Engineering Geology
Prof. Debasis Roy
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

Lecture - 31
Plate Tectonics -2 and Earthquake Characteristics

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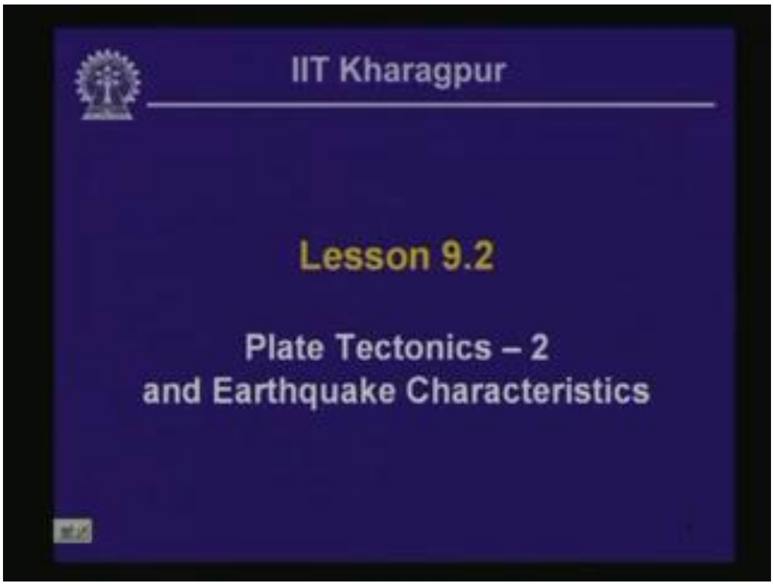

Hello every one and welcome back. Today, we are going to continue with our unfinished discussion on plate tectonics to begin with. And then we are going to move onto look at a few important characteristics of earthquakes.

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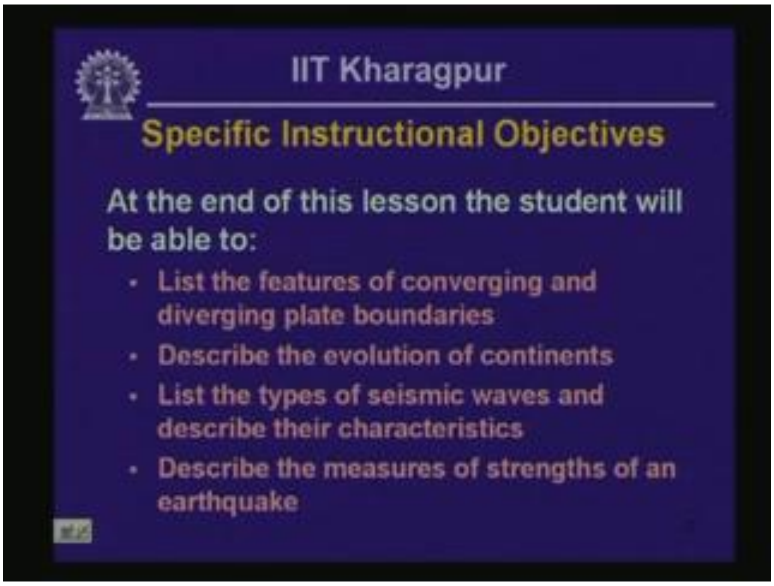

Now let us get on with the objectives of what we want to try to accomplish at the end of this particular lesson. At the end of this lesson, we would like to be able to list the features of converging and diverging plate boundaries; we started looking at this aspect in the last lesson itself, and we are going to continue and complete this discussion. Then we would like to able to describe the evolution of continents; this is also really an unfinished objective of the previous lesson continuation, in fact of the previous lesson. List the types of seismic waves and describe their characteristics; this is a new topic. And describe the measures of strengths of an earthquake.

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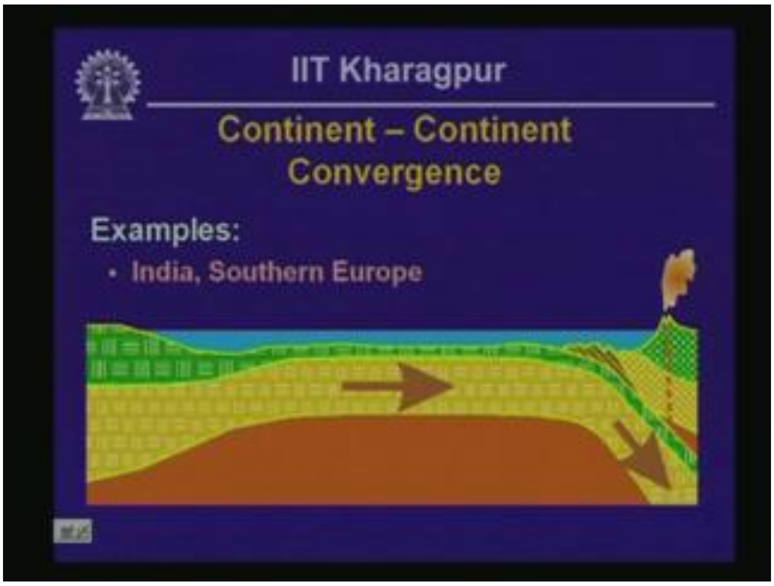

So, let us move on with the continent to continent convergences, the third type of convergence which we want to look at. We have already looked at the convergence between an oceanic plate and a continental plate and as well as we looked at convergence of two oceanic plates. Now here what we are going to look at is convergence between two continental plates.

One of the examples of this type of convergence is the Indian plate colliding with the Eurasian plate and the plate boundary where that is taking place is the Himalayan mountain ranges. And also there is another example for this type of convergence and that is in the southern part of Europe where again there is another very important mountain range which is the Alps.

Now this type of convergence actually begins as you can see on this particular cartoon here as a convergence between oceanic plate and a continental plate. So, in the cartoon shown here the section shown here, basically you can see all the features that we have already discussed when we were talking about the convergence between an oceanic plate and a continental plate.

So, here what you have got is the oceanic plate on your left and the continental plate on the right. And you can see here the accretion zone shown by cross-hatched brown jagged areas near the right corner underneath the ocean. And then you can see the volcanism which is typical of convergence between oceanic plate and continental plate towards the right end of this particular section.

And as earlier, a subduction is taking place where the oceanic plate is actually moving underneath the continental plate. You can see what I try to do here is to maintain the same type of color scheme and hatching scheme as we have discussed near the end of the previous lesson; in that, the lithosphere is indicated by actually green and orange scripted layer, whereas asthenosphere is indicated by flat orange deep orange layering as was done in the previous cases.

And the direction of plate movement is shown by three thick brown arrows, and that is also the same type of symbol that we used when we discussed about the convergence between two oceanic plates and one continental and one oceanic plate. So, as I mentioned that this particular convergence begins as a convergence between an oceanic plate and a continental plate.

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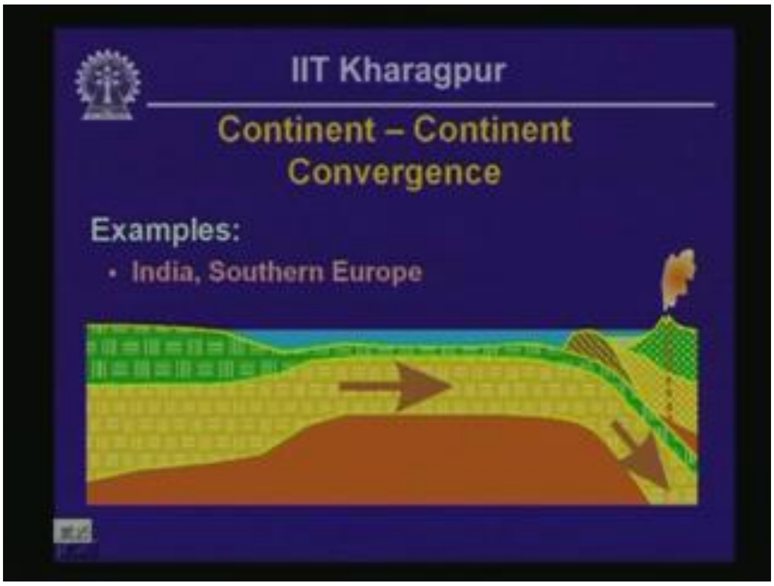

And then basically what happens? The ocean starts getting squeezed; the distance or the area which is covered by the ocean, it gets narrower and narrower as the continental mass towards the left starts moving further to the right. And what happens? The outcome of that is that you can see that the zone of accretion actually starts piling up; actually it becomes higher and higher, and the margin of the continental plate also starts piling up.

Another thing you should notice here as well as in any ocean to continent convergence is the trench that develops near the location where the oceanic plate starts subducting. And that is because there is a frictional locking really of the continental plate near the shoulder, where the dip of the oceanic plate suddenly starts to increase. What happens actually there because of the frictional locking? The continental plate is really dragged down a little bit along with the subduction of the oceanic plate.

And as a result, a trench generally develops near the location where the oceanic plate goes underneath the continental plate, and that particular feature is called a trench. And, in fact, there are examples of very significant trenches near the margins of oceans such as the margins of the Pacific Ocean near the Philippine near the island chain of Philippines. There is a very deep trench called Marianas Trench, and that is, in fact, one of the deepest features on the surface of the earth, where depth of the trench is, in fact, greater than the entire height of the Himalayan mountain range, okay.

So, now, we continue with the discussion on continent to continent convergence. Here the continental plate on the left starts actually is moving as you have seen already to the right, and the ocean mass the area underneath the ocean has squeezed has become smaller as a result.

