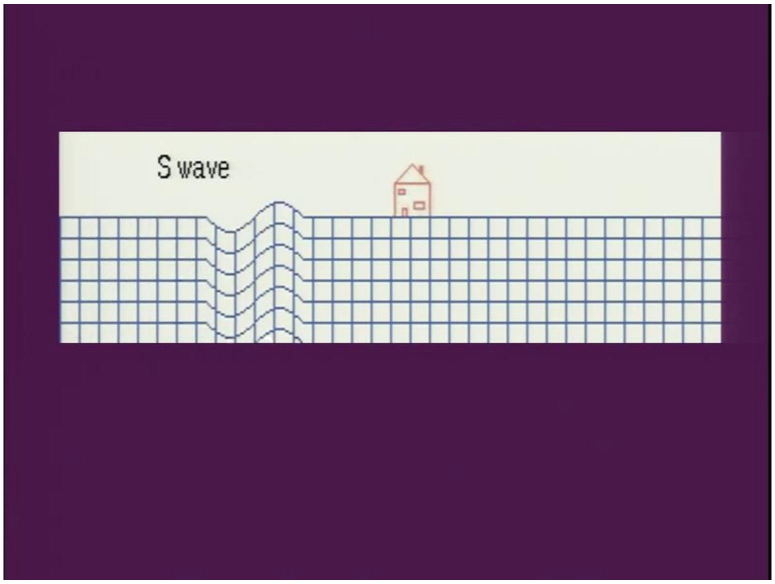

So, S wave when they travel, they will just moves the material up and down whereas, the P wave which we have seen the usually push and pull the ground. So, they this wave is comparatively dangerous, because it will move the surface up and down and result into the partial damage.

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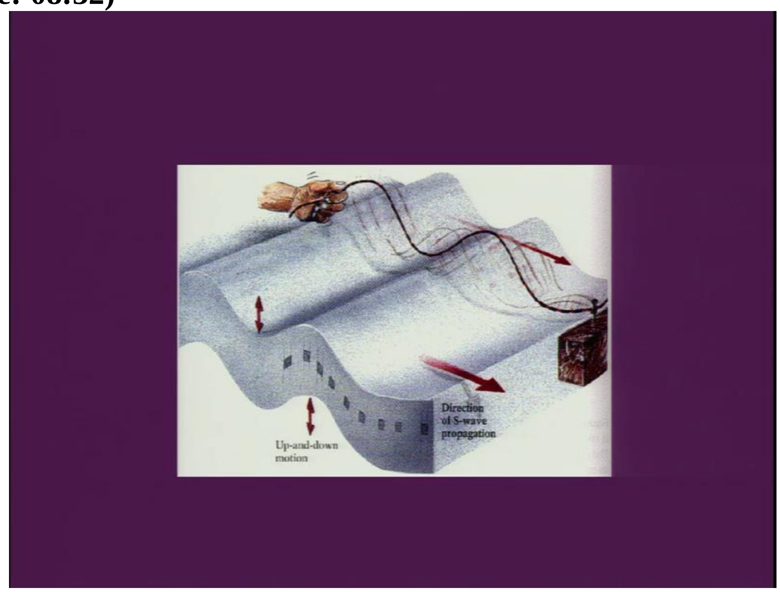

So, similar to this what has been shown so, particle moves up and down and the surface moves up and down so, this moves the motion is up and down in the direction of the propagation.

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So, during several earthquakes, some features are been left out on the Earth is surface and this is 1 of the example from 1999 to earthquake of Taiwan, where the S wave has moved and resulted into the down and up of the region and also the damage, which is a little bit by that.

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Similarly, we observed during 2001 Bhuj earthquake. So, the waved up bridge here is because of the passage of the estimate. So, any building or any structures sitting on the top of the surface will experience this up and down.

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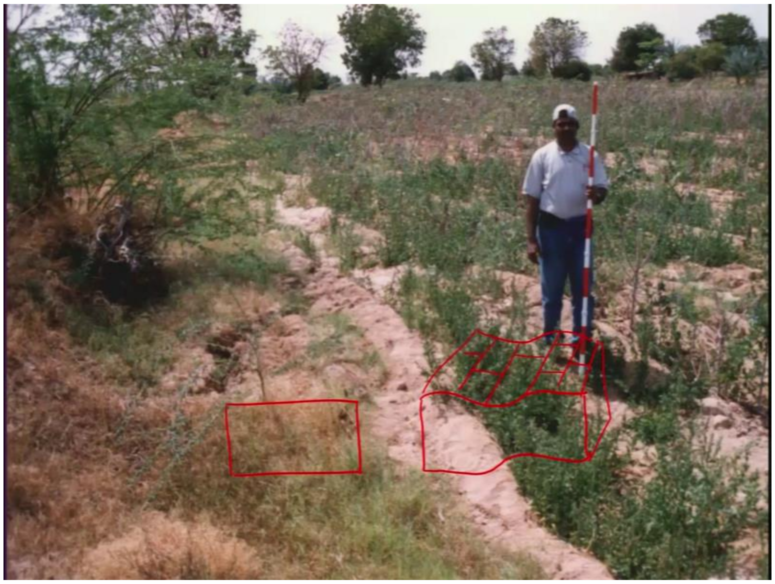

