Conservation Geography
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Module - 2
The Earth
Lecture - 5
Structure of the Earth

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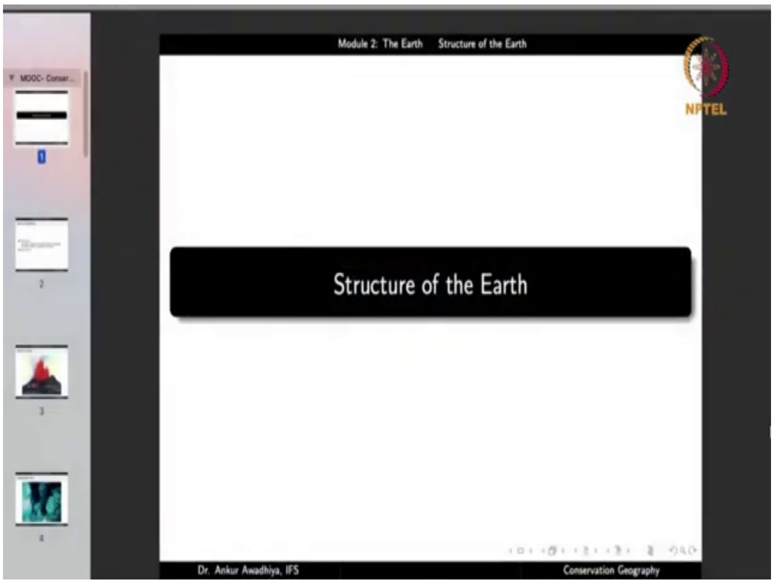

Namaste. Today we carry forward our discussion on the Earth. And in this lecture, we shall have a look at the structure of the Earth. Now, the Earth is a very big planet, how can we get to know what is inside the Earth? Because what is inside the Earth has a very big ramification on the kinds of processes that we are going to observe on the Earth.

So, we need to have an information about what is there inside? What is the Earth made of, what are the different layers? Now, in the last lecture, we had a look at the different layers of the Earth, the crust, the mantle, the core, which was divided into the outer core and the inner core. But then the question is, how did we come to know that this is the structure.

And it is really important to know how we came to know about the structure of the Earth because it gives us a confidence about whether we are thinking in the right direction, whether we have the correct data, the correct information or not. So, in this lecture, we will have a look at how did we come to know about the structure of the Earth, how did we conclude that the Earth is having such and such structure.

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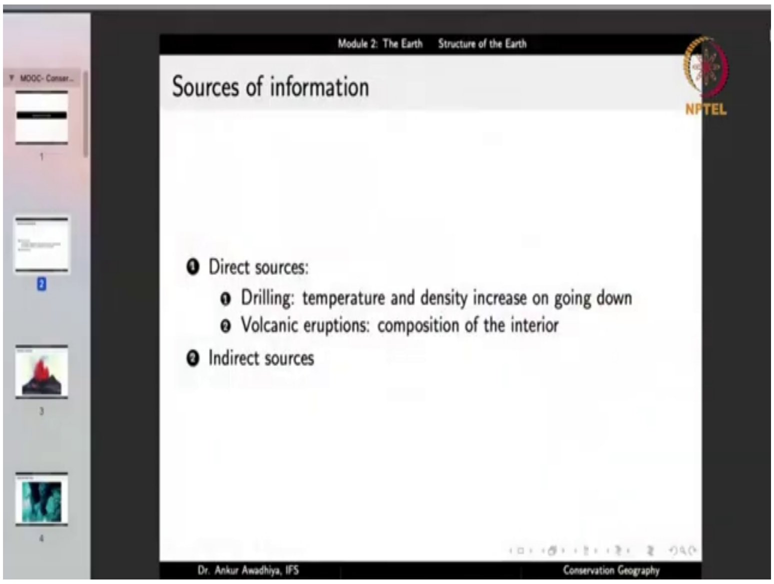

So, essentially, there are two kinds of information that we can make use of. The first is a direct source. Now, a direct source is a source that you can directly look at. So, for instance, if there is a volcanic eruption, and there is material that is coming from the inside of the Earth to the outside, so we can take this material that has come from the inside of the Earth, we can put it through a chemical analysis to understand what is there inside the Earth. Or, in other case, we can dig a deep mind.