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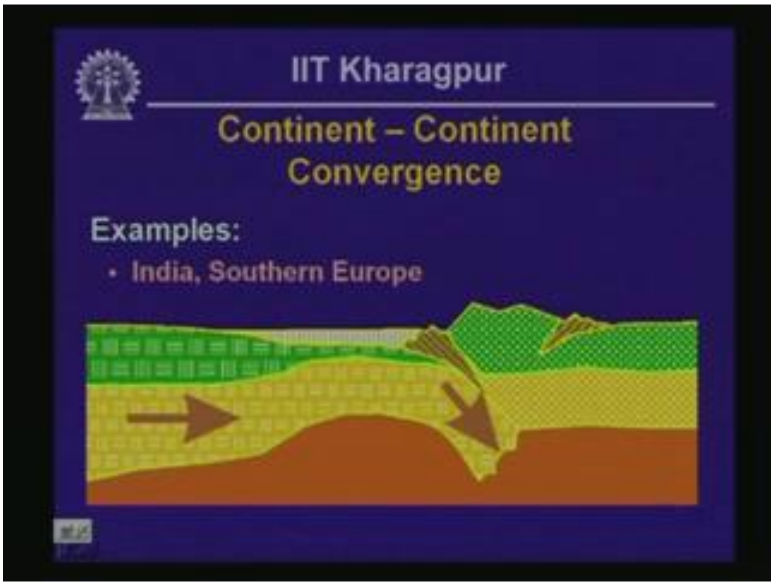

And finally, what happens? The ocean is going to completely get eliminated totally, and the area between the between the new continental plate between the continental plate on the left and the continental plate to the right. The shallow water bodies, they get readily filled up with sediments, and that is indicated here with a grey hatched block in between the plate on the left near the centre of this particular cartoon actually.

You can see one important feature to notice here is that since continental plates typically are of similar density, the subduction action of the one continental plate underneath the second one, it gets muted; it does not want to go down underneath to the continental plate. And what ends up happening is really sort of a head on collision between the two continental plates without any significance subduction as you can see here is that the deep subduction what we saw in the previous cartoon is absent in this particular cartoon. And what happens? The collision of the two continental plates gives rise to the pushing up actually of a significant mountain chain at the boundary of the two plates.

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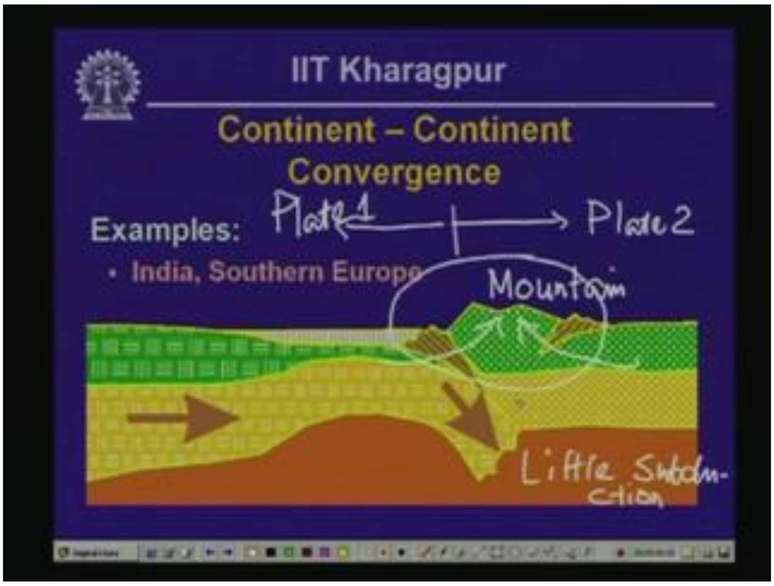

And that is indicated here in this area where the continental plate on the left is coming and colliding with the plate on the right actually. So, this one is one plate. Let us call it plate two, and this one is plate one. And, in fact, the collision here is almost like a head on collision with very little subduction in this area little subduction action, and a mountain chain starts building up because of the collision. And the height of the mountain chain keeps on rising as the convergence progresses, okay.

So, this is the process basically of continent to continent convergence, and as we have seen an example a present day example of the mountain chains that develop as a result of continent to continent convergence is the Himalayan mountain chain as well as the Alps of southern Europe. Now what I want to stress, what I want to emphasize at this point is that you should realize that there is a huge change in the stress regime near the plate boundaries because of the convergence activities that goes on.

And this particular change in stress regime thus indeed lead to failure of large blocks of rock, and the outcome of that failure of the large mass of rock is essentially an earthquake So, always what we see is that there is a preponderance of earthquake activities near the plate boundaries; that is not to say though that all the earthquakes that are being recorded so far takes place along the margins of plates. There are earthquake activities near the middle of continental plates, and we are going to look at the details;

why those kinds of earthquakes happen or occur later on in one of the future lessons of this course.

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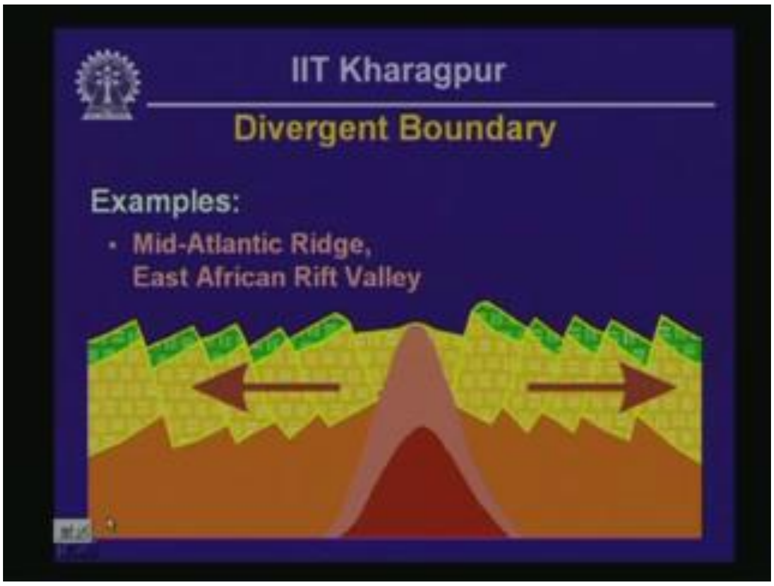

We have got one more thing to consider here. And that is the process of divergence. Basically, divergence takes place near where magma plume comes and daylights near at the surface of the earth. And that typically takes place where the thickness of the plate or thickness of the lithosphere is minimum; typically, that happens near mid-oceanic ridges. We are going to look at some of the examples in the next slide. One of the examples I have already shown in the previous lesson and that was the the example of mid-Atlantic ridge; that is an example of a mid-oceanic spreading center.

Then there is another one; that is a continental hot spot really at the middle of an existing continental plate, and that is the east-African rift valley. We are going to look at these both of them, the locations of these features in the next slide, but before that let us look at the features associated with the divergent boundary. What happens here is that the thickness of the lithosphere is really very less, and as a result, magma is pushed; it gets pushed to the surface. And as it pushes, it moves the existing rock laterally away from the spreading center. And you can see that in this particular cartoon or vertical section where thrust faulting takes place.

Actually it is not so much of faulting because of the rate elevated temperature regime at which this particular thing goes on this type of divergent; at the divergent boundary, the temperature is so high that the rock really even in the lithosphere, it is quite ductile. And as it gets pushed away from the centre of spreading, it cools off and solidifies. And because of the fact that because of ductility and because of the lack of thickness of brittle rock available in this area, basically what we typically see is that near spreading centers; whatever earthquakes take place, they are of relatively of much smaller strength than the earthquakes that occur near convergent boundaries. Now these are the features really associated with a diverged boundary, and that could be as I said at the mid-oceanic ridge or at a continental rift valley; active rift valley as we are going to see in the next little bit.

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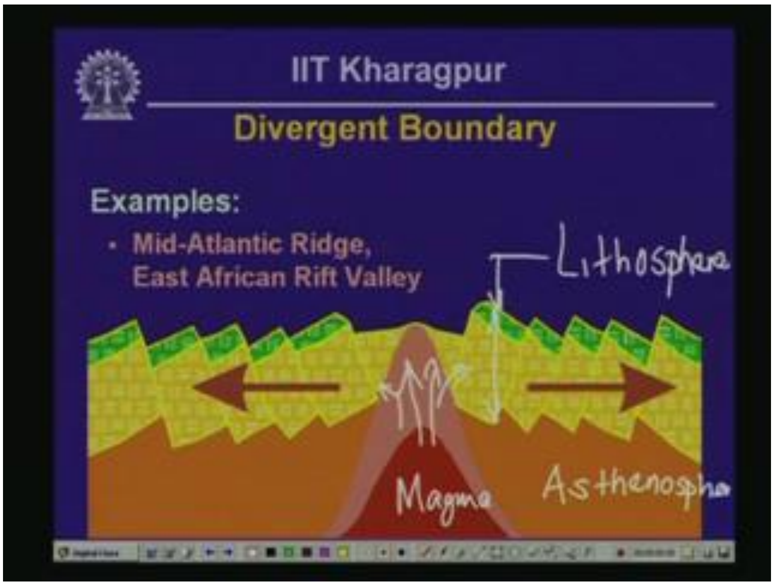

So, here this is the magma chamber as is evident; this is the magma chamber. And magma gets spud out and that spewing out itself actually triggers the lateral movement of the continental crust. And as earlier this one, the orange shaded area indicates asthenosphere, and this one the thickness this thickness here is the crust or lithosphere really. This is the lithosphere, alright.

So, that actually takes care of the plate boundaries. There is another type of boundary as I have already mentioned, and that is called transform boundary. And as I have indicated in the previous lesson is that transform boundaries, one plate slides past another. And there is no subduction takes place normal; no reverse faulting takes place; basically, reverse faulting or normal faulting takes place. And an example of such type of boundary is near the south west coast of United States.