And similar was the case as the in the central area in 2001. You can see the waved up surface because of the passage of the S wave. Now such signatures of the passage of the S wave. Now that can also been taken into consideration. So, suppose you are having the as we have seen in the Chi Chi earthquake, that you are having this structure which is which was like this very well constructed and because of the passage of the S wave and you will find that the structure has been waved up.

Now, this features can also be taken into consideration when we are looking at the archaeological sites. And to some extent we were able to see the wave of platforms in the archaeological sites wherever they were been exposed and this understanding helped us in knowing that particular side was affected by the passage of the seismic wave.

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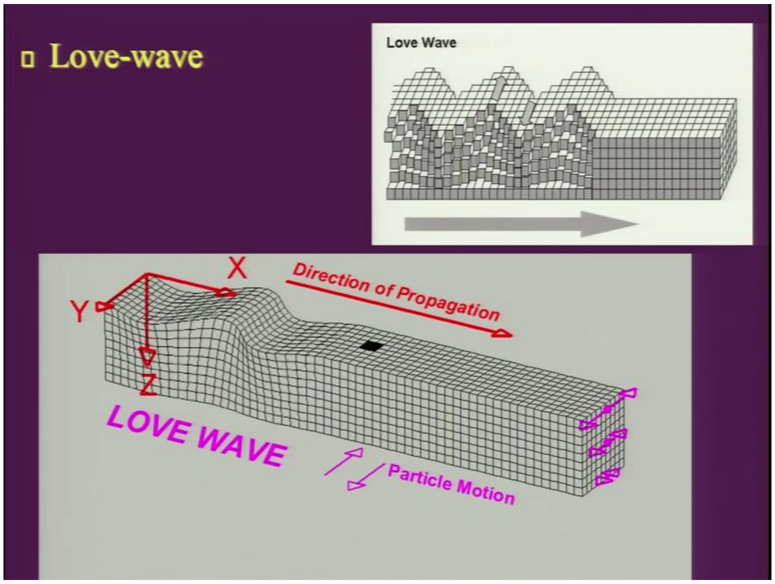

When coming to the next one that is the surface wave, we have love wave. Now, the love wave is having the combination of both it will make the surface move up and down as well as side by side. So, this is not typical way of the propagation of the S wave the particles are moving side by side and up and down.

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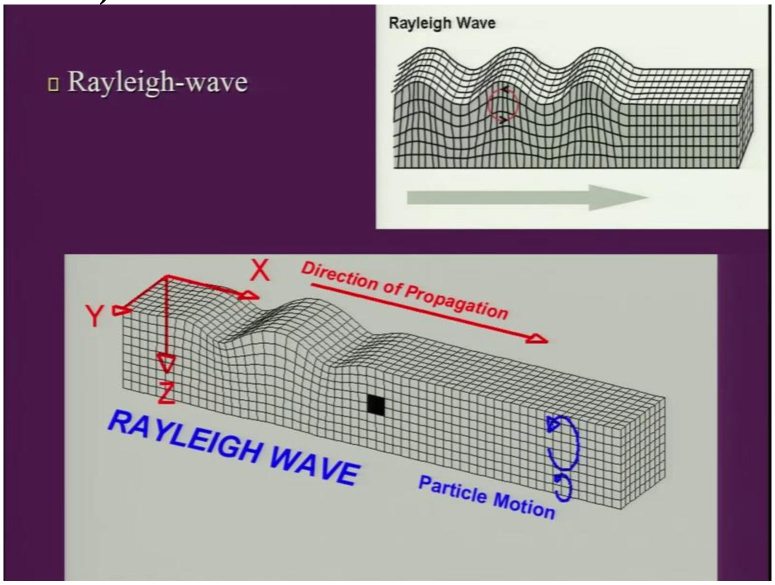

Whereas the Rayleigh wave you have an elliptical motion and the direction of propagation is in the same direction of the wave motion is the in the same propagation of the propagation of the wave.