And we can make observations, what are the kinds of elements or compounds that we find at different depths, what are the temperatures and pressures at different locations inside the Earth. So, there are two major direct sources, the first is drilling. And through drilling, we came to know that the temperature and density increase on going down. Now, the temperature increases, because the inside of the Earth is still very hot.

In the last lecture, we saw that the Earth began as a molten mass. So, there was a congregation of different smaller molten pieces, they were banging into each other, they were getting attracted because of gravity. And when they collided with each other, there was a conversion of gravitational potential energy into thermal energy, which melted everything. So, the Earth began as a molten mass.

Now, with time, the Earth has been cooling down. But this cooling down has only occurred on the surface, but deep inside it is still very hot. And because of that, when we drill a mine when we go down, we will find that the temperatures increase with depth. Secondly, we also saw that when the Earth was a molten mass, then there was a separation or a segregation of materials based on their densities.

So, that denser materials sank towards the center of the Earth. So, materials like iron or nickel, they sank towards the center. Whereas those materials that were lighter in density, they remained on the top. And this is what we see when we drill a mine and we take samples from different depths. The samples that are taken from greater depths, they have a greater density.

So, this is a direct source of information that we got that temperature and density increase on going down. The second is volcanic eruptions, which can give us the composition of the interior. So, we can take the lava, we can put it through chemical analysis to understand what kinds of materials are there inside the Earth. Now, in this lecture, we will make frequent references to what we had seen in the previous lecture.

And essentially, the knowledge that earlier the Earth was a molten mass has come out of our understandings and our readings of different sources of information that we have today. Because remember that 4.6 billion years ago, there was no human being to take data. So, we are only making inferences.

And these inferences we are making out of the pieces of information that we have today. And one of those pieces of information is the direct sources. And we can make use of them. And another source is the indirect sources that we do not have a direct access to. So, we cannot see the inside of the Earth, but we can make certain deductions. So, those are the indirect sources.

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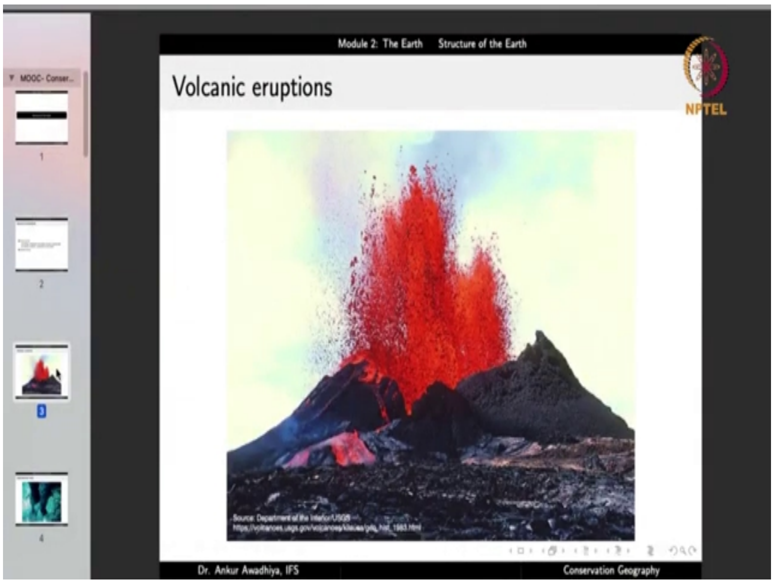