Now before I quit this particular slide, I want to mention that at the spreading boundary, basically what you get; I want to emphasize this point is that at the spreading boundary, typically, the earthquakes are much less severe than the earthquakes that are observed at the convergent boundaries. And, in fact, the largest earthquakes that have been recorded do take place near the area where an oceanic plate is subducting underneath a continental plate, alright.

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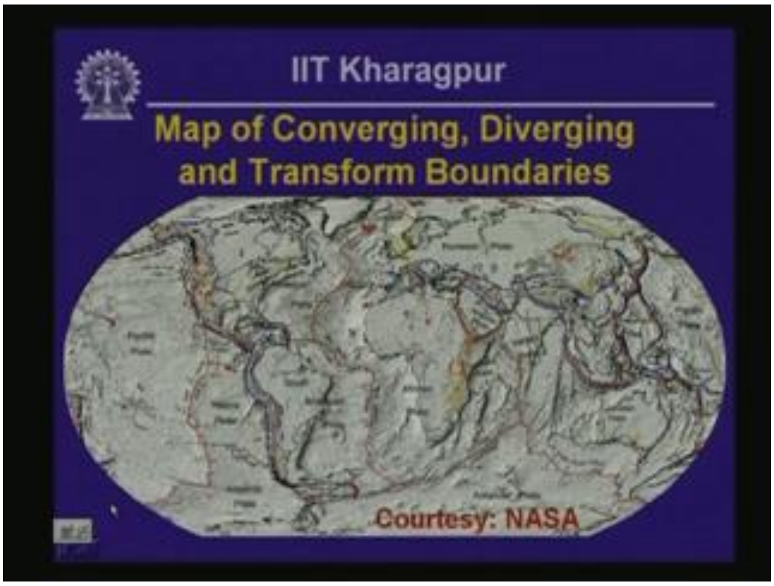

Now this particular map, this has been taken from NASA. This particular map actually shows all the plate boundaries of the earth, and we have seen these plate boundaries earlier. But here we look at the plate boundaries in the light of what we have learnt so far after we finished the convergent, divergent and transform boundaries. And here all the different plate boundaries are separated color quoted separately.

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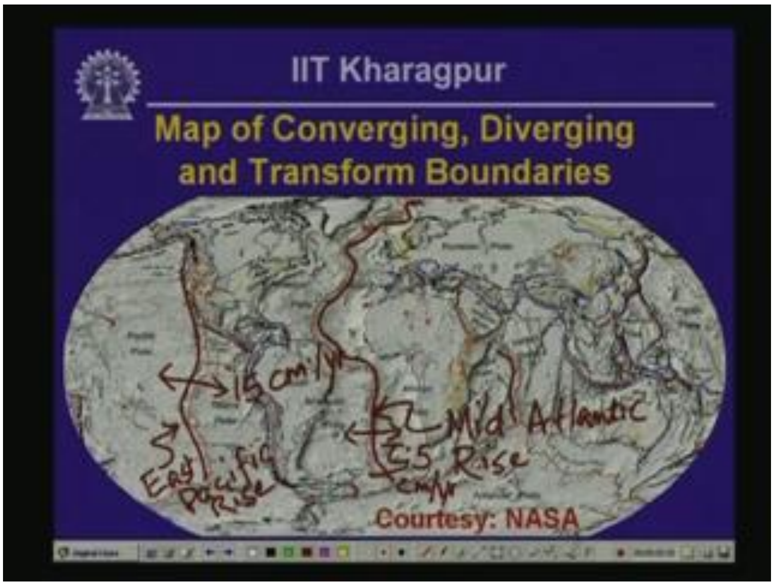

So, the red coded plate boundaries here such as these such as here, here and here. They represent spreading boundaries where ocean floor is spreading apart, and the researchers have also estimated a rate of spreading. So, for instance, the spreading rate at the east pacific rise; this one here is the east pacific rise; this one here is the east pacific rise. That is the feature of the plate boundary here is very similar in nature as the mid Atlantic rise east pacific rise is this one. And this one here is the mid-Atlantic rise which we have looked at earlier.

Now the rate of spreading at east pacific rise has been estimated to be about 15 centimeter per year, and that is one of the largest spreading rates that has been estimated anywhere on the surface of the earth. In comparison, the spreading rate at mid-Atlantic rise is about 3.5 centimeter per year. So, those are the spreading boundaries spreading centers and then what you also can see on this particular slide is that there are blue coded plate boundaries, and these areas there is a convergence going on.

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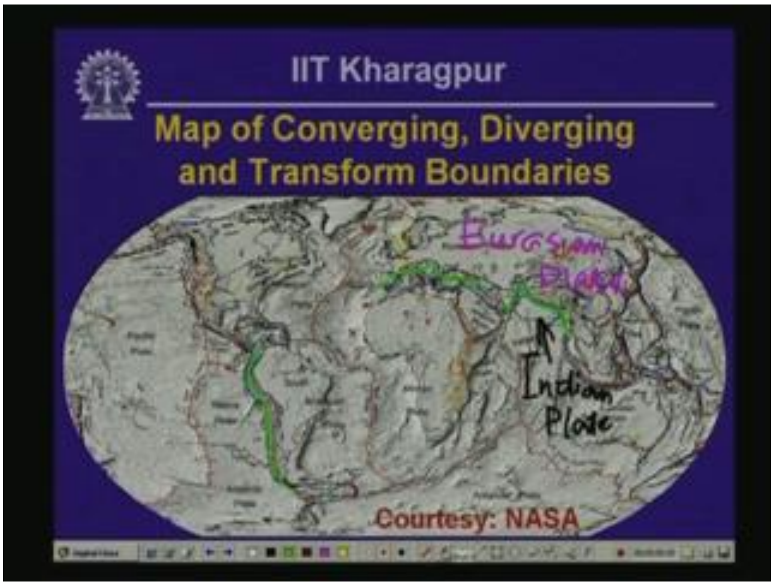

One example of that is the northern boundary between the Indian plate and the Eurasian plate. So, this one here this one here is the Eurasian plate, and the Indian plate is here. So, this is the Indian plate. So, you can see that there is a convergence because of the fact that the Indian plate is moving up towards the north predominantly. As a result, there is converging boundary at the top at the north end or the northern margins of the Indian plate. There is a similar converging boundary along the west-coast of South America and along the margins of the Mediterranean as we have already seen. Now I also want to mention want to indicate on this slide.

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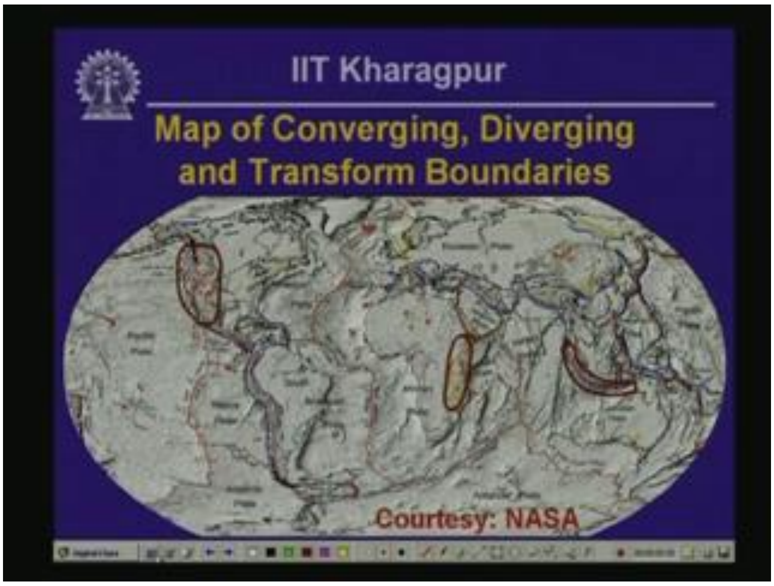

I want to highlight on this particular slide is the mid-oceanic or rather a spreading center along the eastern part of the African continent, and this is called the east-African rift valley. Here what is happening? A spreading is going on really in that manner which is very similar in nature as the spreading that takes place near the mid-oceanic ridges. Now you can see some red dots; you can see red dots actually at many places on the surface of the earth.

For instance, at this location here near the western part of the North America at many locations there, along the African rift, then along the boundary near the archipelago of Indonesia. These areas basically are the centers of volcanism where the plate thickness is little bit limited, and magma is actually day lighting on these areas along these centers. So, these areas are called hot spots where magma is getting ejected on to the surface of the earth, okay.

So, these are the plate boundaries and different features that are associated with the volcanism at the plate boundaries and within the intra-plate areas. Now we can look at the history of the earth or really how the continental how different continental plate, they started evolving from very early on in the geologic history of the earth. I want to mention here is that what we are going to see what we are going to look at is the evolution of continents or the the maps of the globe as we see. And what was the appearance of these continents way back in geologic history and what would it be like in the far future.

Now these inferences have been drawn from the idea of oceanic or from the fossil evidence within the rock masses, dating of rock formations that are found in different parts of the globe. And these allowed actually rock masses to be correlated from rock masses within one continent to be correlated with that in another continent which are relatively separated by a vast expanse of ocean or some other continental masses at the present time. And the rate of movement of the plates at the present time has been extrapolated, and that allowed us to visualize what the earth would look like or what the continents would like in far future.