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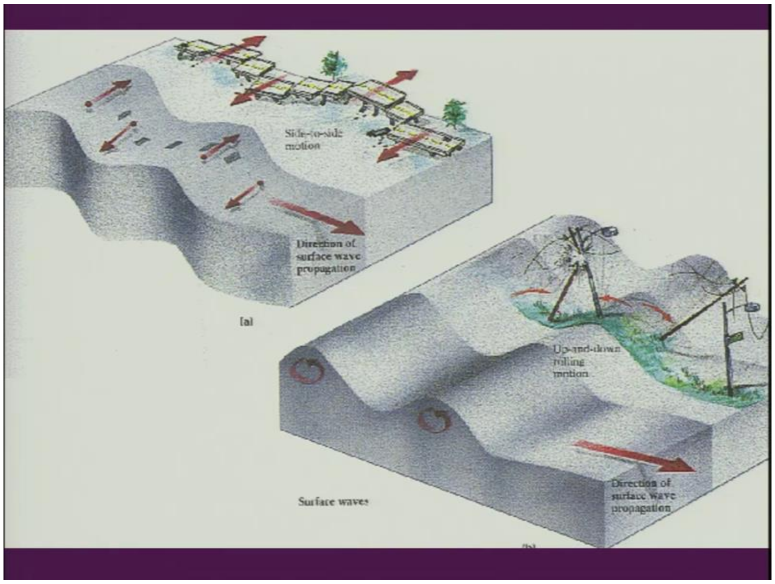

So, the love wave will move the and the surface side by side whereas the elliptical 1 will move the material up and down pay rate for example, if you are having 2 buildings sitting close to one another or you are having the light poles or trees, they will bank at a certain point because the oscillation of this 2 structures will be different. So, this will result into the collision and more destruction.

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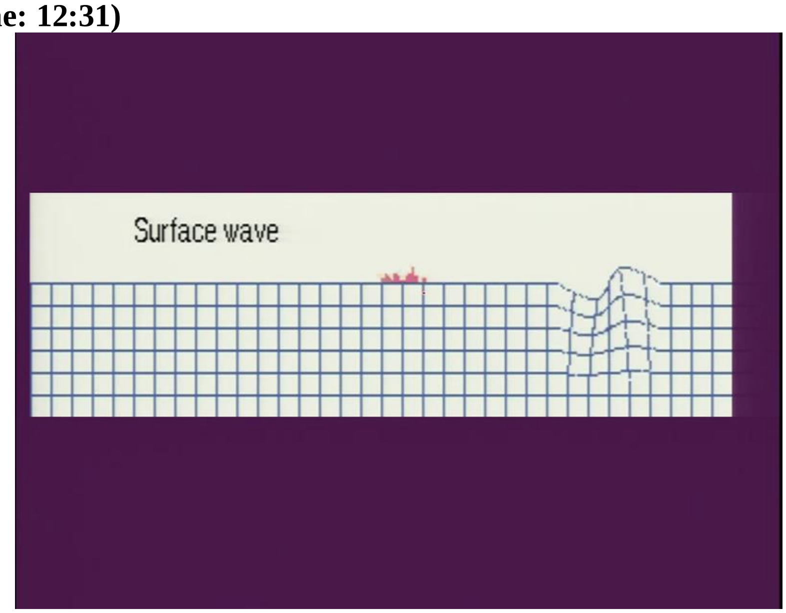

So, the surface wave when it moves, then it will completely destroy then this structure. So, in terms of the wave what we saw as this was partially damaged, but during the propagation of the surface wave, this will result into total damage.

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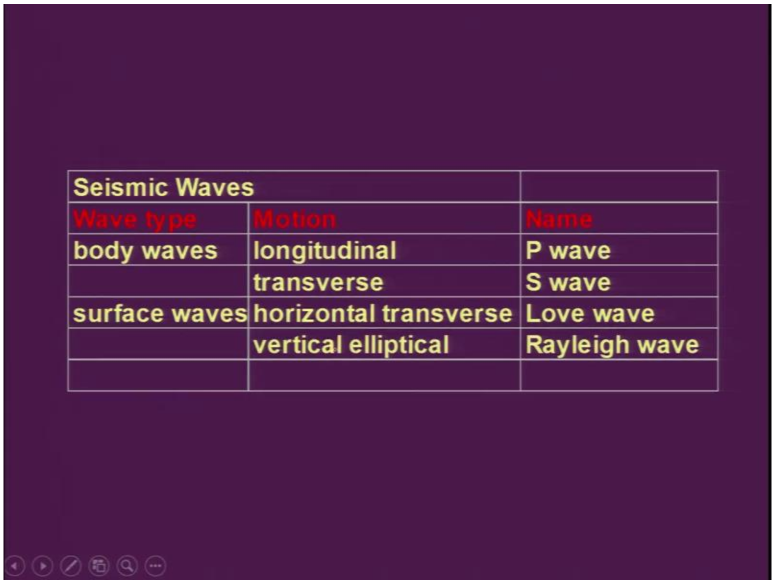

So, in short if we take into consideration the wave types are body wave and S wave motion longitudinal transfers for the body wave that is P wave and S wave and horizontal transfer love wave and then you are having vertical elliptical relative. So, this you should remember, because this is going to be helpful while understanding the overall damage patterns.

