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

Lecture - 30
Plate Tectonics

Hello everyone and welcome back. Today, we are going to start talking about some topics on related to earthquakes.

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And we are going to begin with the topic of plate tectonics in this particular lesson. Before we get into today's subject matter, we are going to look back at the question set of the previous lesson.

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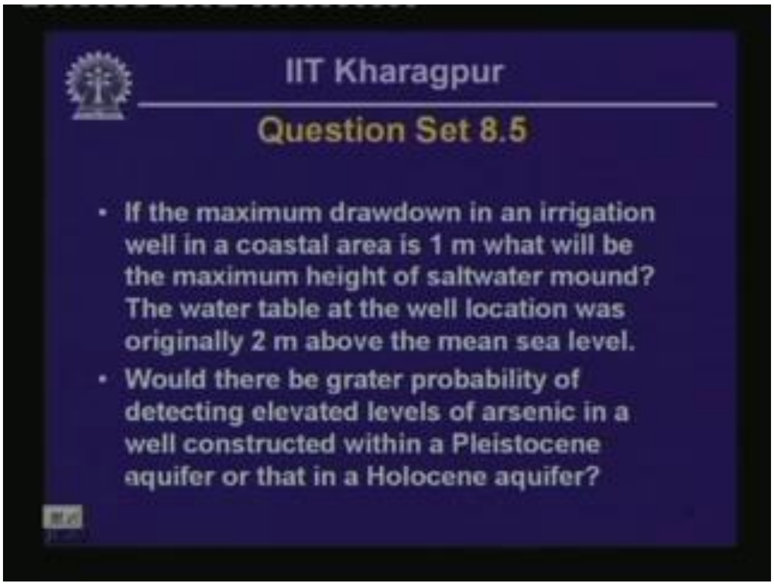

These were the questions that I gave you last time around. The first question was if the maximum drawdown in irrigation well in a coastal area is one meter, what will be the maximum height of saltwater mount? The water table at the well location was originally two meter above the mean sea level. Now if you recall we talked about Ghyben-Herzberg principle in the last lesson. And what we found there was that the height of fresh water above the level of the surrounding salt water or the mean sea level; if that is some height, and if that height actually changes by, say, one meter for that, there will be a salt water mount near the bottom of the aquifer, which is approximately 40 times the depth by which the water table, the fresh water is drawn down.

So, in this case, we have drawn down the water table by one meter. So, we expect that the salt water mount to rise about 40 meters near the bottom of the aquifer. So, if the fresh water column has a smaller depth, it extends to a smaller depth than 40 meter, then the entire aquifer at the well location is going to be useless, because it will be totally occupied by salt water. Now the second question that I gave was would there be a greater probability of detecting elevated levels of arsenic in a well constructed within a Pleistocene aquifer or a similar one constructed within a Holocene aquifer

Now Pleistocene aquifer is a very old these are actually geologic ages; Pleistocene is a geologic age which extends to about 10000 years before present, and after that, the geologic age is called Holocene. So, Pleistocene aquifer it is a very old aquifer. So, as a result, what you would expect that the arsenic that would have been generated that would have been there within the aquifer must have been flushed out because of the flow taking place over so many years.

That kind of flushing is less probable in case of a newer aquifer because of that for a well constructed within Holocene aquifer; we might have a greater chance of detecting an elevated level of arsenic in comparison with the similar well constructed within a Pleistocene aquifer, okay. So, that actually wraps up the questions of the previous lesson; now we get on with today's subject matter.

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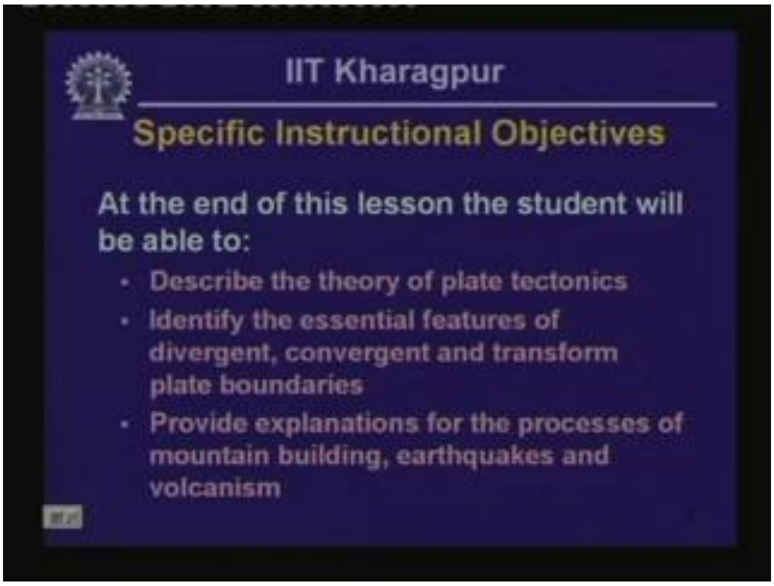

What we want to accomplish at the end of this particular lesson are the following. We would like to be able to describe the theory of plate tectonics. Then we would like to be able to identify the essential features of divergent, convergent and transform plate boundaries. The meanings of these things are going to be become clear later on in this particular lesson; meaning of divergent, convergent and transform plate boundaries going to be discussed in detail later on. The third thing that we want to be able to do is to provide explanations for the process of mountain building, earthquakes and volcanism from the theory of plate tectonics, okay.

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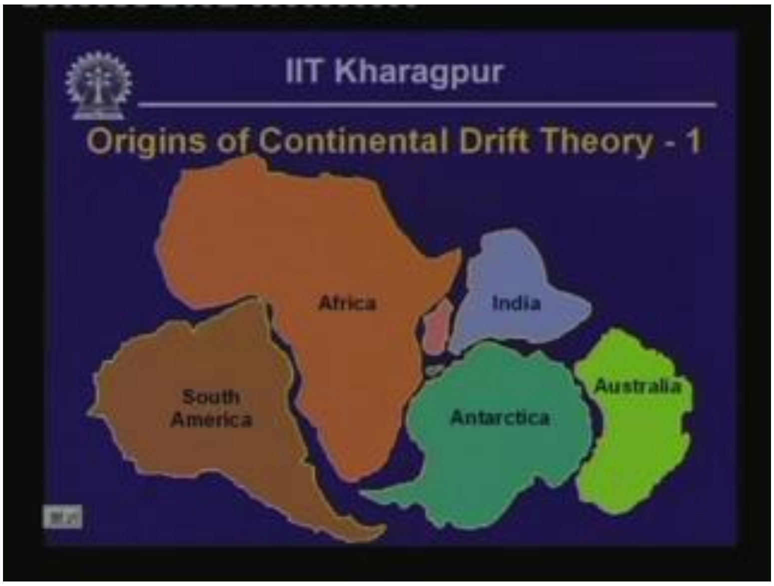

So, these are the objectives, and now let us try to introduce the topic of plate tectonics. Now if you have looked at the maps of different countries of the world or different continents of the world, then you might have wondered that some of the boundaries of land masses, they could easily fit with the boundaries of a corresponding land mass which is at the present time separated by vast distances.

For instance, the southwest coast southwestern part of Africa could fit very well with the north eastern part of South America, which is separated at the present time by the Atlantic Ocean. And that is illustrated on this particular slide; you can see that what we try to do here. We try to fit together the land masses of South America and Africa just by just by moving them together and fitting them like a jigsaw puzzle.