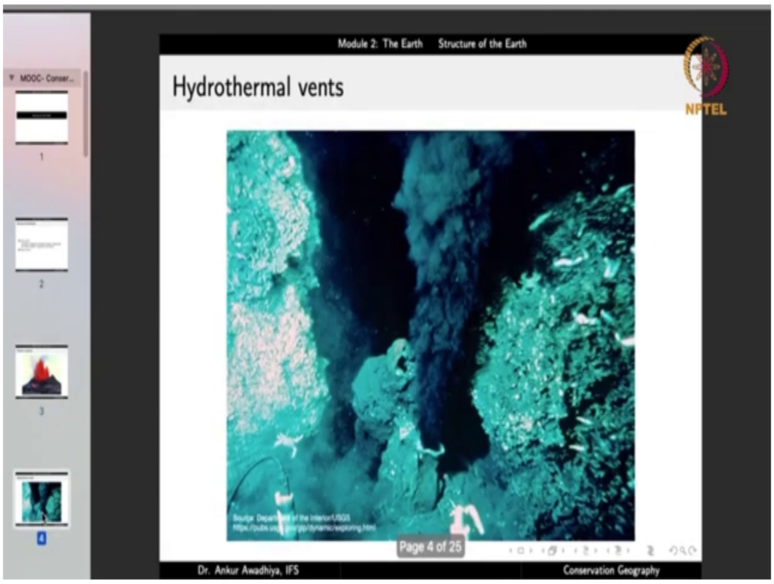

And then the direct sources, the most important ones are the volcanic eruptions. Now, volcanoes can occur on the surface of the Earth, or they can even occur deep down in the oceans. Now, in a number of locations, we have these volcanic eruptions, and the magma that is inside the Earth, it comes out, it becomes lava.

And in certain cases, there are very spectacular explosions. And we can take samples from these. Similarly, there are hydrothermal vents that are inside the sea. So, they are there on the ocean bottoms and the sea bottoms. And here is well, there is some material that is coming out from the Earth. And we can take samples from here as well.

So, we can use a submarine and take certain samples from here. Typically, these hydrothermal vents are also very hot. And they also give us the information that the inside of the Earth is very hot, and at the same time, we can take samples and put them through chemical analysis.

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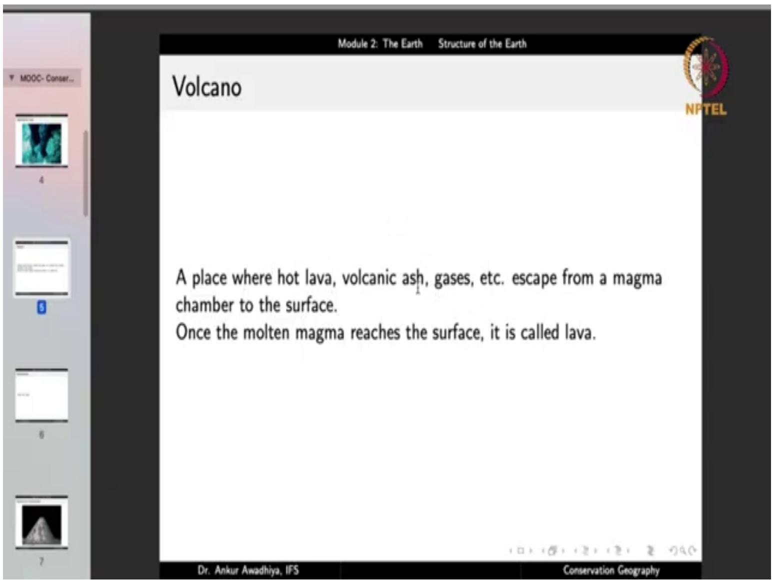

Now, when we talk about volcano, let us define a volcano. A volcano is a place where hot lava, volcanic ash, gases, etcetera, escape from a magma chamber to the surface. So, the important thing here is that there is a magma chamber below the surface of the Earth, in which there is magma. This magma comes to the surface at a place that is known as a volcano.