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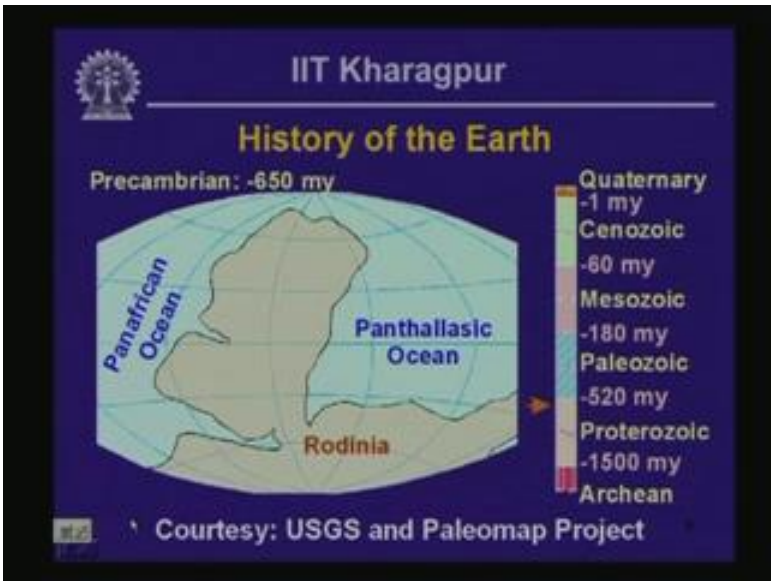

And that is what has been shown on these simplified maps. I got this information from information shown on these maps from USGS and from a project which has been completed recently called the Paleomap project, okay. What is shown on this particular cartoon is how the earth looked like 650 million years ago in the Precambrian age. And on the right what I have shown on this particular cartoon is a bar chart showing showing the names of different geologic ages and the boundary between our geologic eras really and the boundary between these geologic eras.

For example, before I move on let me explain that looking at the bar chart on the right of this particular slide Archean age or Archean era is a 3000 million years long geologic era which began from about 4500 million years ago, and it lasted until about 1500 million years ago from present followed by proterozoic that lasted between 1500 million years from now to 520 million years from now approximately followed by paleozoic between 180 million years ago and 520 million years ago followed by mesozoic which lasted between 180 million years ago to 60 million years ago.

Then we have got cenozoic which lasted between 60 million years ago and about 1million years ago, and the present geologic era is called the quaternary which started about a million years ago counted from now. So, that is the bar chart; that is explanation on the bar chart which you will see on each one of these slides that are going to come right after this particular one. And there is an arrow orange arrow on the right side of the bar chart that shows the approximate timing of the map of the earth that is shown on the left.

So, the map of the earth that is shown on the left is actually the one in the Precambrian era which is approximately 650 million years ago. And at that age, there was a super continent called Rodinia. And what we have got on the left of this particular map is Panafrican Ocean and on the right is Panthallasic Ocean. Now look at how these continents breaks up.

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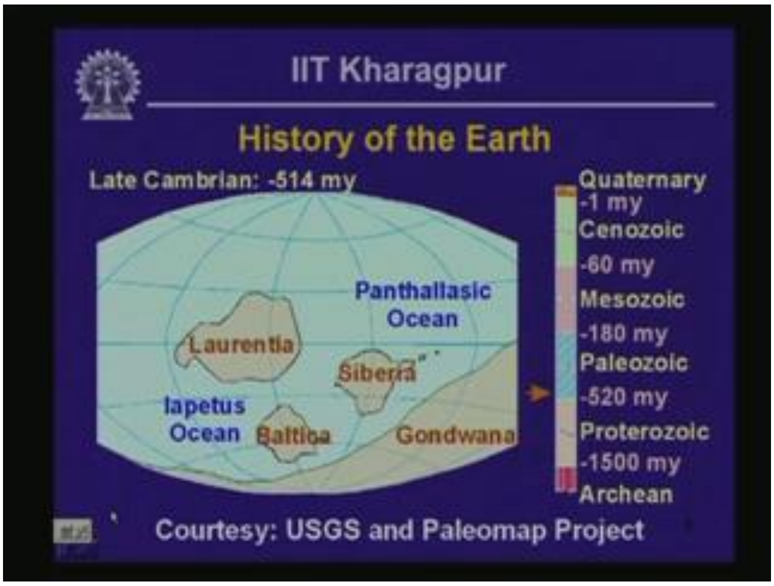

About 514 million years ago, the map of the globe looks somewhat like this. What you have got here is a super continent near the southern edge southern periphery southern end of the globe called Gondwana. And there were three continents little bit further north. Laurentia, Baltica and Siberia, and Laurentia really is the land mass which forms which covers much of North America at the present time So, this is the map of the globe that was there in the Precambrian age about 514 million years ago.

Precambrian, in fact is a part of the Paleozoic geologic era. It is near the beginning of the Paleozoic era. What you have got here is an ocean near the south west called Lapetus Ocean, and you also have got Panthallasic Ocean as earlier.

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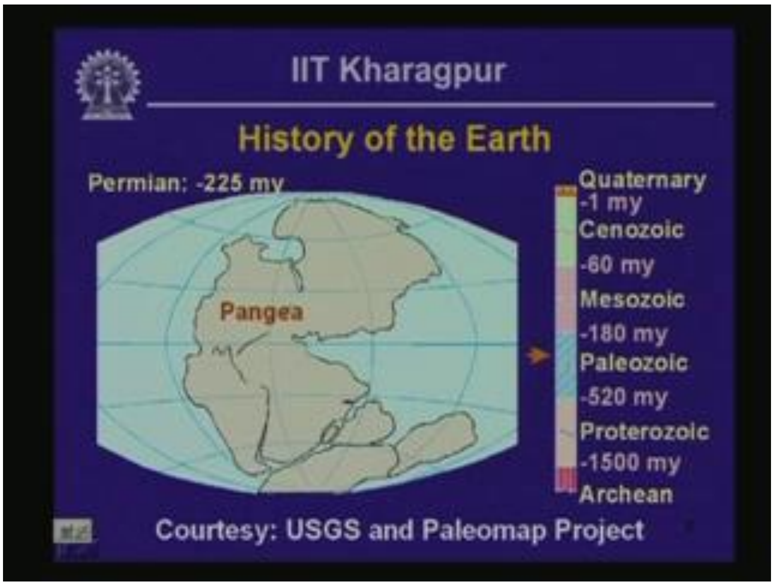

Then we look at the map as it looked like about 225 million years ago. You can see the formation of a super continent here, and this is called the super continent of Pangea. And you can see the outline of the present of the modern continents started evolving; you can see the outline of the South American continent towards the bottom left of this particular super continent called Pangea. Africa to the bottom right just east of South America, then on top of South America is the present day North America.

And Eurasia is further to the north and east to the north eastern corner of the super continent of Pangea. This was how the map looked like in the Permian age about 225 million years ago. And we are still in the Paleozoic era as in the previous slide.

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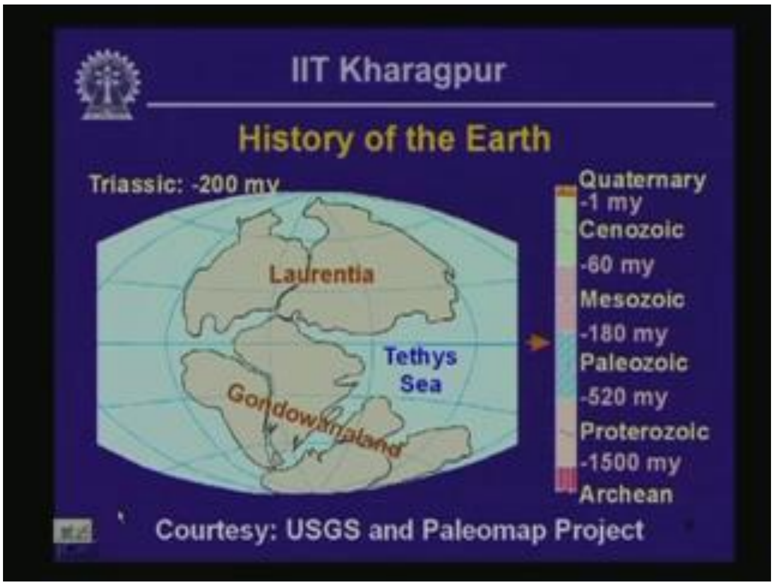

Now we move on to Triassic era about which is about 200 million years ago, and you can see the super continent of Pangea has started breaking up. We are still in the Paleozoic geologic era, and here the continents have started breaking up as we can notice here with the Laurentian continent near the northern part and Gondowanaland. This is another super continent which is starting to build up towards the southern peripheries and between Laurentia and Gondowanaland, we have got the Tethys sea.

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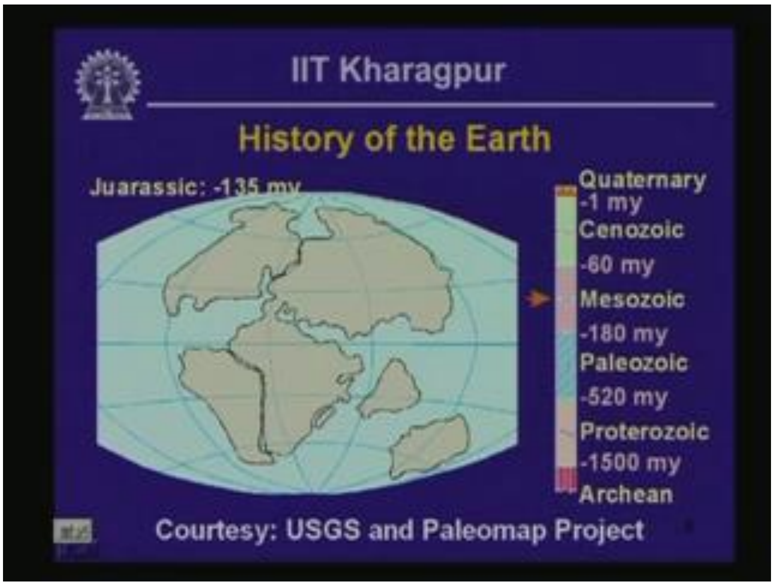

Let us look at what happens further down in the Jurassic age which is near the middle of the Mesozoic geologic era that is being kept track on the bar chart on the right. And you can see here that the outline of the continent of Africa and the south American continent, they are still together, but India has started drifting away from Africa. It is starting to drift north and east, and you can see here is that the Eurasian continent is still in contact with the North American continent.