Then you come to the east; you could you could see that the west coast of India could fit, in fact, with the eastern coast of Africa if you put in between the island of Madagascar which is shown with pink shading over there. And also another interesting thing is that the south eastern coast of India of the present configuration of India could fit, in fact, with the coastal boundaries of Antarctica quite well.

Similarly, the eastern part of Antarctica could; in fact, with the southern portion of the present land mass of Australia and that is illustrated on this particular slide as I indicated. And people started wondering about these things long time back as we would see in the next little bit that why that is so, or whether this is a just a matter of coincidence, or this could, in fact, tell a very wide ranging wide ranging feature of the evolution of continents of our planet.

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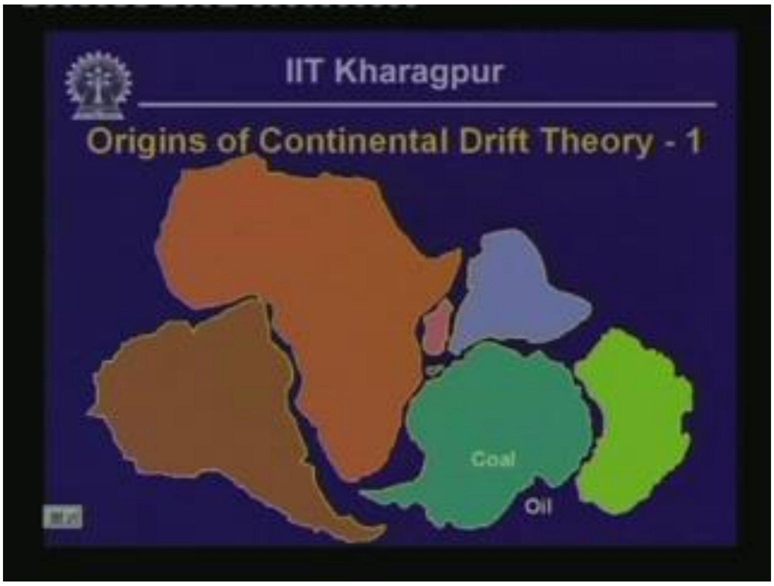

Now that was the beginning. Then what was observed that in some parts of Antarctica, huge deposits of coal were discovered and also off the coast of Antarctica, they found reservoir of petroleum. Now you could imagine from your general knowledge that coal is a deposit that will form from decaying of plant matters and such is the case with petroleum as well where decay of organisms is the process responsible for the development of the reservoirs of petroleum.

Now then the question comes that in the icy expanses of Antarctica, how come there are deposits of coal, and off the shell of Antarctica, how come there is a huge deposit of petroleum reserve? To answer because if you consider the present climate, then I mean there could be no vegetation could grow in those areas or no organisms, decay of which could give rise to the development of huge quantities of petroleum is possible in the areas of such low temperature as those encountered in Antarctica.

So, obviously, there was a time when the temperature of Antarctica was much elevated much much greater than what it is right now. And vegetation and organisms were there in those areas in that continent in a great abundance. And decay of those organisms and vegetation gave rise to the development of the coal and oil reserve in that area.

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Another thing that was observed is the distribution of animal’s species and plant species across different continents which are separated by vast expanses of oceans at the present time. For example, cynognathus, this is basically a reptile of the Triassic age and lystrosaurus. Lystrosaurus, this is another Triassic species. They are found across the continents of South America and Africa, and fossils of lystrosaurus were found across Africa and India. These are the distribution of fossils or the dead bodies of these reptiles were actually lithified in time.

And they are found as fossil remains in different rock formations of these continents, and the distribution of these fossils are across land masses which are again separated at the present time by vast expanses of ocean. Glossopteris is a plant species, and that was found across many parts of southern South America, southern part of Africa, southern part of India, central part of Antarctica present Antarctica and eastern part of present day Australia.

So, these things actually give rise to the questions how these plants and animals species could be found in land masses that are separated by vast expanses of ocean. So, the hypothesis began that may be way back in the geologic history, these land masses were indeed connected to each other. And these mammals or these plants and animals species could actually be present over parts of the land mass which later on got separated from each other, okay.

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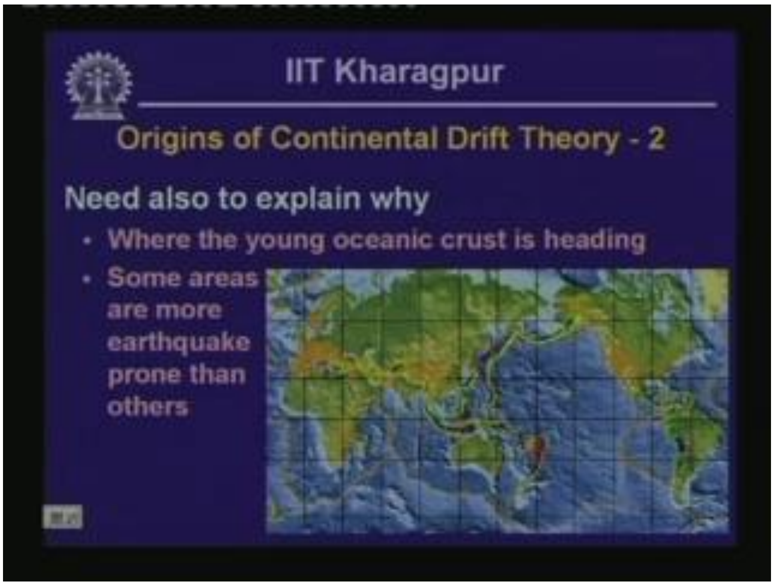

We also need to explain another aspect that actually gave rise to the continental drift theory was the necessity to explain actually where young oceanic crust is heading. What was found I would say very significant developments in instrumentation and geologic investigation of knowledge; that actually resulted from it in the 1950s. From that, it was found that the age of the oceanic crust or the crust of the planet earth which is underneath the wide expanses of ocean; they are relatively much young in comparison with the continental crust or the part of the earth's crust which are underneath the land masses.

So, then the question arises if the oceanic crust is young, then somewhere actually new oceanic crust is being created. And since it is being created, it has to be consumed somewhere, because otherwise, the earth's surface has to grow to accommodate the creation of the young oceanic crust. So, the necessity arose at in 1950s as to where the oceanic crust that is being created is heading or it is being consumed. Then the other question that kept bothering geologists and seismologists was that some of the areas on the surface of the earth are more earthquake prone than the other.

Now that becomes clear if you plot the location of the earthquakes that had been taking place on the surface of the earth on the map, and what is seen is that the earthquakes are clustered at preferentially in some parts of the globe where as other parts are much stable so far as earthquakes or seismicity is concerned. Now earthquake activity is called seismicity as you might know already.

Now that is illustrated with the map which is on the bottom right of this particular slide, and earthquakes over several decades are plotted on the map on the surface of the earth and. And these are indicated by orange green and blue dots and red dots actually, and you can see that earthquakes are preferentially occurring in these areas in these areas.

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There are in fact some lines along which the earthquakes are taking place, and there are areas of diffused seismicity such as these. And once again if you go to the western part of North America once again, there is an area of diffused seismicity plus there is a well defined line along which earthquakes are occurring on the margins of the Pacific Ocean. So, these are the areas which are highly active seismically, or they are earthquake prone, whereas if you look at the areas such as these, such as these, very few earthquakes have been detected in the history of mankind in these areas.