And in this magma, what comes out, you have hot lava, you have ash, that is burns things, mineral deposits, you can have gases, and so on. And once the molten magma reaches the surface, it is called lava. So, the difference between magma and lava is that once it is inside the Earth, it is magma. Once it has come to the surface, it is lava.

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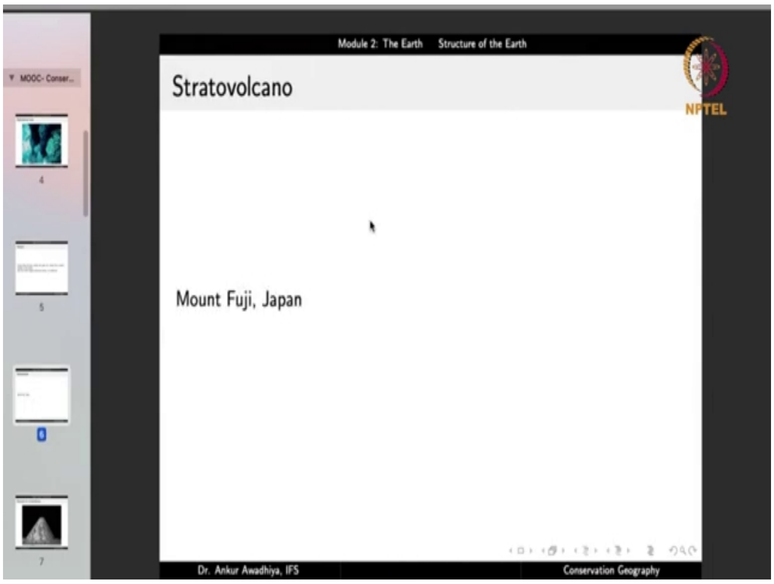