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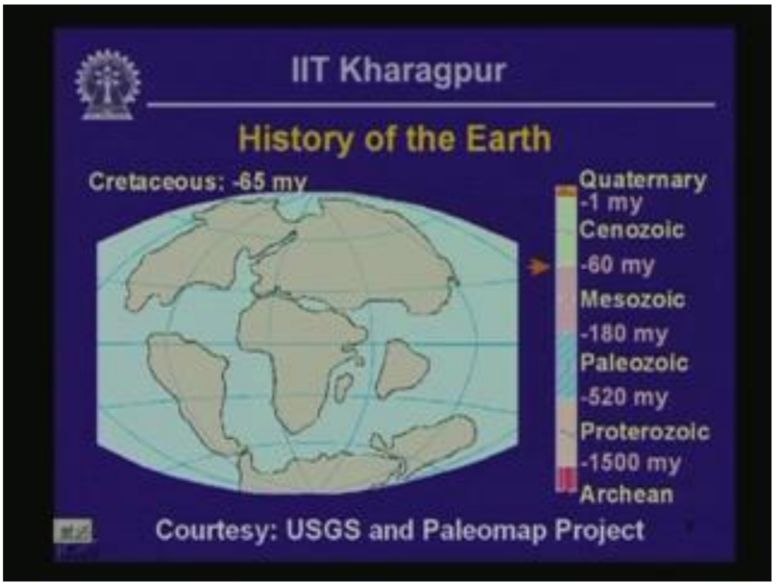

Cretaceous 65 million years ago and we are pretty much near the boundary of Mesozoic and Cenozoic geologic era. And you can see that Atlantic Ocean is starting to open up between Africa and South America, but the North American continent is still in contact with the Eurasian land mass. And India is still drifting further; the Indian plate is still drifting further to the north and east.

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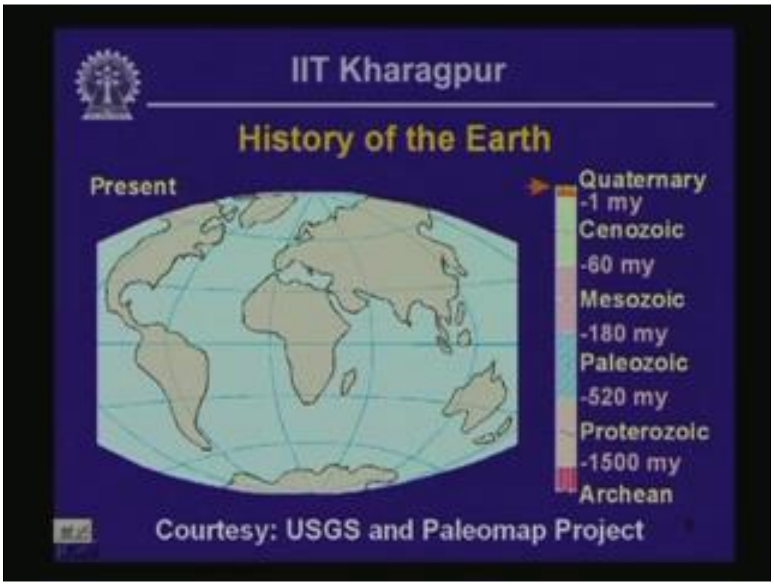

In the present map, India has already collided with Eurasian plate; the Atlantic Ocean has opened up right from the North Pole to Antarctica.

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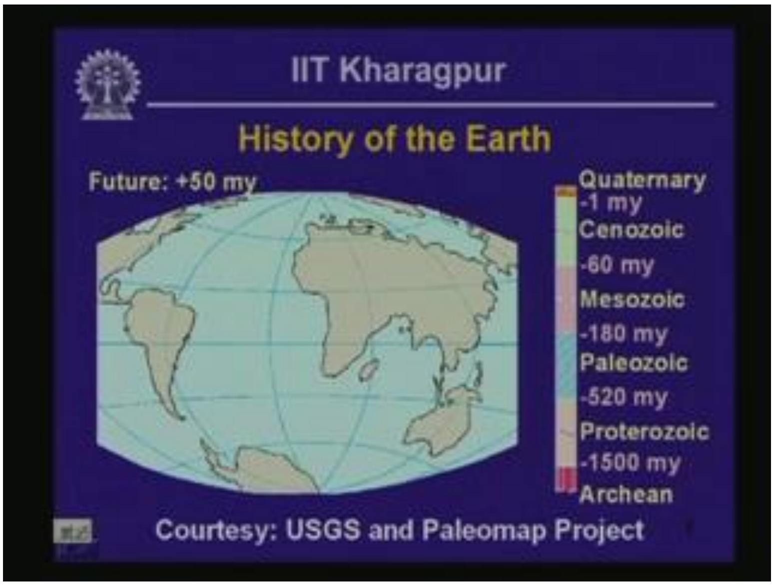

And let us look at what happens 50 million years ahead in future. Atlantic Ocean opens up even further, and what you can see is that the Mediterranean Sea has closed up. And the continent of Africa is in contact is totally converged with the Eurasian continent. And you should also notice that the Indian plate is actually sort of rotating in the clockwise direction from this particular view point. Also you can see a part of Indonesian archipelago is expected to converge with the continent of Australia.

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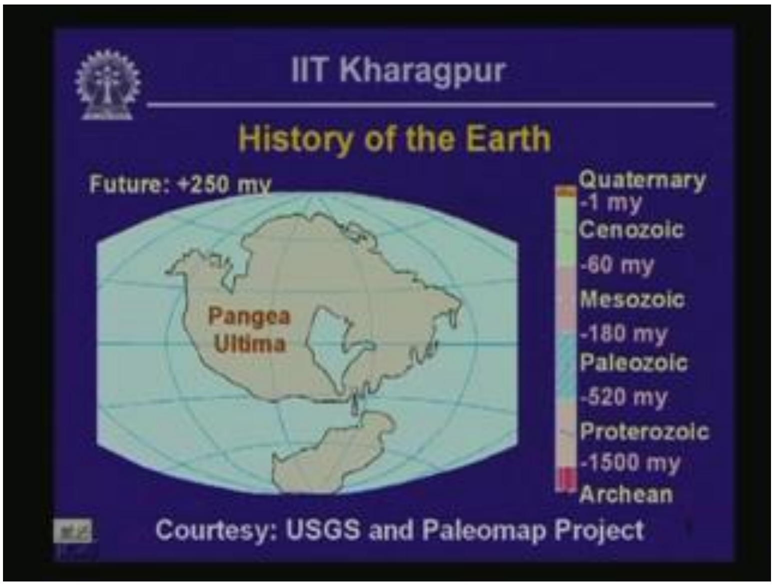

Then we look at 250 million years from now. A super continent will again form, and this particular super continent is given the name of Pangea Ultima. And what you see here is that the Atlantic Ocean, it has closed and the Indian remnant of Indian Ocean you can see here.

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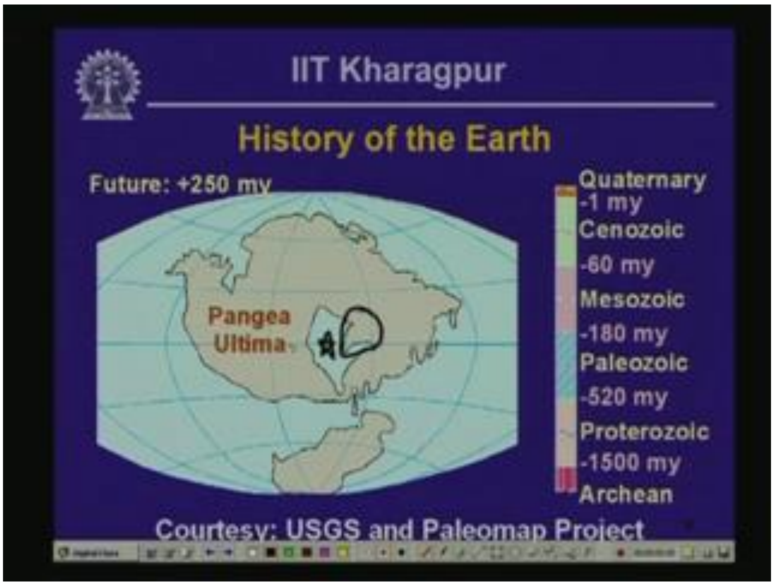

It is just like an inland sea at this point of time, and the Indian plate looks like this. So, what you have got here is a complete convergence of Africa, Eurasia, India, North and South America. All these land masses as they exist today, they are going to converge and form a super continent called Pangea Ultima. So, what you see here is that over the geologic history several different continents, they collide with each other. Then they break apart and they colas again after at new converging boundaries.

So, over this entire time scale, mountain chains are going to build up at the converging boundary at the locations of continent to continent conversions. And then when the continents spread apart, new spreading centers form as we see from these series of maps that I just now presented. And new ocean starts forming near the spreading centers along the spreading centers.

So, you are going to expect that there are mountain chains that are going to evolve from all these continent to continent convergence. And oceans keep on forming at the spreading centers across the spreading centers. And two such examples of mountain change we can see right now, and they are the Himalayan and the Himalayan mountain chain and the mountain chain of southern Europe or the Alps.