So, these are the questions that started bothering geologists as to why in some areas of the earth you have got so many earthquakes, whereas in other areas there are so few earthquakes occurring, okay.

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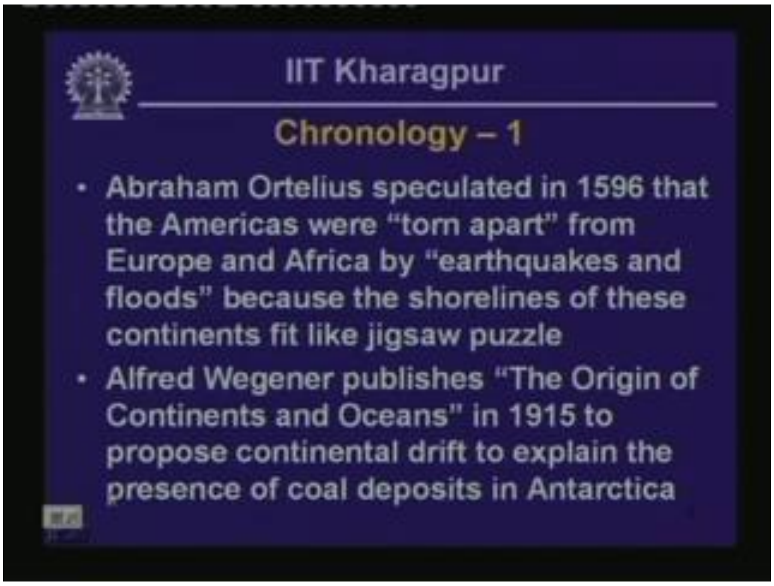

So, then these in order to answer these questions, what evolved is the theory of plate tectonics. In fact, Abraham Ortelius speculated in 1596 way back in 1596 that the Americas were torn apart from Europe and Africa by earthquakes and floods; earthquakes and floods actually this is what he said; I have used quotation to indicate that, because of the shorelines of these continents fit like jigsaw puzzle and we have seen that already.

We have seen that the north eastern coast of South America actually fits rather well with the south western coast of Africa. So, we have seen that, and these are the reasons why Abraham Ortelius started speculating that possibly these continents were torn apart from each other because of upheavals like earthquakes and floods in geologic past. He did not have any proof; he just speculated based on the fact that the maps of these continents fit together like jigsaw puzzle. Then first person actually to propose the theory of plate tectonics and put it in a scientific light was Alfred Wegener; he is a German meteorologist, in fact.

He published his work, the origin of continents and ocean in 1915. And in that, he proposed the continental drift theory to explain the presence of coal deposits in the present day Antarctica. So, as we have seen that if you consider the present day climate of Antarctica, no way coal deposits of such great abundance could actually develop in such an icy expanse as Antarctica.

So, in order to explain the presence of coal deposit, Alfred Wagener he suggested that Antarctica must have been much warmer at sometime in the past of earth's geologic history. And now it occupies such a position on the earth's surface that it does not receive as much solar energy, and it has become cold. And the climate of the continent has changed remarkably over the intervening period. So, that was the beginning of the theory of plate tectonics.

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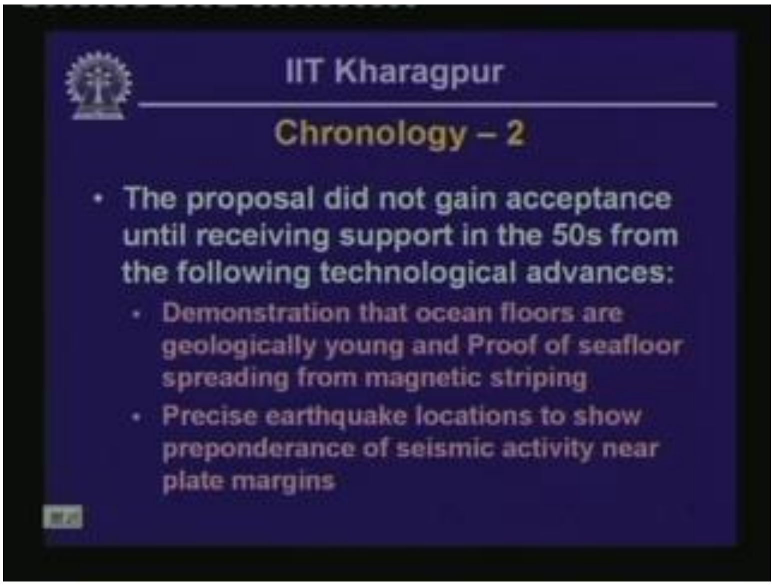

Now the proposal of Wagener, he did not gain acceptance until 1950s. So, 1915 when he suggested the theory of plate tectonics from then to 1950s, geologist did not pay much attention to what was proposed in the hypothesis of continental drift theory, because there was no direct evidence. Although, there were enough circumstantial evidence as we have seen already, and Wagener tried to justify his proposal based on all those circumstantial evidence such as the existence of coal deposit in Antarctica plus the presence of several different animal species in continent in land masses that were separated by vast expanses of oceans at the present time.

Now what happened in 1950s is that scientific and technological development led to the detection of several different things. And the most important of that from the point of view of plate tectonics is that what geologist found is that ocean floors are geologically much younger than the continental land masses. And there were, in fact, stripe like features on the ocean floor and let us look at that actually let me illustrate that.

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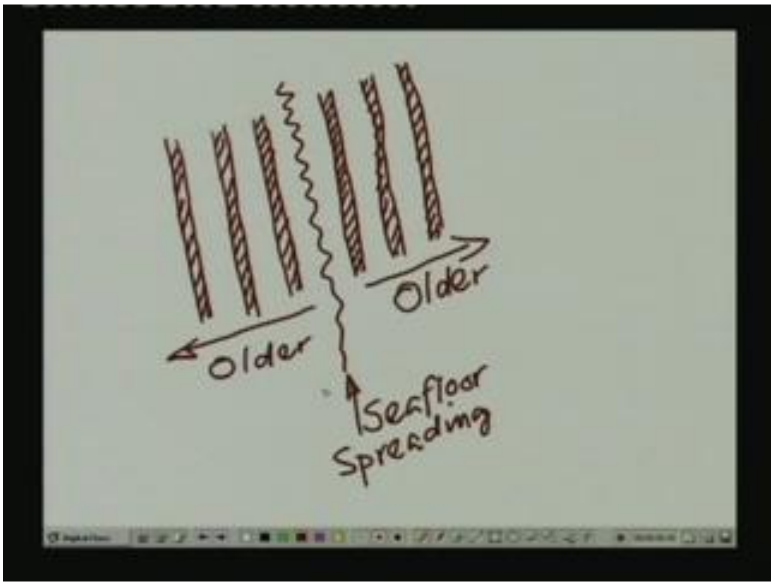

There are stripes; they detected magnetic stripes on the ocean floor, and they started wondering why those magnetic stripes are occurring in that manner. And these stripes become older as you move in a certain direction from a feature of the ocean floor. And as you would see in the next little bit that this is the spreading center from where new and young crust is being produced, because of the ejection of magma. So, these are area where sea floor is spreading apart.

So, what it is actually? If you go on either side of the spreading center on the line where this sea floor is spreading apart, you will see what geologist found in 1950s is that the sea floor becomes older as you go away move apart from the center of sea floor spreading. They also actually found this from careful cold sampling of the sea floor rock formations and dating dam using some of the techniques that we have discussed earlier.