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Now, coming to the earthquakes some of you must have experienced the earthquakes, because we have experienced in 21st century mostly like 2001 then we had 2004 then we had 2005 then we had 2015 these are and talking about the major destructive earthquakes. So, 2001 was in Portugal and the western part of India and 2004 was in Andaman Nicobar subduction zone. And 2005 and 2015 in the Himalayan region.

So, as I was been emphasizing right from the beginning that we have 3 major regions, seismically active regions and all these 3 have experienced earthquake in the span of hardly 10 to 15 years starting from 2000 to 2015.

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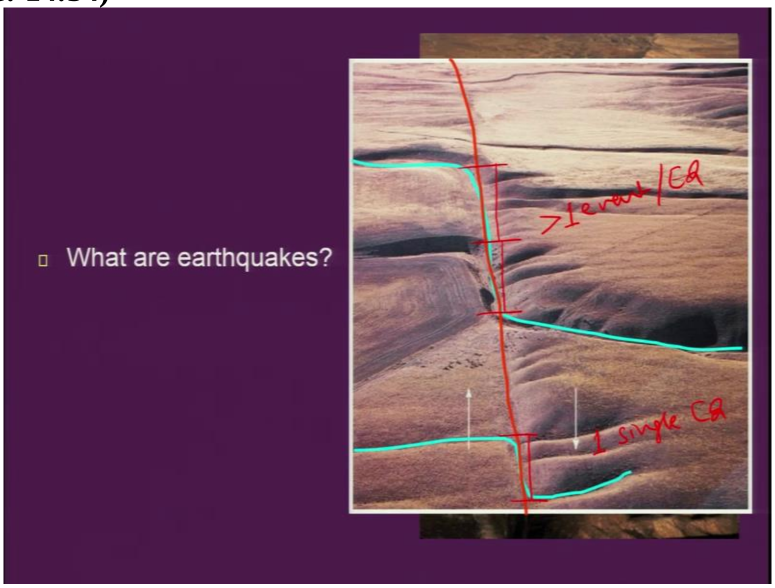

So, earthquake process is important before we get into the details of value seismology. So, earthquakes usually are the sudden release of the stored energy within the Earth is crust and will result into the displacement and the manifestation which we see on the surface will be something like this and these are the features which we are going to learn in detail that such features we will pick up. And we will try to understand that what is the history of earthquake on such features which are termed as fault lines?

And since they are active and capable of triggering earthquake in near future, as we termed this as an active false. So this photograph which I am showing the aerial photograph of the San Andreas Fault system, very sharp, a feature with that exist on the Earth is surface indicative of past the tectonic the formation, and likely to trigger the earthquakes in future along this one. So this is an example of a right lateral shift. So whatever the landforms you see on the surface, will also get modified because of the moment on the earth reaches the Earth’s surface.

So, 1 side what we see as here there is a very sharp line and the landforms that is your surface is been modified, where this portion is up and this is this portion is down and the moment which has been shown is by this 2 arrows that this block of the crust has moved in this direction and this is moving away from us so, this is towards right and we term this is right lateral strike slip fault this the strike that the orientation of the fault and the streams which are flowing from here are been deflected along this line.

And this will keep like the records preserved on the Earth is surface if they are not eroded and one can quantify that what is the amount of displacement which has occurred along this particular fall. So, for example, this stream has been deflected covering a larger area as compared to this one and we can say that this was the this stream recorded or was deflected during the recent or younger earthquake, but this one is having the cumulative amount of displacement So, if you take this lens here. So, this will be almost like twice over here.

So, this stream has moved in more than 1 event or 1 earthquake and this 1 during 1 single. So, this you can, easily make out using the expertise or the understanding of the landforms which are preserved on the surface. So, this is going to play an important role this what you can mark is the default line and this is what will play an important role in doing the initial identification of that default.

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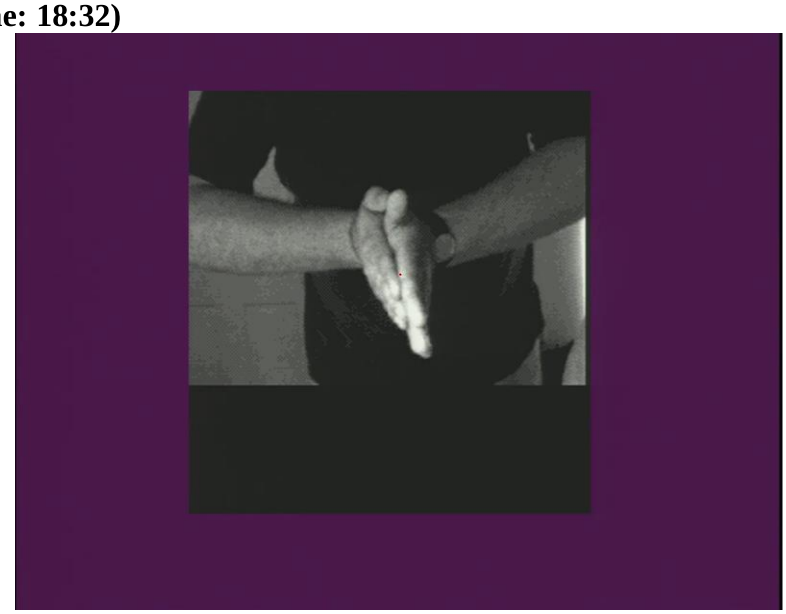