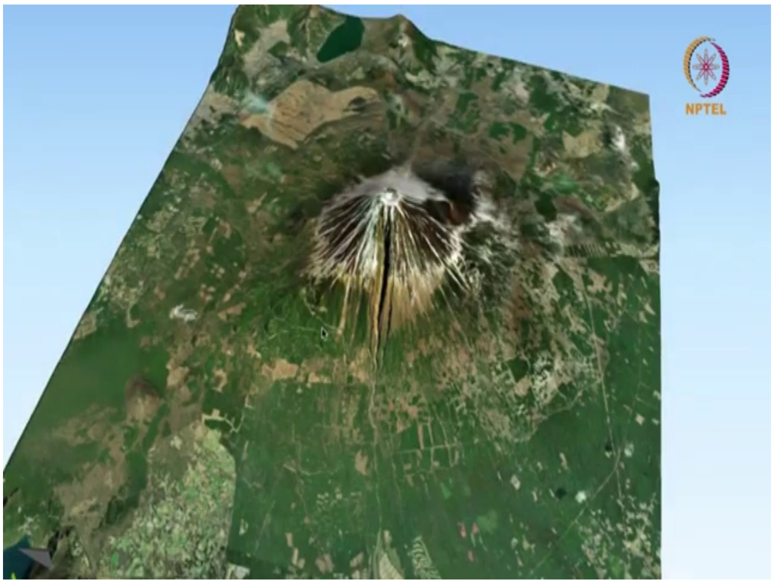

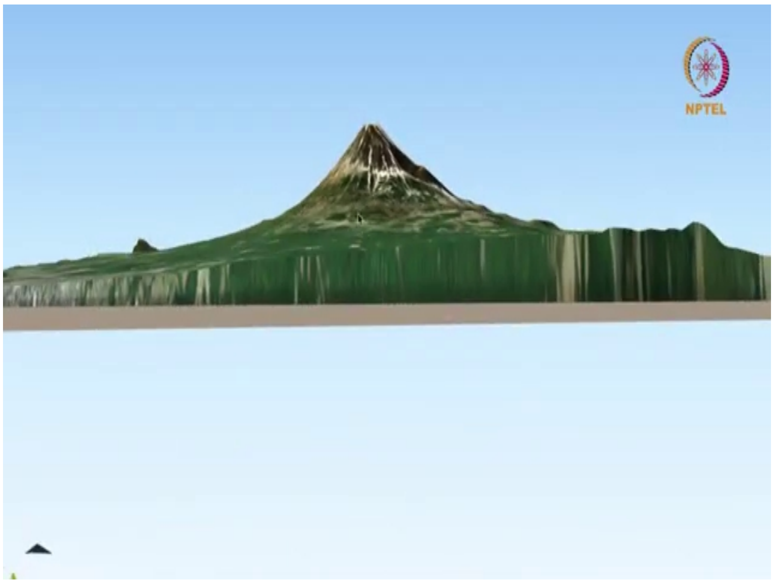

So, let us now understand a volcano by looking at an example. Now, this is Mount Fujiyama of Japan. And to make this more this 3-dimensional model, what I've done is that I have taken the satellite imagery and overlaid it on top of a 3-dimensional model of the Earth. And this 3-dimensional model of the Earth is having certain magnification on the z-axis, so as to enable us to understand things in a better way.

So, if you look at this volcano, the first thing that is amply clear is that it is having a conical shape, so the bottom is much broader, and it goes on tapering towards the top. So, it is a conical volcano. On the top, you have a depression. And this is the location from which the magma comes out in the form of lava.

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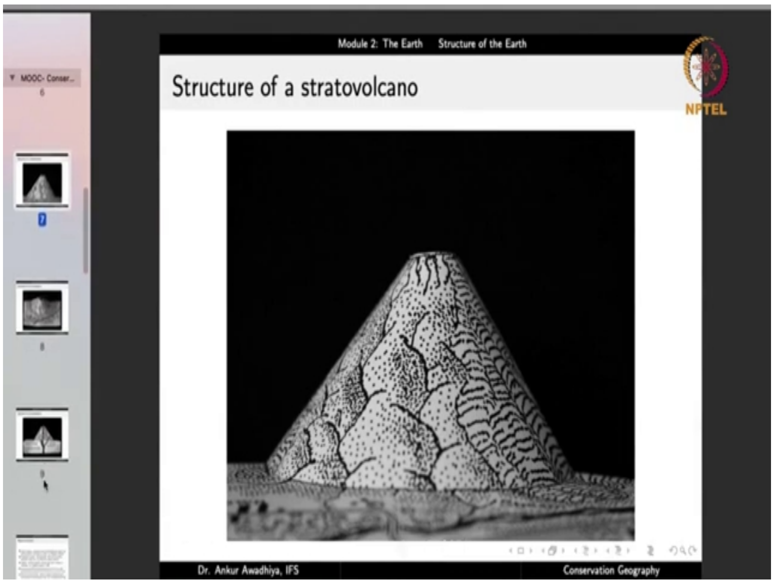