They also found that they examined the magnetic minerals within the rock masses of the sea floor of the oceanic crust, and what they found is that there are stripes of opposite polarity of the magnetic minerals in the manner that I have sketched here. So, for instance, the shaded area that I am drawing now; the polarity of the magnetic minerals are in a certain direction, whereas the polarity changes in between those stripes.

Then the question they started asking is why this kind of reversing in polarity is taking place. And what they suggested as an answer is that the earth’s magnetic pole or the magnetic north; this is a well known fact that the magnetic poles of the earth, they reverse polarity in every now and then. And so, what happens is that when these sea crust is forming, then if the polarity changes, what you are going to start finding is that there are stripes of rock; there are stripes in which the orientation of the magnetic minerals is in a certain direction depending on the current polarity at which the magnetism was developing within these minerals because of the cooling of the magma and so on and so forth.

So, that was, in fact, a very good explanation of this observation in which stripes of different polarities of magnetic minerals were absorbed on the sea floor rock mass. And, in fact, if the sea floor is young, and if it is spreading in the manner that becomes evident from the presence of polarity of the magnetic minerals within the sea floor rock masses, then the question comes; the question that we already post that actually crops up as to where this particular sea floor is heading, and where it is being consumed because we know that the surface of the earth is not growing.

So, whatever is being created at the spreading center must be consumed somewhere else within the crust of the earth. Then also the second the second point that you need to consider is that precise earthquake locations were possible actually because of the development of technology in 1950s immediately following the Second World War, in fact. And it was becoming very clear that earthquakes indeed occur preferentially at some areas on the surface of the earth, whereas other areas on the surface of the earth are relatively free from the earthquake hazard. Now the answer of these questions as you will see in the next little bit; all these points can be explained very well from the context of plate tectonics, okay.

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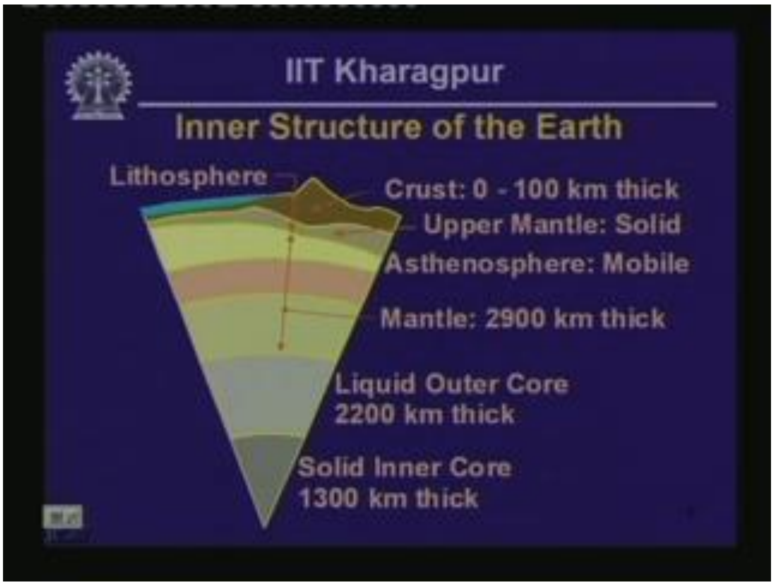

Now before we get into plate tectonics, let us recapitulate the inner structure of earth. We looked at the inner structure of earth sometime back, and you may recall from that; we have got a crust of approximately 0 to 100 kilometer thick underlain by upper mantle. And that is an upper mantle and crust is composed mainly of solid and brittle rock. Underneath the upper mantle is a shell called asthenosphere, and asthenosphere is under elevated temperature, and it is relatively mobile. As a result, it is in a viscous semi liquid viscous form.

Then underneath the asthenosphere, you have got inner mantle and then you have got liquid outer core which is the thickness of it is indicated on the sketch there. And then finally, near the center of the earth you have got solid inner core. Now the solid part which is near the surface of the earth is called lithosphere, and that is comprised of the oceanic and continental crust and the upper mantle.

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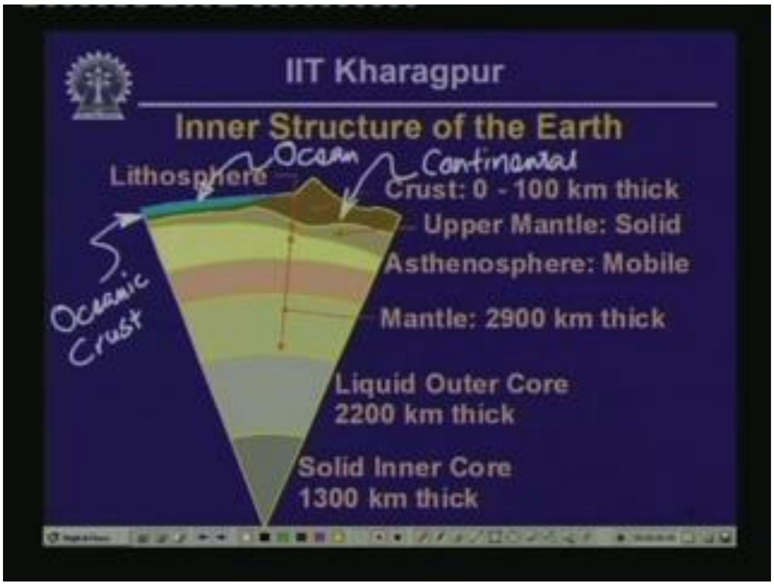

And here in this particular sketch I have shown the oceanic crust is on the left, and continental crust is towards the right. So, this one here is the oceanic crust. And you can see that oceanic crust is relatively much thinner in comparison with continental crust. So, this part here is continental crust, and this is the ocean that I have shown on this sketch, okay. So, that is the structure of the earth.

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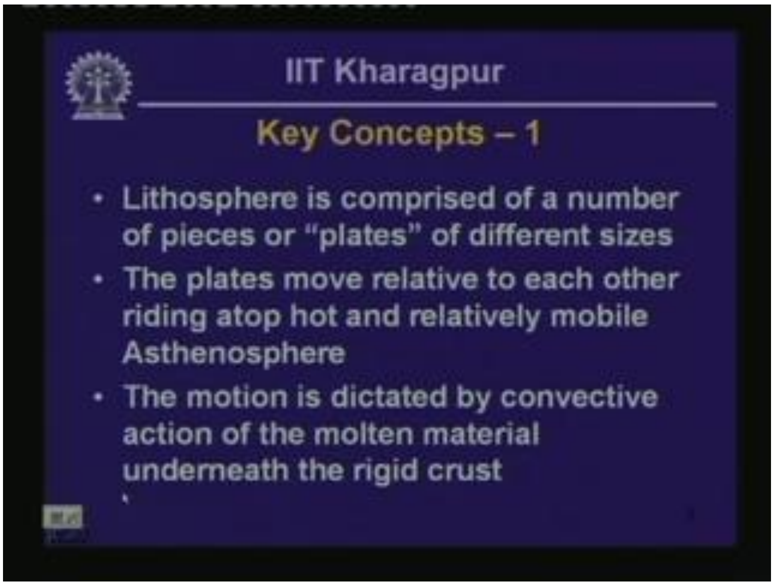

Now I can introduce the key concepts of the theory of plate tectonics, and what it suggests? The corner stone of the theory is that lithosphere is comprised of a number of pieces or plates of different sizes; that is the key ingredient of this particular theory. Then the theory suggests that the plates are in relative motion with respect to each other. And they ride on top of the hot and relatively mobile asthenosphere, and this relative motion of these plates is dictated by convective action of the molten material that is underneath the rigid crust.