One of the mountain chains I want to mention at this point of time that covers a long stretch along the eastern part of North America from south west to north east, and that is called the Appalachians mountain chain. And that particular mountain chain was formed in a very similar manner under very similar circumstances about 390 million years ago when the continent of Laurentia collided with another land mass that we saw in one of the previous slides.

Let us let us run this particular slide once again to explain. Actually Laurentia collided with Baltica at about 390 million years ago. And at that time, the mountain chain of Appalachian formed near the margins of the converging boundary. And you can see the remnants of that particular mountain chain right now in the eastern part of North America, okay.

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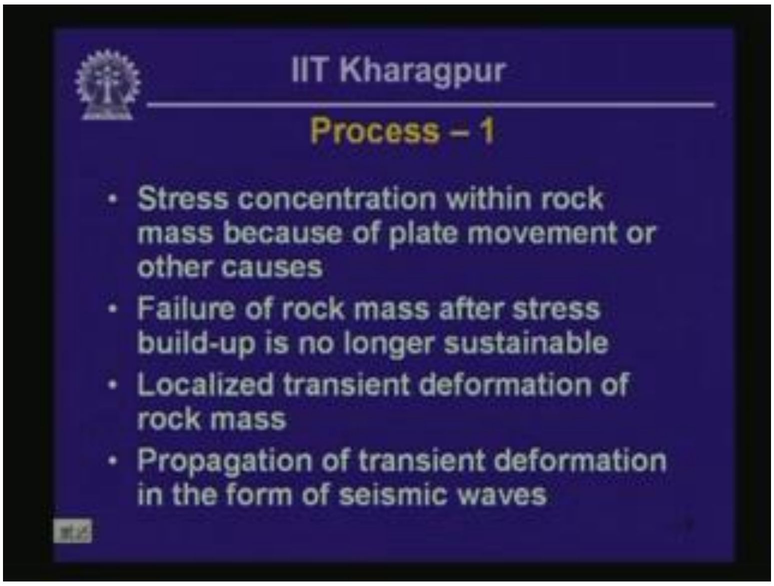

So, we move on to the earthquake process with that knowledge how earthquake is triggered. Earthquake essentially is triggered because of stress concentration within rock mass because of plate movement or because of other causes. And the other causes could be volcanism at inter plate locations or activation of rift valleys at the centre of pre-existing rift valleys remnants of earlier continental features near the middle of the existing continents.

So, these points of weaknesses could be reactivated because of stress concentration because of the collision of plates or because of volcanism or any other reason or even accumulation of huge sediment load; we are going to look at the details of these triggers in one of the future lessons. Then failure of rock mass after stress build up occurs when the elevated stress cannot be sustained anymore. And what happens because of the failure is a deformation occurs a sudden explosive deformation occurs near the location where the failure is taking place.

And the localized transient deformation actually propagates, the pattern of deformation propagates as a stress wave, and these stress waves are called seismic waves. We are going to look at the essential features of this seismic waves in the next little bit.

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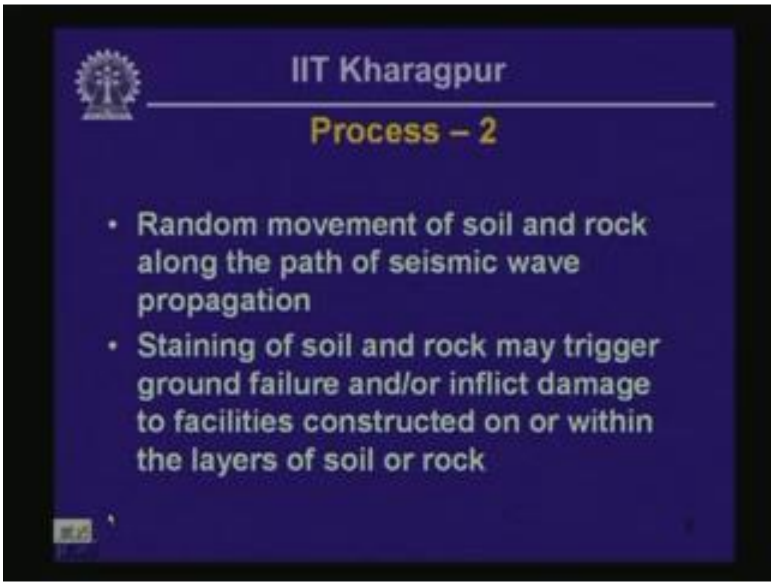

And when stress wave propagates from one location to the other, then random movement of soil and rock is going to occur along the path of the seismic wave propagation. And straining of soil and rock is going to trigger ground failure; straining of soil and rock, it could trigger actually ground failure, or it could inflict damage to facilities constructed on or within the layers of soil or rock.

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Okay, we have to look at a few definitions in this connection. Now let us say the failure of rock mass is triggered at the location underground shown on this particular cartoon; that location is called the focus or hypocenter of an earthquake.

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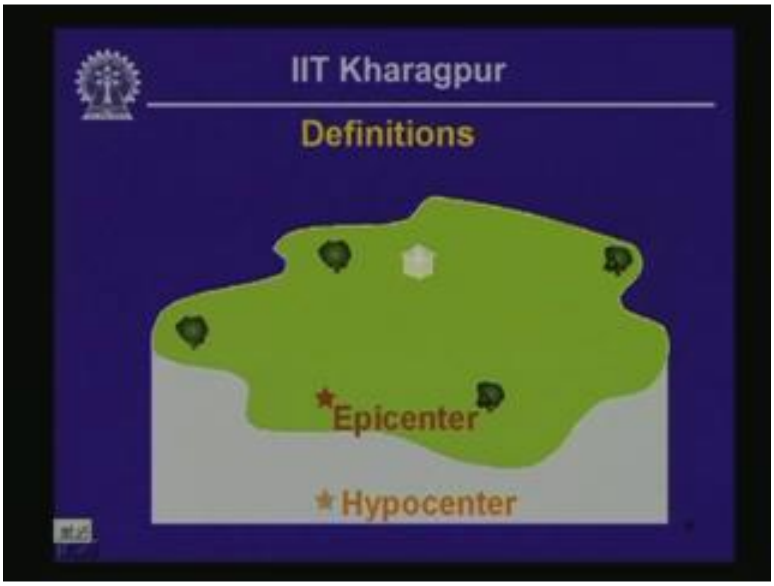

Now if you project the hypocenter to the ground surface, then you are going to get the epicenter; that is the definition of epicenter.

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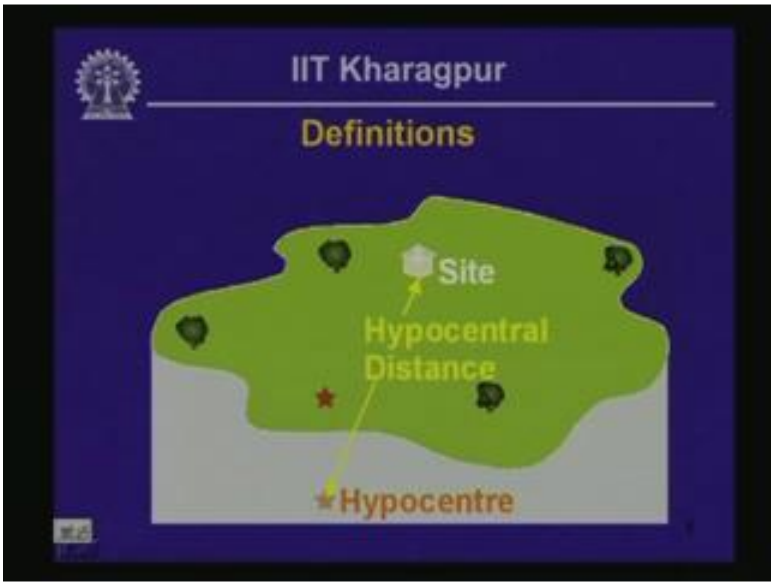

Now if you find the distance from the hypocenter to a site, then that is called the hypocentral distance.

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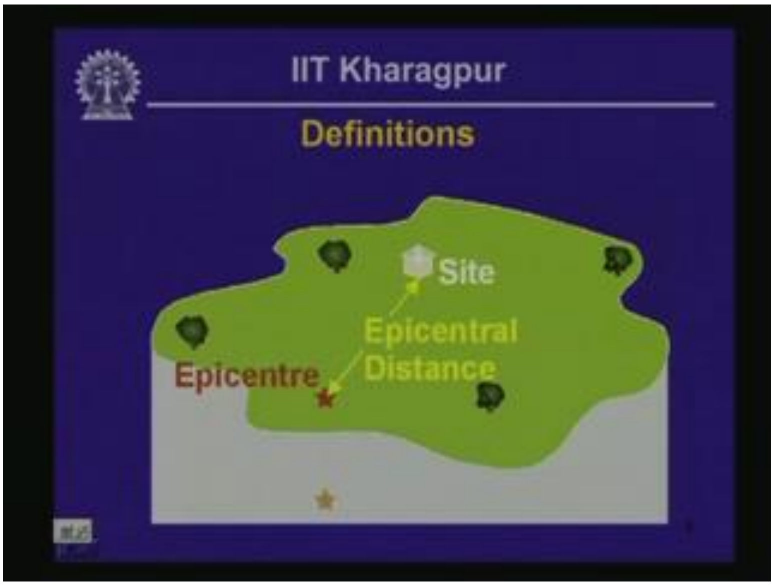

Similarly, if you compute the distance between the epicenter and a site, then what you get is an epicentral distance.