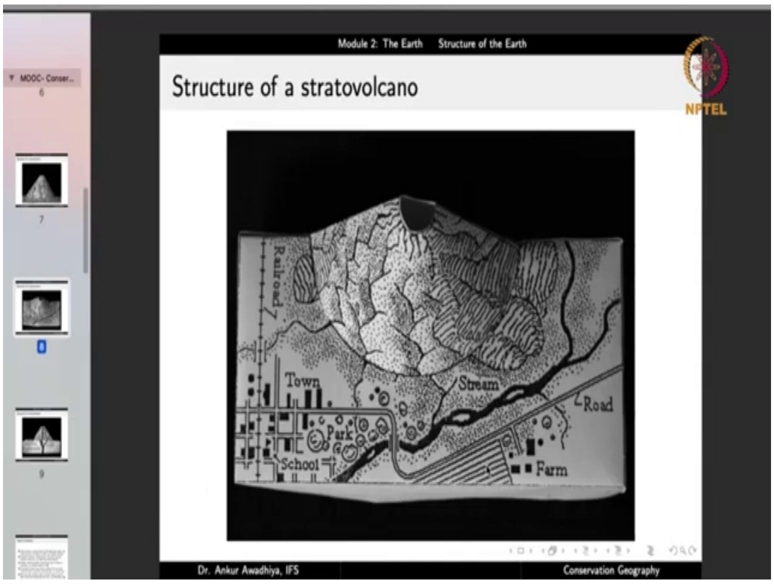

Now, if we look at one such stratovolcano, what we will observe is that on the outside, it is having a conical structure. And there might also be certain towns or villages that have come up in the nearby because typically, these volcanoes do not erupt at all times. So, there will be an explosion in a volcano, there will be in an eruption, it will give out magma for some time.

And then after a while, it may even become dormant. We also have a number of extinct volcanoes, volcanoes that earlier used to spew out lava, but they are now not spewing out lava for a very long period of time. So, you can have an active volcano that is spewing out lava, you can have a dormant volcano that has not given out lava for some period of time, but it may give out lava after some time.

And you can also have extinct volcanoes that have given out lava in geological timescales. But for a very long period of time, there has been no activity. Now, in the case of a stratovolcano if it is a dormant volcano or if it is an extinct volcano, you can even have a number of towns and cities and villages that come up in the vicinity.

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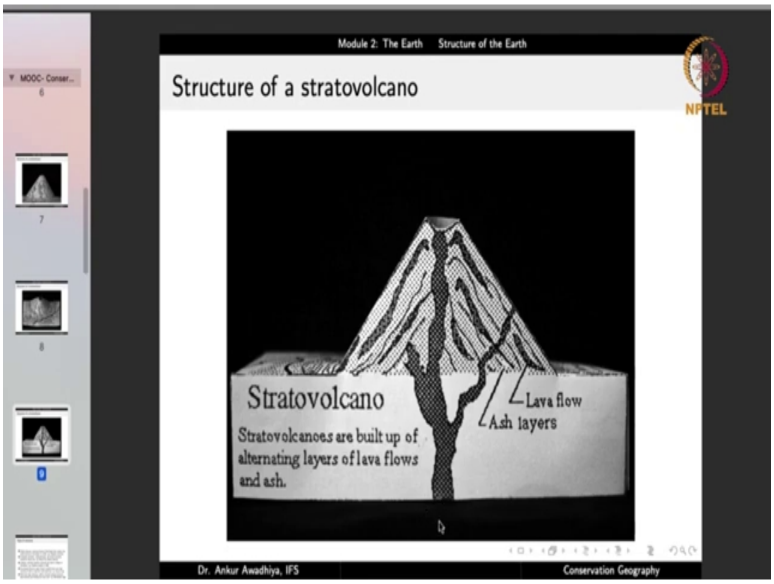

Now, if we took a section of this volcano, what we will observe is that there is a magma chamber inside and the magma comes out through these conduits. And one of these conduits will be reaching to the top but you can also have conduits that are coming to the surface at other locations. And when this volcano began, so at this point, it would have given out a certain amount of lava, certain amount of ash that gets deposited. And then after a while, it becomes dormant, then after some time, it again gives out lava and ash, and so on.

And so, what happens is that we have a situation where you begin with a small volcano, which is made out of the ash and lava. Now, after some time, again some amount of lava and ash comes out. And so again, you get another layer of ash and lava, then you get another layer of ash and lava, then you get another layer of ash and lava, and so on. And at each of these points, the conduit is now getting taller and taller.

So, basically these stratovolcanoes are very much like layered structures, they are very much like the layers of onion. And so, this is how a stratovolcano will look like. Now, the benefit of a stratovolcano for us is that it is giving out lava that we can analyze. But stratovolcano is not the only kind of volcano that we have.