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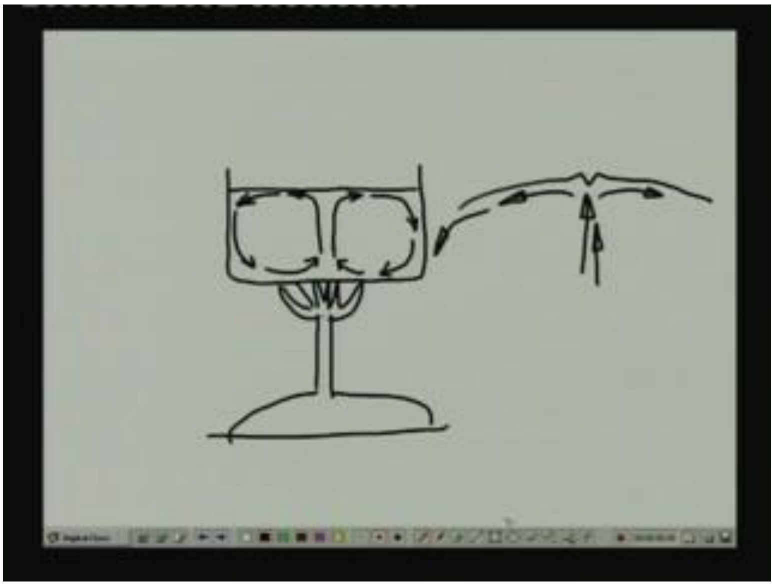

Now you can imagine what I mean by that is this; let us say you start heating a bowl of water over a stove. And what you will see is that because of the heating action, there will be an upwelling of water, because the water which is near the flame that is going to get heated up. And there will be an upwelling of the water, and then as it starts moving from the location of upwelling, it is going to become colder. And then this particular water is going to start sinking as it becomes colder, because it is going to become denser as it becomes colder as well.

So, this type of motion is called convection, and a similar mechanism is suggested for the mobility of the plates that right on top of the asthenosphere. Asthenosphere is receiving the heat from the geothermal energy within the deeper areas of the asthenosphere, and that actually is triggering the convective motion in exactly the similar manner. So, what happens there is we can draw a parallel in this particular case. Let us say you have got let us consider a part of the earth surface near the spreading boundary which we have looked at in the few minutes before few minutes earlier.

Over there, the sea crust actually there is spreading boundaries on the surface of the earth on the continental crust as well. We will see those things later. In a spreading boundary, the molten material is coming to the surface, and that is being pushed out because of the ejection of more and more magma. And that motion is triggered by the driven upwelling of magma driven by internal heat within the deep underneath the earth's surface and that movement the sea floor is going to spread.

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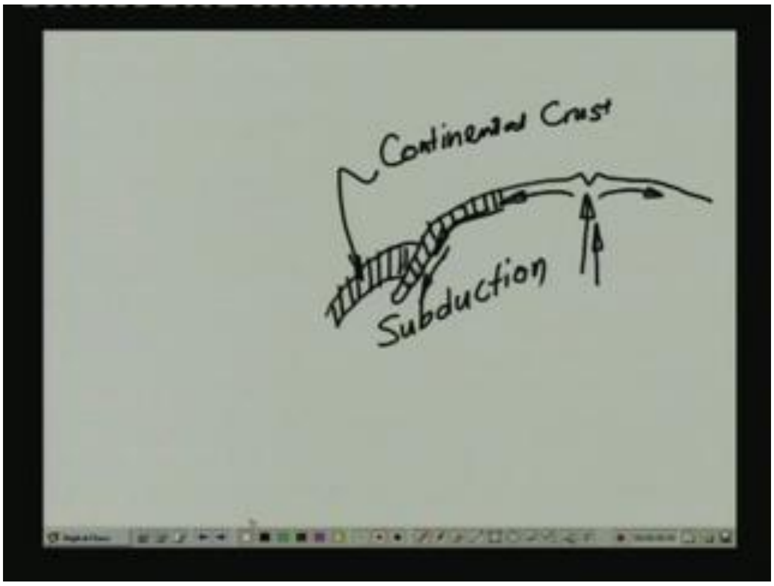

And it is going to reach at a distance it is hypothesized; it wants to actually get down below the surface of the continental crust. So, let us call this thing the continental crust. And because of the fact that the rock mass underneath is typically much heavier than those found underneath continental crust. So, they are going to once they come in contact with the continental crust, once they start bucking against the continental crust; they are going to start going down underneath the continental crust, and this particular action is called subduction.

And once the subduction takes the rock masses beyond a certain depth beyond a few hundred kilometers, there the temperature becomes so high that the rock melts, and it is consumed in the magma that is underneath the lithosphere. So, that actually gives a complete picture because now we know where the young sea floor is heading and how the young sea floor is being consumed underneath the continental or interpolate boundaries, okay. So, so this is already we have covered.

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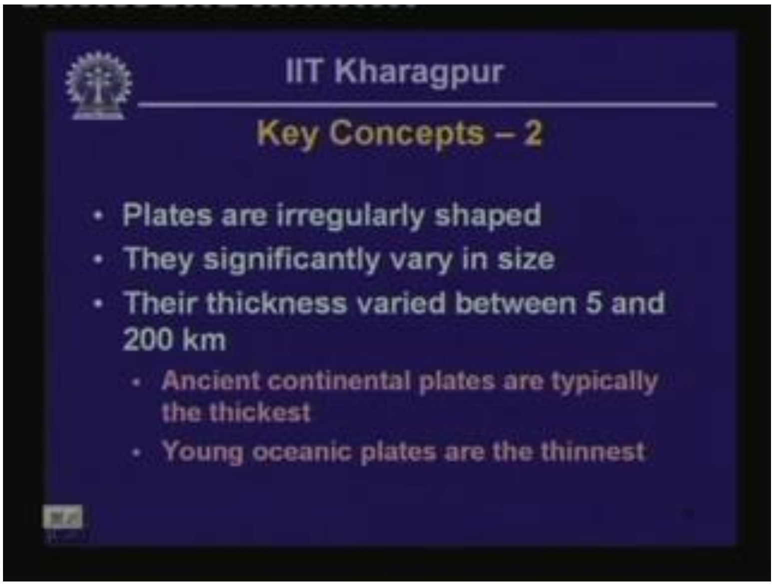

Now the plates that we are talking about, they are irregularly sharpened. And you can draw a very good analogy if you consider the heating of milk really, and you must have seen that when a part of milk is heated, then a crust like thing forms at the surface of the milk. And that is very similar, in fact, with what we are talking about here in this particular case as crustal plates.

And these plates are irregular sharpened; they significantly vary in size, and their thickness varies between 5 and 200 kilometers. As we have seen that underneath the ocean, the thickness of the crust is much smaller, and there you could have a very thin plate indeed, whereas underneath mountain chains, the thickness of the crust could be quite significant, and it could exceed 100 kilometer in some places.

Ancient continental plates are typically thickest, and this is also what is established, and young oceanic plates are typically the thinnest. And that is quite obvious because where the plate is thin at those areas magma which is underneath the plates, they can find their way onto the surface of the earth, and that constitutes the spreading boundary as we have seen earlier, okay.