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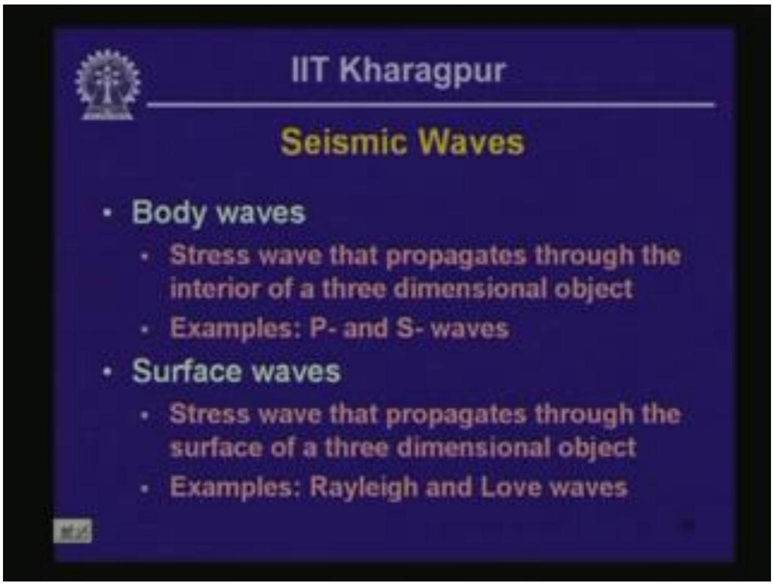

Now let us look at the features the characteristics of seismic waves. There are two types of seismic waves really. The waves it is exactly similar to, say, for example, if you throw a pebble on the surface of water in a pond or a water body. Then what you see is a wave is going to be triggered when the pebble hits the water surface. And the disturbance actually propagates radially from the location where the disturbance was originally triggered, the movement of seismic wave is exactly analogous to what you see when water wave is generated.

But here what is happening? The wave is triggered because of the failure of rock mass, and patterns of transient deformation is going to move radially away from the location where the disturbance was triggered because of the failure of rock mass. So, the waves could propagate as body wave where stress waves propagate through the interior of a three dimensional object. Examples are p-waves and s-waves, or they could propagate as surface waves where stress waves propagate through the surface of a three dimensional object; examples being Rayleigh waves and Love waves.

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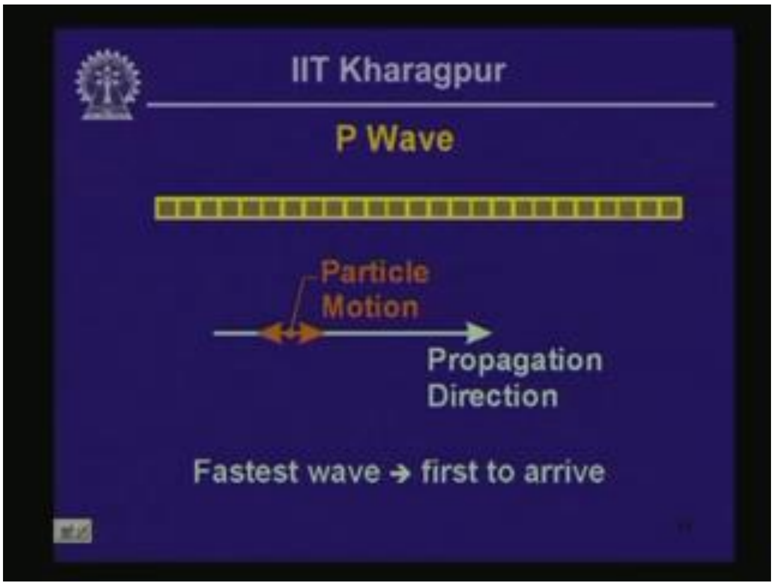

Now p-waves how they are developed, how they are generated is indicated on this particular animation. Here we actually hit a series of elements in that manner in the manner shown by the arrow there. Then what is going to happen? A deformation wave is going to propagate in that manner; here the propagation direction is like that, and the particle motion is parallel to the propagation direction. It is the fastest wave. So, that is the first to arrive from the focus to a particular site.

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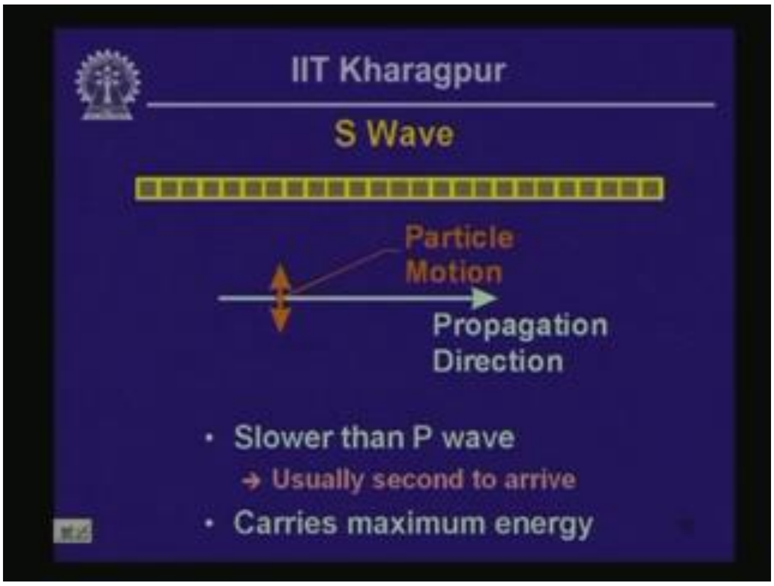

Then S wave is triggered by hitting; it can be generated by hitting in a transverse direction the same set of elements what we considered before, and if a sudden deformation is triggered because of that, a deformation wave is going to propagate in this manner. So, this is called the S wave. And here you have got the propagation direction like this, but the particle motion is taking place in a direction transverse to the direction of propagation of the deformation wave. It is slower than p-wave usually second to arrive at a give site, and it carries maximum energy during an earthquake.

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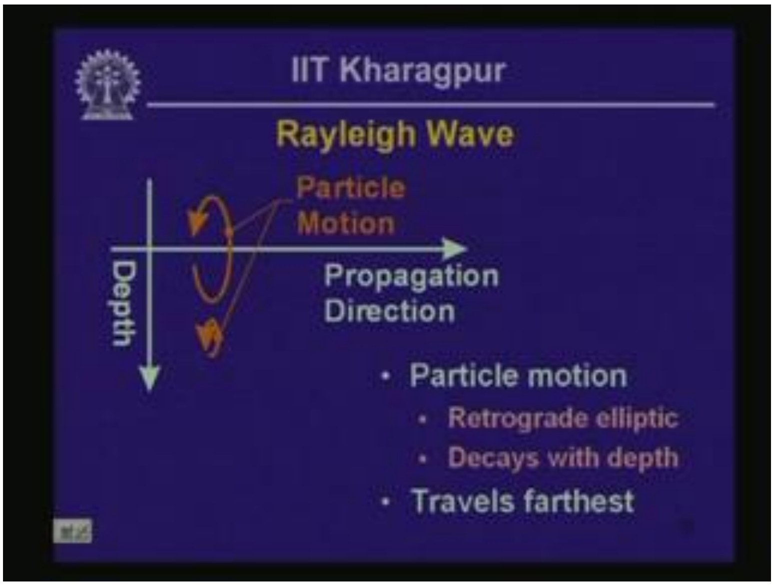

In Rayleigh wave, you have got retrograde particle motion taking place in an elliptical manner like that, and the extent of motion actually the intensity of motion decays as you go down deeper from the surface of the earth. So, here you have got a particle motion retrograde elliptic particle motion that decays with depth, and this particular wave actually travels the farthest. It does not decay as readily as P wave or S wave.

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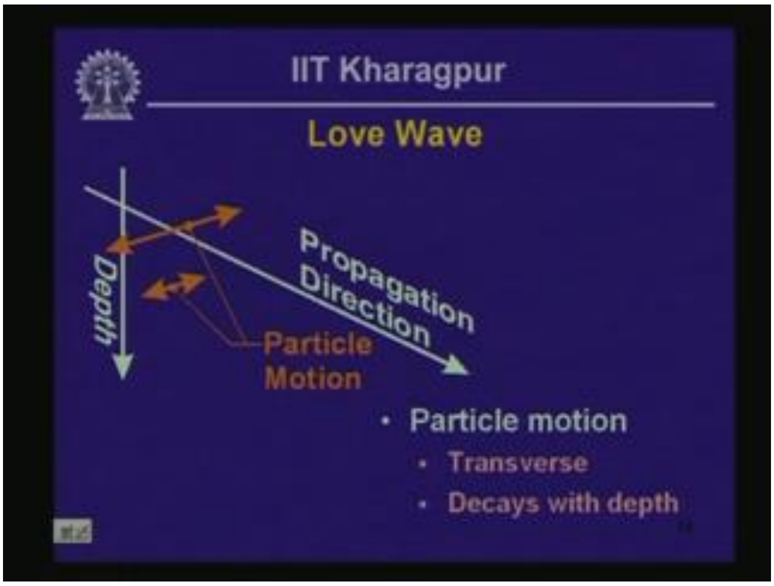

Love wave is very similar to Rayleigh wave except here the particle motion is transverse to the propagation direction, but here also the particle motion decays with depth.