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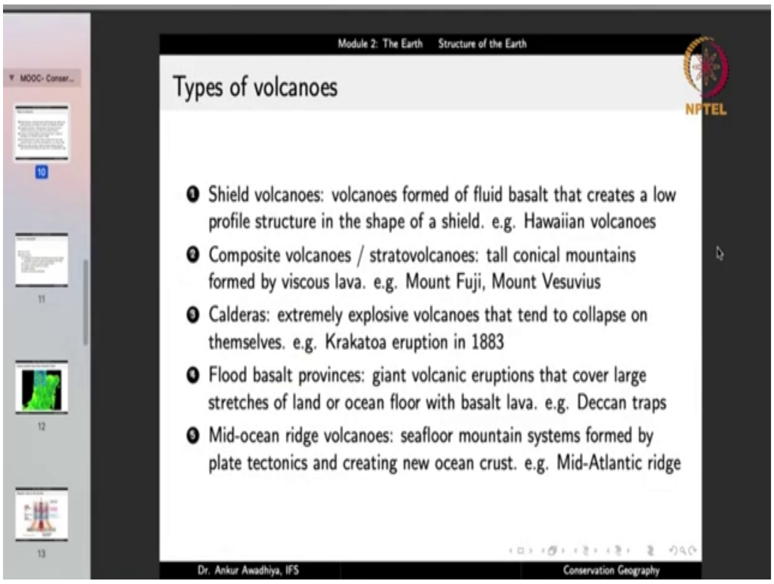