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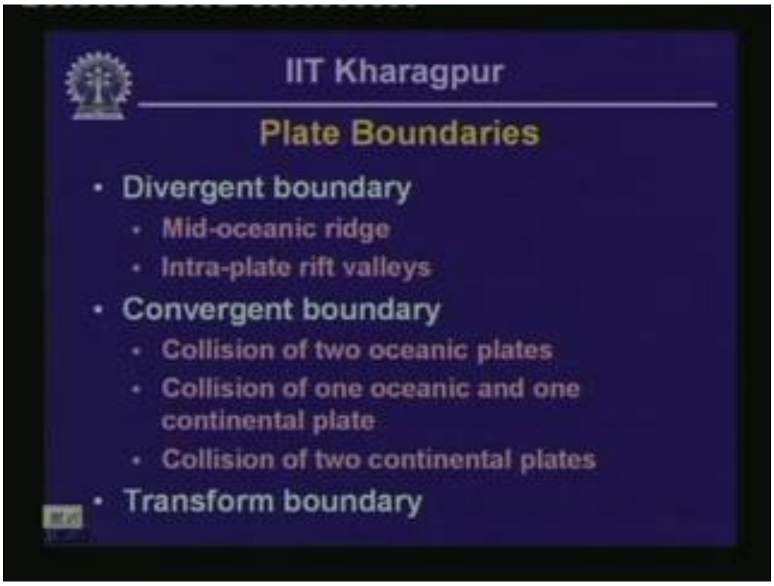

Now we want to look at the plate boundaries; what are the types of plate boundaries? Plate boundaries could be divergent boundaries, and divergent boundaries are the boundaries where sea floor spreading is taking place or where magma is getting ejected to the surface and pushing out the crust on either side of the divergent boundary. Typically, divergent boundary is found at mid oceanic ridges, or they are found at intra-plate rift valleys such as the east African rift valley; these are some of the very good examples of divergent plate boundaries.

Then secondly, there are convergent plate boundaries. At convergent plate boundaries, collision between two oceanic plates could take place; collision of one oceanic and one continental plate could take place, and collision of two continental plates can take place also at convergent boundaries. Collision of two oceanic plates is found off the east coast of Japan; we will see this in the next little bit. One oceanic and one continental plate; good example of that is the west coast of in northern part of North America. And collision of two continental plates, a good example of that is the northern boundary of the Indian plate; we are going to look at that in the next little bit.

And then, there is transform boundary. At transform boundary, two plates are sliding past each other. They do not want to override each other; they are just nearly sliding past each other. And one such transform boundary is the west coast of southern part of North America, California, in fact. That has got a very remarkable transform boundary between the pacific plate and North American plate. And at that location, the pacific plate is simply sliding past the North American plate without over riding or without actually sub ducting underneath the North American plate, alright.

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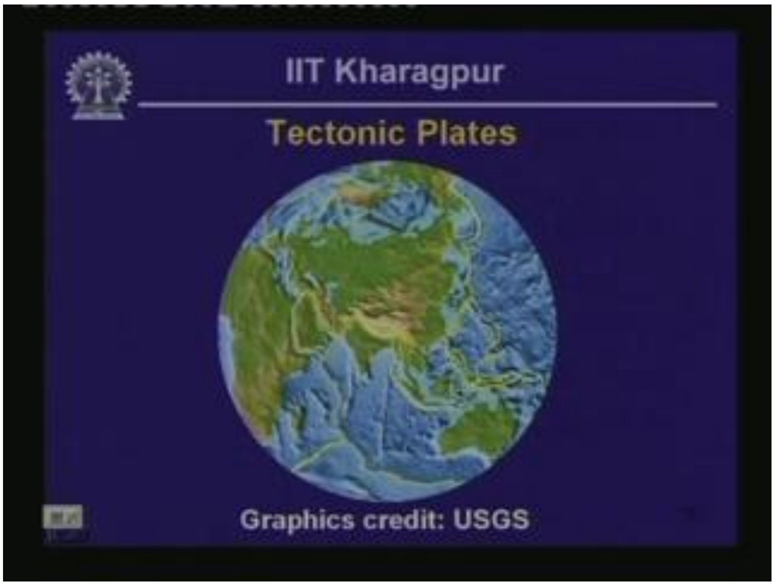

Now this particular animation shows you the plate boundaries that are found in different parts of the world and what we start we begin this particular animation with the India more or less near the center. And what you are seeing near the center and bottom right of this particular slide is the indo-Australian plate which includes the land masses of India, the central part of Indian Ocean and Australia. It goes to the south of the archipelago of Indonesia and south of it still farther south of it is Antarctica. And the yellow lines sketched on this particular animation will represent plate boundaries; you just watch the animation, okay.

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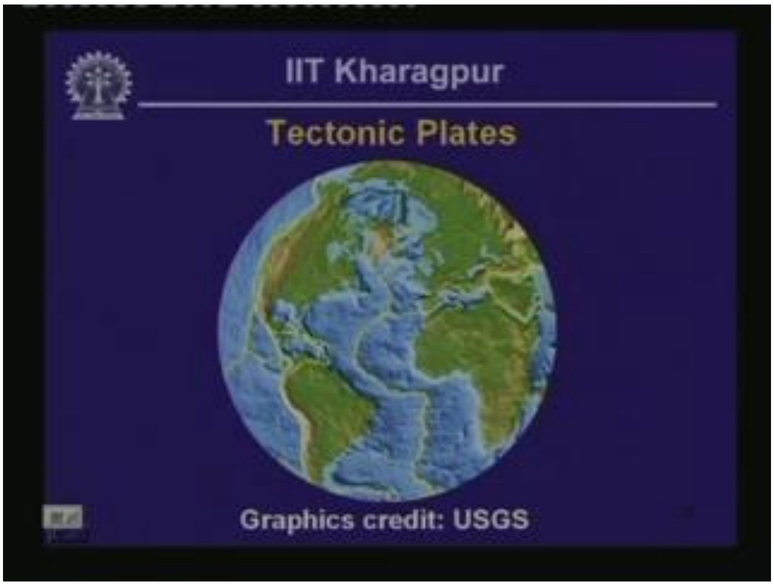

Now what we have done? We have rotated the globe a little bit and now what I need to show here is the plate boundary; you need to look at the plate boundary that goes straight from the northern tip to the southern tip near the center of this particular position of the globe. And that actually goes to the middle almost of the Atlantic Ocean goes across Thailand of Ireland of Iceland. And this is one of the most remarkable examples of mid oceanic ridge spreading center. In fact, the Atlantic Ocean is spreading because of the upwelling of magma along these particular plate boundaries. So, this one here is a spreading boundary, okay. Then let us continue this particular thing.