Now, earthquakes basically we see and the moment along the various fault lines is important and this is 1 of the best example which has been given by USES, or if you take your both hands and try to press along this contact and you apply force from your body arms and try to move along this one either you move towards your hand right hand side towards your side or you move this away and try to move with the pressure here. So, you are applying force and the strain is the building up our stored here along this line and the time will come it will slip.

So, when it slip it will give a shot of a jerk on you are either on this new on the audio enhance and that jerk basically is your earthquake. Similar thing happens in the interior of Earth. But what is important here is not how many such weak zones because this here we have just marked 1 weak zone here. But if you are having multiple weak zones and if you are compressing those weak owns by applying force.

So this for example, if you are taking this to arms, but if you say that this 2 arms represent the plate, different plate 1 plate here and other plate and they are colliding or slide trying to slide along this weak zone and they will and what rate it will slip.

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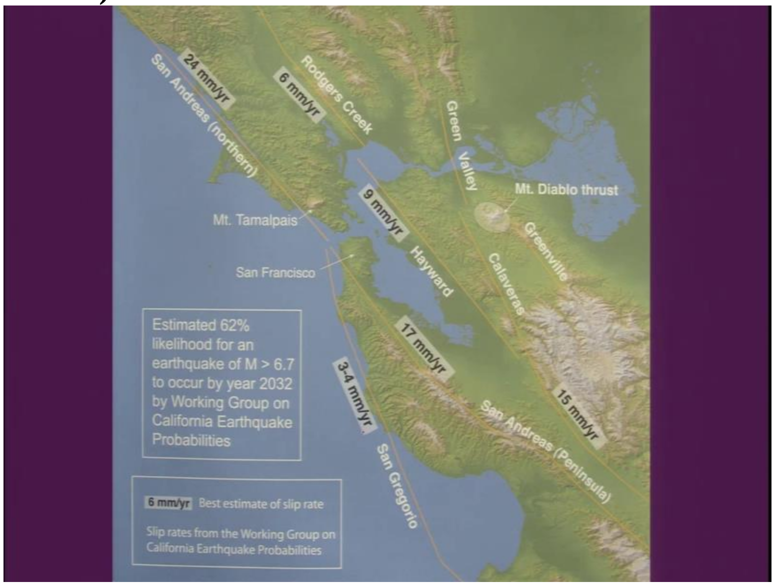

So in US and the most active zone is the San Andreas Fault system. So, San Andreas Fault system is not an single fault line along which the slip occurs again and again but it has many scrub plains and all the slip plains or the fault lines they behave differently in terms of the slip. So for example, on this fault we are having this slip is around 3 to 4 millimeter whereas on this fault it is around 17 millimeter and the 9 millimeter and the 6 millimeter. And they here along this 1 is almost along the 15 millimeter.

So, all this falls are slipping at different rate and this data is important for us because the larger the amount of slip consumed by the respective fault the chances of having the earthquake will increase in terms of the recurrence. So, the time period will be differ time period will differ on of the occurrence of earthquake on this different fault for example, this portion is having almost 24 millimeter. So, the recurrence along this fault line will be shorter as compared to us what we see on the other fault lines.

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So, another example which was been shown is that if you take the instead of just you are 2 arms or the palms, you put the playing cards, which are and it is playing cards or having different contacts and try to move. So, they will not move at the same speed or the same velocity, they will slip at different rate and that is what has been given here. So, for example, if you consider that the slip is taking place between the Pacific plate and the North American plate, which is the North American plate is moving like this and the Pacific plate is moving like that.

So, the different fault lines which are formed or the weak zones are formed because of this deformation will slip at different rate that what has been shown over here. You are having different slip rates per year, it has been given in millimeters. So, this can be identified based on battery seismic investigation, as well as this can be done using high resolution GPS measurements. So North American plate and the Pacific Plate.