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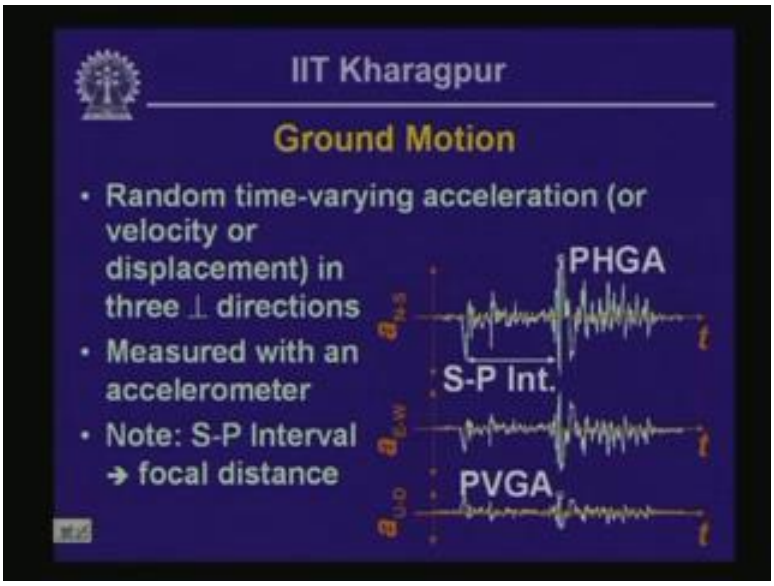

Now ground motion is a sum total; it is actually a sum, it is essentially a combination. What you see is a combination of the effect of all the stress waves that we just now looked at. They originate at the location where earthquake is originally triggered, and when you measure the disturbance that is caused when the waves arrive at a given site, what you get is essentially a time history of random particle movement shown by time varying acceleration here in three orthogonal directions.

These particle motions typically measured with accelerometer and here I have also indicated what is defined as the peak horizontal ground acceleration or PHGA on the plot of the acceleration time history in the north south direction. And acceleration time history in the up down direction; what you can see the peak amplitude there is called the peak vertical ground acceleration. I have also indicated the interval between the arrival of P wave and the arrival of the S wave, and that is given the term S-P interval.

Now you can see that if you calculate the S-P interval from the ground motion measured at three different sides, you can find out the location of the focus of an earthquake. By considering the velocity of P wave movement within the intervening rock mass and the velocity of S wave movement within the intervening rock mass. And this is the way actually earthquake focus is fixed or located by instrumented information from several different sides on the surface of the earth.

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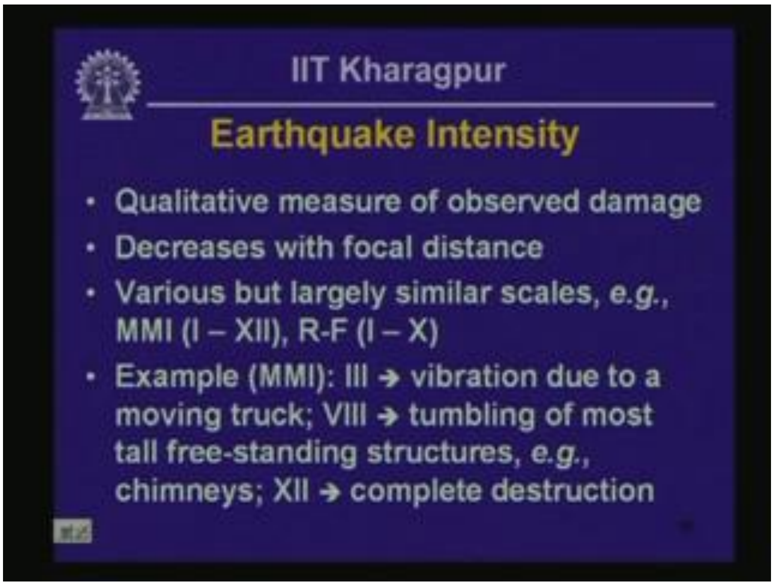

Now you have to measure the strength of an earthquake. One of the ways to express the strength of an earthquake is the intensity of earthquake. It is essentially a qualitative measure of observed earthquake observed damage decreases with distance; there are various scales used for this particular purpose such as Modified Mercalli Intensity MMI. And it goes from intensity one to intensity twelve or Rossi-Forel scale that goes from intensity one to intensity ten.

Intensity one is the weakest earthquake where as intensity ten or twelve indicates the strongest shaking at a given site. An example is shown at the bottom bullet on this particular slide. For example, in the MMI scale, the intensity three indicates it is very similar to vibration due to a moving truck. Intensity eight is it denotes an earthquake which causes tumbling of structures such chimneys or smokes tag. And intensity twelve represents complete destruction of structures in the given site.

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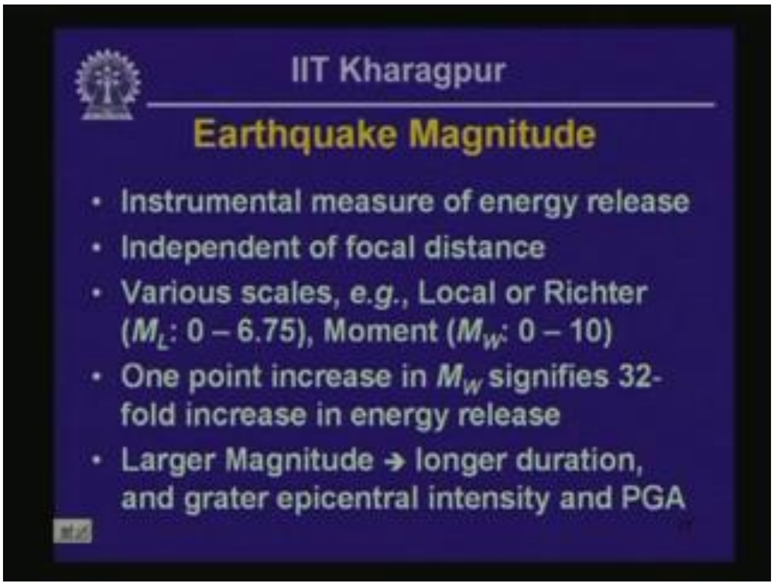

Earthquake magnitude on the other hand is an instrumental measure of energy release; this is independent of focal distance. There are various scales once again such as local or Richter magnitude, it is denoted with m subscript l that goes from 0 to 6.75; this scale saturates at a magnitude of about 6.75 or you could have moment magnitude scale which goes from 0 to 10. You should note that one point increase in moment magnitude scale signifies about thirty two fold increase in earthquake energy release, and larger the magnitude, longer is the duration of the earthquake and greater is the epicentral intensity and PGA.

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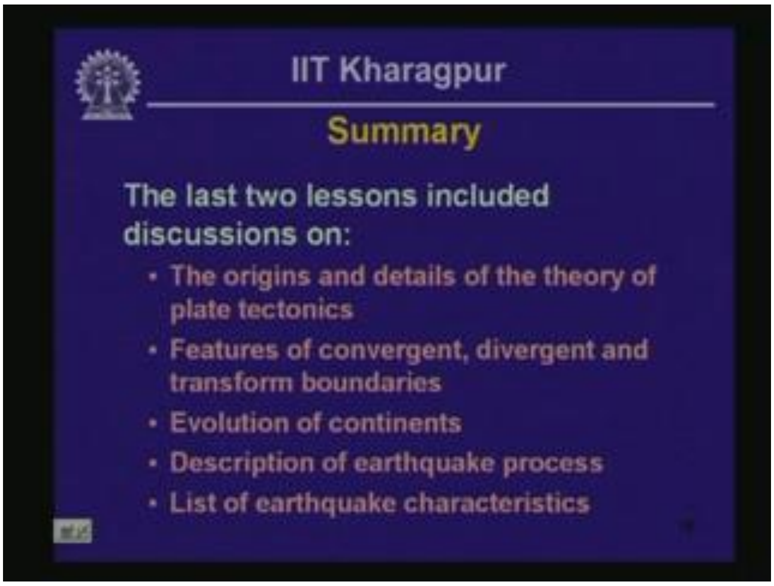

Now let us summarize what we learnt in the last two lessons. We looked at the origins and details of the theory of plate tectonics. We looked at the features of convergent, divergent and transform boundaries. We looked at evolution of continents through the geologic history and down into the future looked at description of earthquake process and list of earthquake characteristics.

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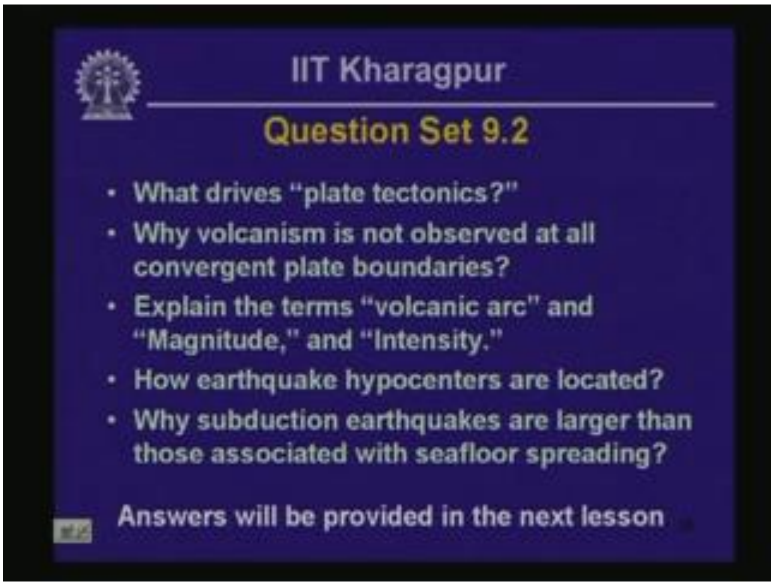

We wrap up this particular lesson with a question set. The first one is that what drives plate tectonics. Then second why volcanism is not observed at all continental plate boundaries or convergent plate boundaries. I want you to explain the terms volcanic arc, magnitude and intensity. Then how earthquake epicenters or how earthquake hypocenters are located, and finally, why subduction earthquakes are larger than those associated with sea floor spreading. Try to answer these questions at your leisure. I will give you mine; we will review these questions when we meet with the next lesson; until then bye for now.