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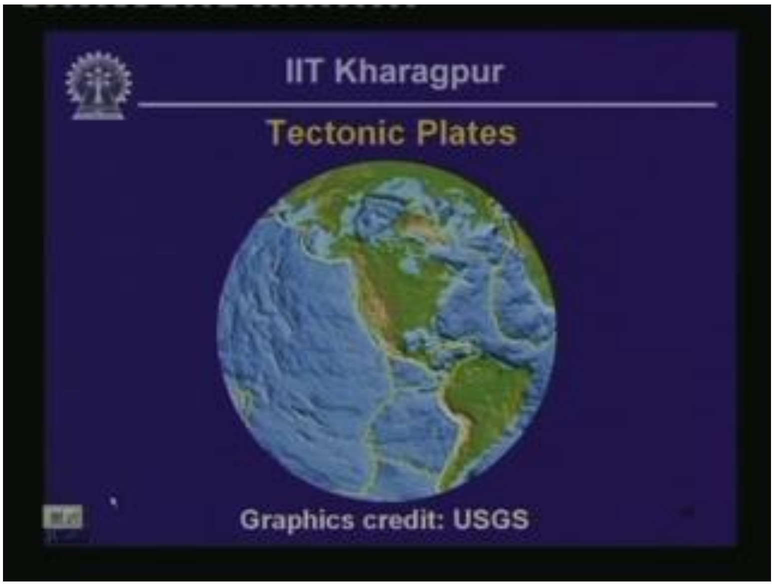

And now we have gone still further west, and we have come to the west coast of North America. And here the north-south line what I want to draw your attention is here near the southern part of North America. And this particular area this particular plate boundary is the transform boundary that we were talking about where the pacific plate is trying to go to the north, whereas out here this is the island chain of the west coast of Alaska. This particular plate boundary is a remarkable example of subducting boundary where the sea floor is subducting underneath actually pacific plate; pacific plate is this one here.

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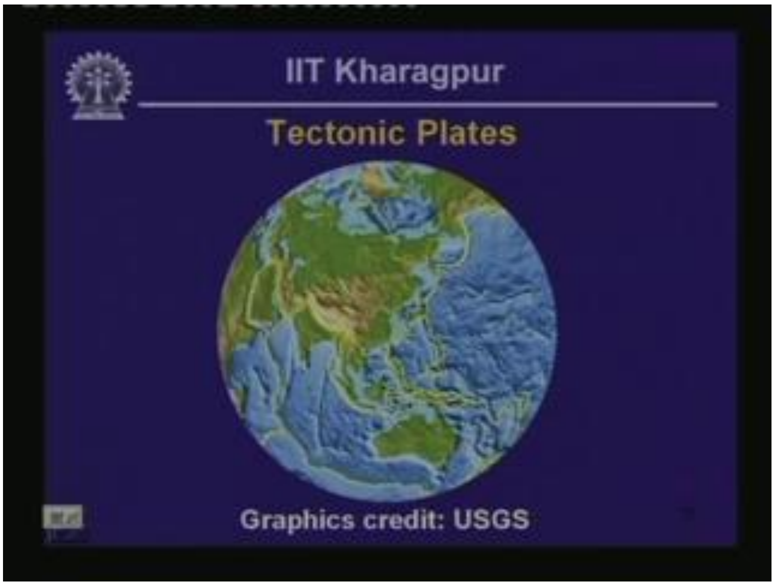

This is the pacific plate this one here; we have gone still further west. So, that is the pacific plate, and at that subducting boundary which we just now saw from the other perspective other view point. This particular boundary is a subducting boundary. Now this one here near the top of this particular configuration is again another view of the spreading boundary which we saw from the other end that is the northern part of the mid Atlantic spreading boundary, okay.

Now this one here is the island of Japan, and out here, the pacific plate is trying to subduct underneath the Sea of Japan actually; this is ocean. This is an oceanic crust you can see, let me get back; so this one here.

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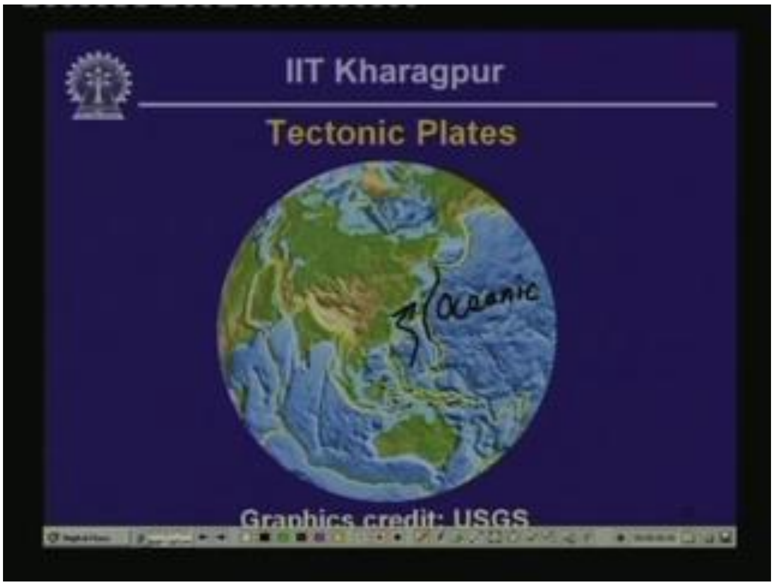

We are talking about this boundary here. So, this one here is a part of Pacific Ocean. So, that is an oceanic crust, and this one here is again another oceanic crust of the east coast of Eurasian plate. And here the Pacific Ocean is trying to subduct under the Eurasian plate, and because of that subduction activity, what we will see in the next little bit; the chain of islands, the Japanese archipelago was it was created, because of the activity that are associated with the subduction namely volcanism. We will see that in the next little bit, okay. Also another thing I want to mention here, you need to look at this particular feature here.

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This one, this is called ninety East Ridge. This is called ninety East Ridge, and this ridge is a remnant of the volcanism that is associated with the northward drift of the Indian plate. We saw earlier that the Indian plate at some point of time was actually connected with the Australian land mass and the Antarctic land mass and the eastern part of African land mass. And it started migrating towards the north, and this northward migration is still going on in fact.

And this boundary on the northern fringes of India; this is another converging boundary, where the Indian plate is colliding with the Eurasian plate. And that collision is also resulting in the uplifting of the mountain chain of Himalayas. So, that is the basic reason for formation of the Himalayan mountain chain as we will see in the next little bit, okay.

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Now let us look at the features associated with ocean continent convergence. And if you recall an example for ocean continent convergence is the subduction activities of the island chains of the west coast of Alaska in northern part of North America, then southwest of Canada and northwest United States; that is also another good example where subduction of Pacific plate is taking place underneath North American plate.

So, what are the features here? What is happening here is that the oceanic crust which is shown here on the left is trying to subduct underneath the continental crust which is to your right. And the movement is shown by thick brown arrows there, and because of the rubbing action, what is going to happen is there will be a zone of accretional features zone of accretion.

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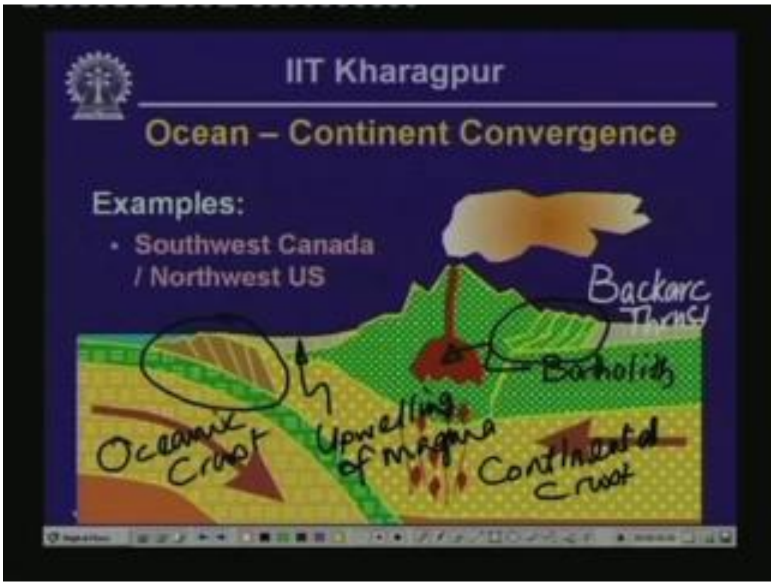

So, the zone that I am talking about zone of accretion, where the rock debris generated because of the rubbing action between the contacts of the oceanic crust; this is the oceanic, crust and this one here is the continental crust. So, because of the rubbing action near the top, a zone of broken rock mass is going to develop. And then behind the zone of accretion, what we are going to get is a valley which typically gets filled out with sediment. And near the margins of the continental crust, the cracks within the continental crust typically lead to the upwelling of magma as indicated here.