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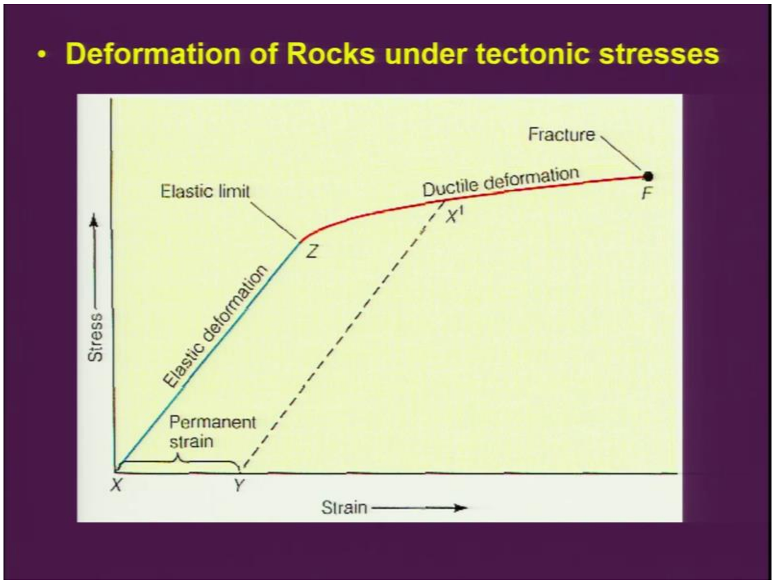

Now deformation of rocks under tectonic stresses. So, any rock or any location you take, usually it gets into the deformation pattern which has been shown here in a simple way. So you have you keep applying stress, you keep building up strain here, so the Earth's material in the Earth is crust will initially deform elastically and after the elastic limit of any material, it will get into the deformation of tactile deformation.

So, this is an elastic one that means, if you apply the stress up to this point, then it may come back because this is deforming elastically but after some time, then it will enter into the tactile So, what we see the folding of the material and finally, if you keep increasing the stress then the point will come it will fracture so, this is a threshold limit of any given material and this fracture is will result into the displacement and the this point at which it will fracture is you are earthquake event.

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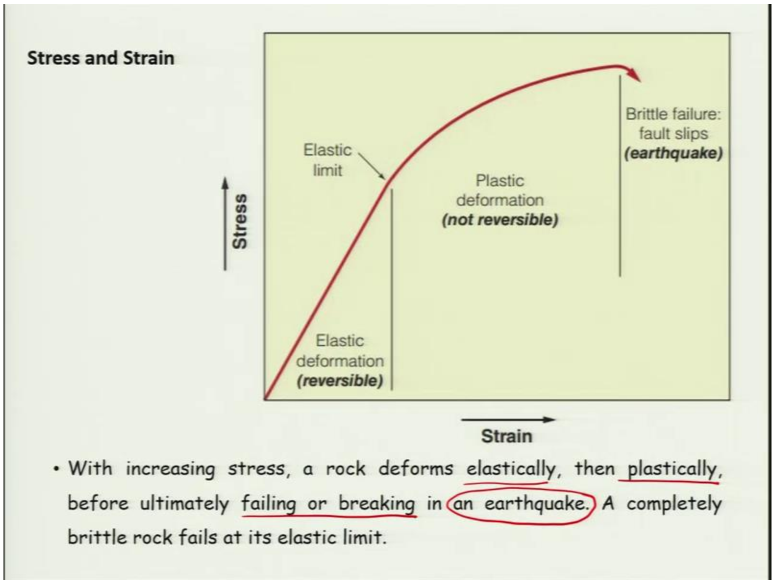

So, elastic deformation is reversible whereas the plastic one that is your tactile getting into non-reversible and then brittle that is your failure and third failure is on the fault slip and that failure or the fracture is your earthquake. So, with increasing stress or rock deforms elastically and then plastically before ultimate failing or breaking that is your failure, which is an earthquake a complete brittle rock fails at its elastic limit.

So, different rock or the material in the earth will have different elastic limit and plastic limit. So, depending on that, we will have a failure. So, this 1 very basic fundamental diagram which explains the deformation pattern of any material that is in the elastic plastic and brittle form.

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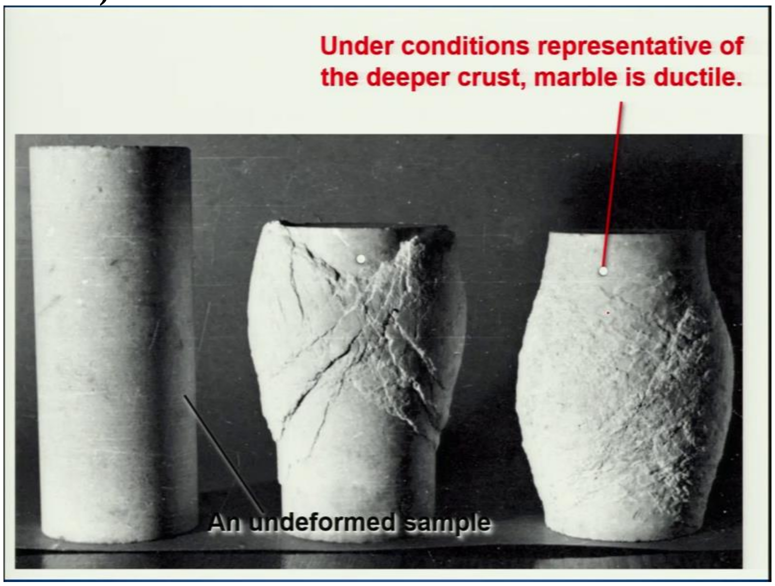