So, this one is upwelling of magma, and this one here is batholiths as you might recall from earlier batholiths. And typically this type of ocean to continent convergence leads to the development of volcanoes along the margins of the continental crust. And on either side of this volcano, there are thrust zones. So, this one is a back arc thrust zone typically it is called. So, this is a back arc thrust zone where rock mass is failing because of the compressive movement or compression that is taking place within the continental crust. And then further out, typically there is a valley which is filled with sediments and that is called back arc valley. So, these are the features associated with ocean continent convergence. Now lets us look at the details of ocean convergence.

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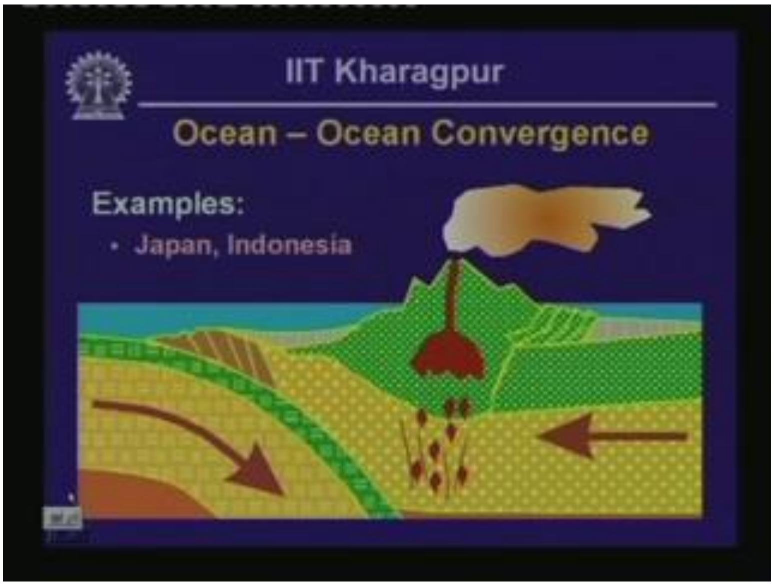

That is again going to be very similar; that is again going to be very similar compared to ocean continent convergence. The features are quite similar as you are seeing here. So, on the right here is one oceanic crust, and on the left, there is another oceanic crust that is trying to subduct underneath the oceanic crust which is on your right. Examples of it as I have already mentioned, Japan and Indonesia are good examples of ocean to ocean convergence. Volcanism is typically associated with this type of convergence, and these volcanoes typically give rise to chain of volcanic islands, and in fact, these things are called island arcs. So, this one here is an island arc.

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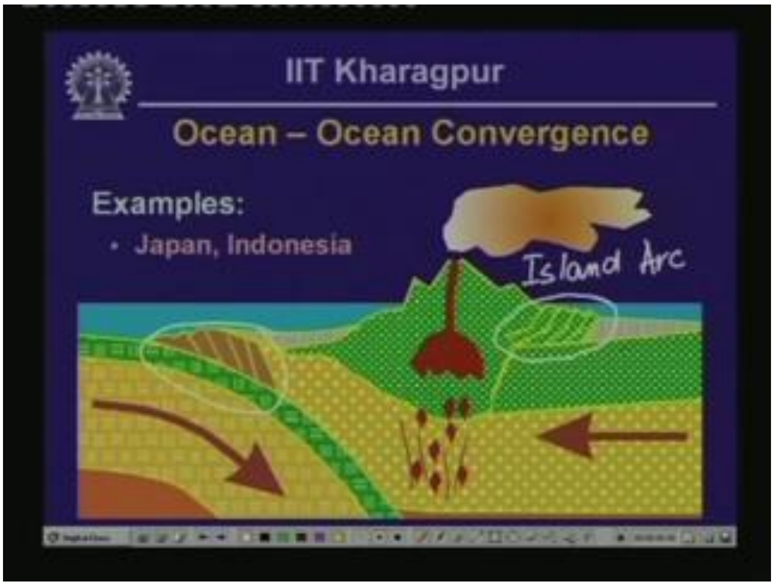

Because on either side of these volcanoes, there will be oceans. So, this is an island arc and the Japanese archipelago in fact is one such island arc. So, here again, you could see that there are thrust zones, there is a zone of accretion, and there is then again back arc and fore arc valleys filled with sediments. Okay, I forgot to mention actually in this particular ocean to ocean convergence cross sectional details that we are considering here as well as in the previous slide where we were considering ocean to continent convergence that the symbols that I am using includes the following. What you will see is that, there is a unit which is cross hatched with white patterns on green background.

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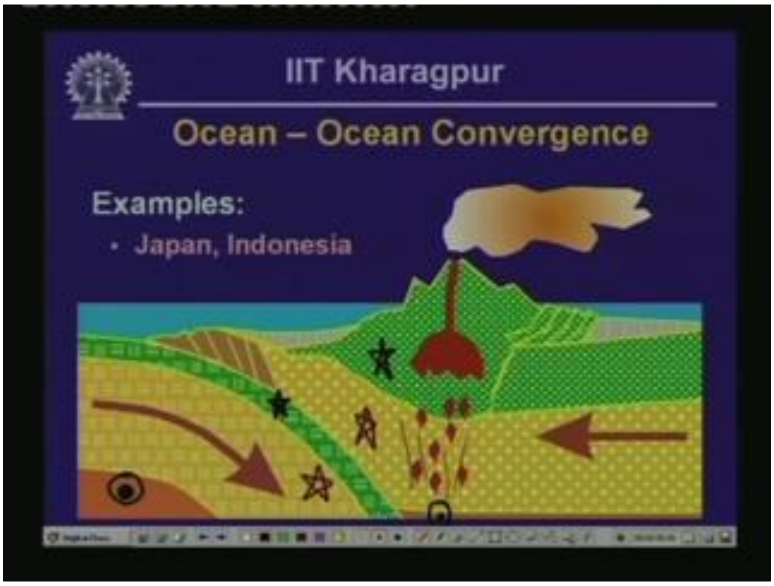

I am talking about this one this feature here and this feature. And then there is another type of shading that I am using includes this one and this one. So, these units that are marked with star, they represent the lithosphere. And the orange shading which is underneath the lithosphere which is shown like this; this one here represents the asthenosphere. So, there is an asthenosphere underneath the oceanic crust as well as in this case. Both the crusts are underlain by asthenosphere, both the oceanic crusts underlain by asthenosphere, whereas in the previous slide where we were considering ocean to continent convergence, we had one asthenosphere underneath the oceanic crust and another one underneath the continental crust.

So, the features here in ocean to ocean convergence are quite similar to the ocean to continent convergence. We are going to stop our lesson here, and we are going to continue with the third type of convergence in the next lesson.

Thank you very much.