Now, there is different formation pattern will be different at different depth of the interior effort. So, for example, if you take the cylindrical core of marble or any material then initially if you have so, if you keep applying the same amount of stress it will deform differently at different depth this is what has been shown here. So, you have under the condition represented and shallow crust where the marble is as deformed in a brittle form.

So, you will see the fracturing but at the greater that what you are having the deeper part of the crust where you have high temperature and pressure so, it will deformed in a tactile manner. So, it will not break but it will change how the volume and it will deforming and tactile fraction. So, we can easily talk about that at if the deformation is restricted to the shallow portion, then we are going to see more faulting and earthquakes.

Whereas, the deeper one will not result into such the formation. So, this will be more dangerous as compared to the earthquakes taking place in the deeper part.

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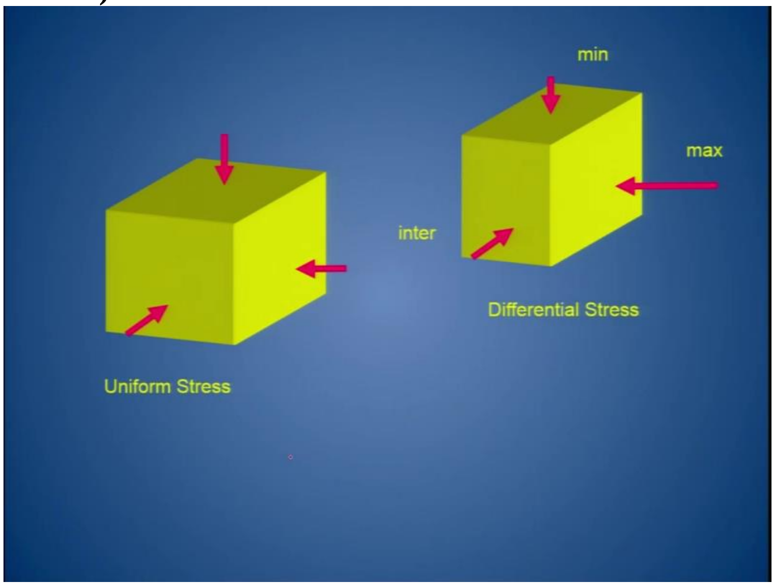

So, this is another example, which has been given that we have the stress pattern if you take sigma 1, sigma 2, sigma 3 in the deeper part, it will have uniform stress whereas, in the surface close to the surface of the crust, then we have differential stress. So, mostly what we see the deformation pattern that is a building up of the mountains and the fracturing on the surface has because of the differential stress. So, where you have the sigma 1 is the maximum and intermediate and minimum one then sigma 1, sigma 2, sigma 3.

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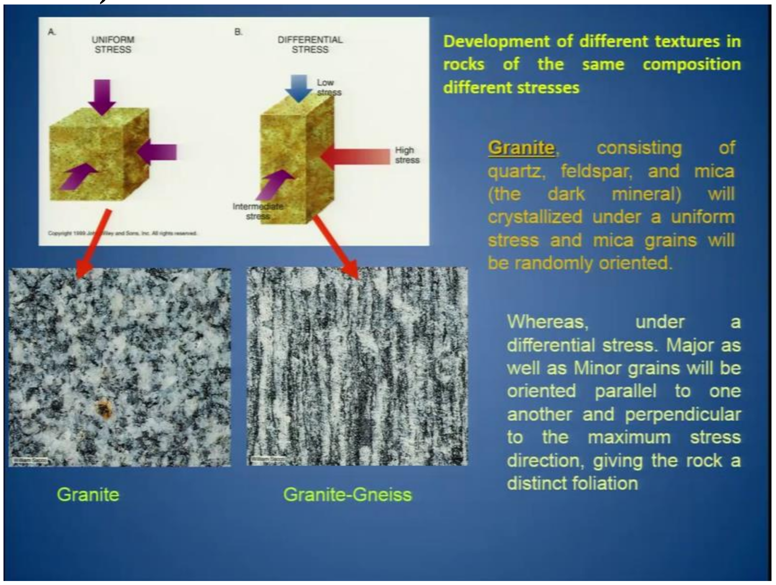

So, for example, further if you take the uniform deformation, this is the picture of an infinite, then you see that they are uniform to deform, but if you are subject the same rock to differentiate stress, then what you see is preferred orientation. So, the granite consisting of quartz, feldspar and mica, which has been shown his the darker ones will crystallized under a uniform stress and mica grains will be randomly oriented.

So, this is what randomly orientation has been seen during the time of or under uniform stress but when they are subjected under the differential stress, Major as well as Minor grains, and that is we are talking about the minerals here will oriented parallel to the parallel along with respect to one another and perpendicular to the maximum stress. So, this way, they will be aligned or oriented perpendicular to the maximum stress direction giving the rocks to distinct foliation.

So, in metamorphic rocks we see foliation which are indicative of that they have undergone in deformation of the differential stress and similar thing happens on the Earth is surface, where you see deformation of the folded mounting chain which are parallel to one another, but they are exactly perpendicular to the highest stress direction.

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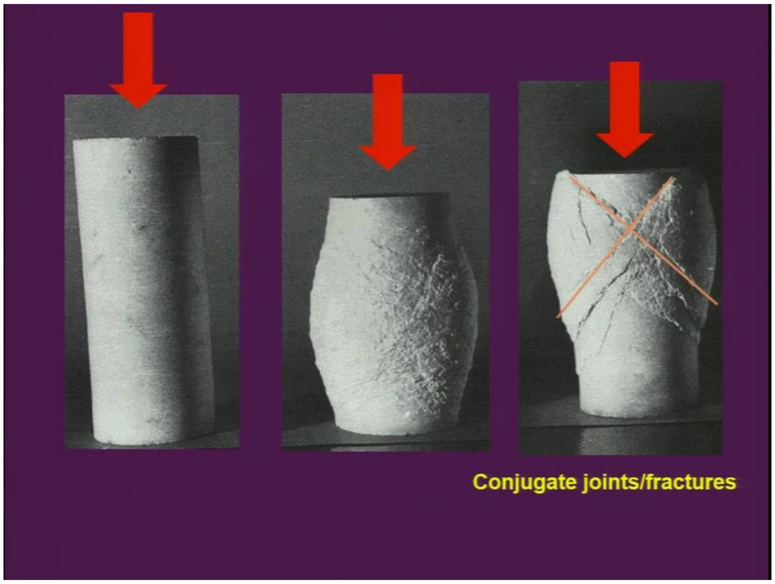

So, this is just to show the fractal pattern. So, you will have mainly the conjugate fault which are developed, if you have the brittle deformation.

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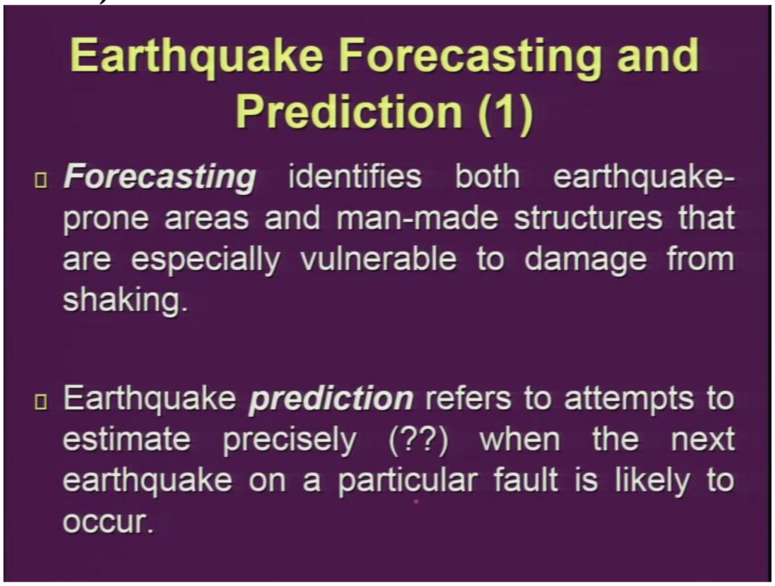

Then earthquake forecasts and prediction. This is another important one, where the seismologists mainly use this information to predict or forecast the earthquake and this basically based on the micro seismic activity the recording of the micro seismic activity, but this sometime, but has proved successfully by they have had been able to identify the event successfully, but in most of the cases, they failed.

But, yes, of course, if you monitor very precisely, then one can easily make out that they will be in major earthquake in near future. So, forecasting identifies both earthquake prone areas and management structures that are especially vulnerable to damage from shaking. So, I think the ultimate goal is to reduce the damage pattern. So, the forecasting is important for the earthquake prone areas as well as for the management structure what whether they are vulnerable to the particular earthquake or not and in particular region.

So, earthquake prediction refer to attempt to estimate precisely and that is why I have put the question mark here, not to some extent we can but not always when the next earthquake on a particular fault is likely to occur. So, I will stop here and we will continue with the next lecture. Thank you so much.