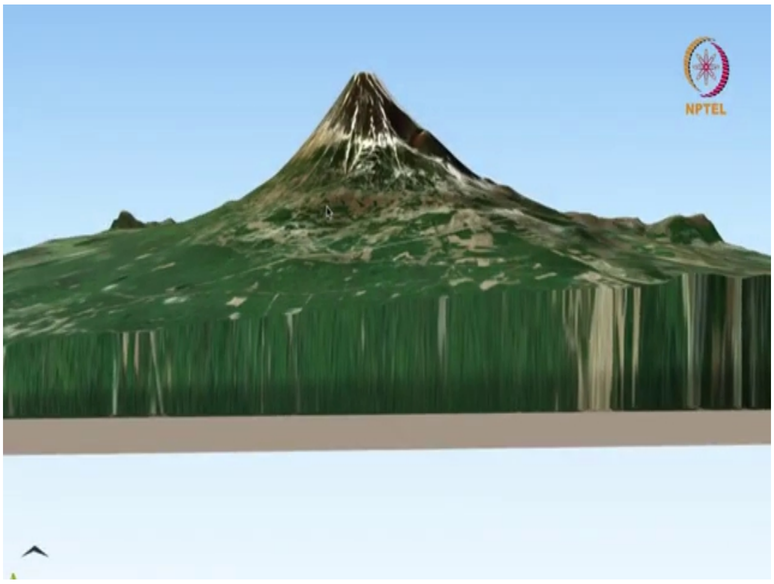

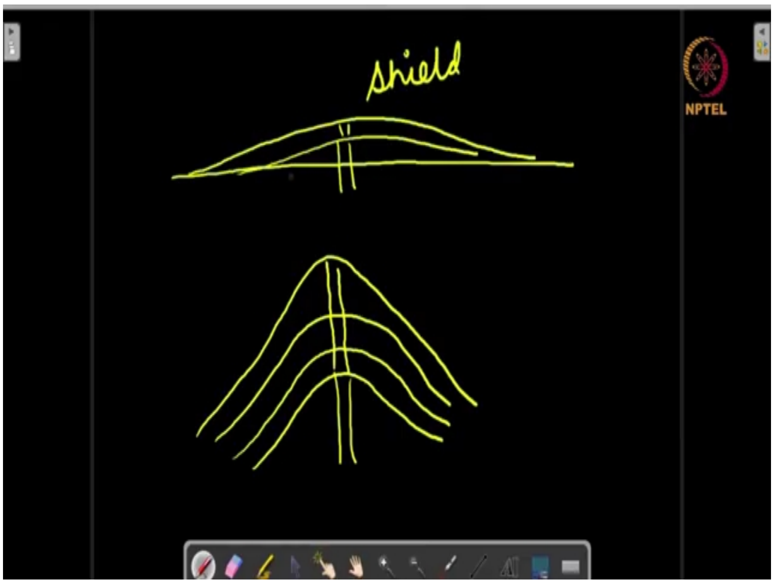

So, we can also have other types of volcanoes. So, we differentiate between five different types of volcanoes. The first one is a shield volcano. Shield volcanoes are volcanoes that are formed out of fluid basalt, that creates a low-profile structure in the shape of a shield such as the Hawaiian volcanoes. Now, in the case of a stratovolcano, it is in the shape of a cone, but in the case of a shield volcano, what happens is that you have the lava that is having the lesser viscosity.

And so, in that case, the lava will spread to a very large area. Then later on, if you have another eruption, you will again have lava that is spreading out to a very large area. So, now this is not in the shape of a cone, this is in the shape of a shield. So, this is known as a shield volcano. And typically, a shield volcano is formed in locations where you have basaltic lava.

Now, basaltic lava is basic lava, it is having a high pH and it is very fluid. So, it is less viscous now because it is less viscous it can spread to larger areas. And so, it creates a shield-like structure. And a good example is the Hungarian volcanoes. Another one is composite volcanoes or stratovolcanoes that we have just seen, they are tall conical mountains, which are formed by viscous lava.

Now, because this is viscous, acidic lava, so it cannot spread to a very large area. And so, it goes on accumulating in layer by layer and it creates a cone, good example is Mount Fuji or Mount Vesuvius. Then we have Calderas. Calderas are extremely explosive volcanoes that tend to collapse on themselves, such as the Krakatoa eruption of 1883. Now, in the case of a Caldera, what happens is that the magma conduit it gets plugged because you have a magma of a composition that solidifies very easily and also it has a lot of gases such as water vapor.

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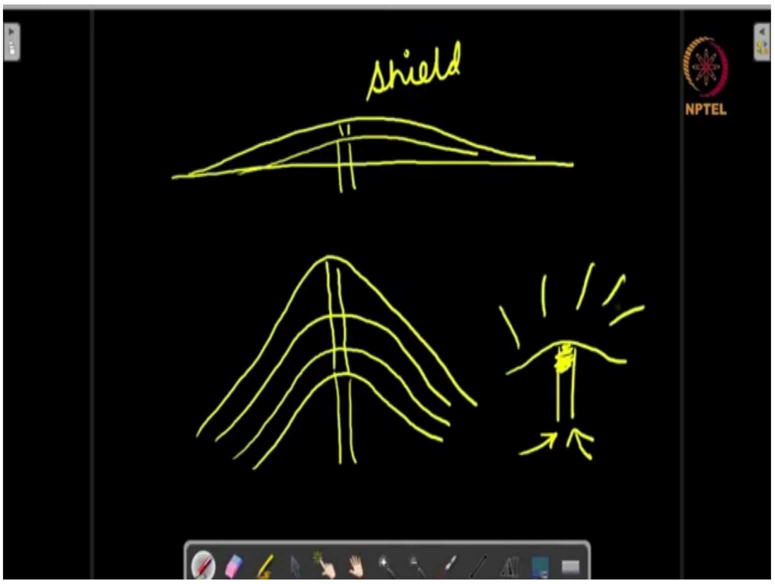

So, what happens, in that case, is that as soon as you have the eruption, so you have a small volcano, but then this portion it gets blocked. And because you have a lot of gases, so there is a huge pressure that is coming up. And because of this pressure and because this conduit is blocked, what will happen is that the pressure will go on accumulating and after a while, there will be a huge explosion.

And after this explosion, there will practically be nothing left. So, this is a Caldera, an extremely explosive volcano that tends to collapse on themselves. So once this explosion has occurred, once this eruption has occurred, you will not find a shield or a cone, you will just find a big-sized crater or a big size lake in that area. Because there was a huge explosion and everything that was erupted. It just is thrown to very far-off areas.

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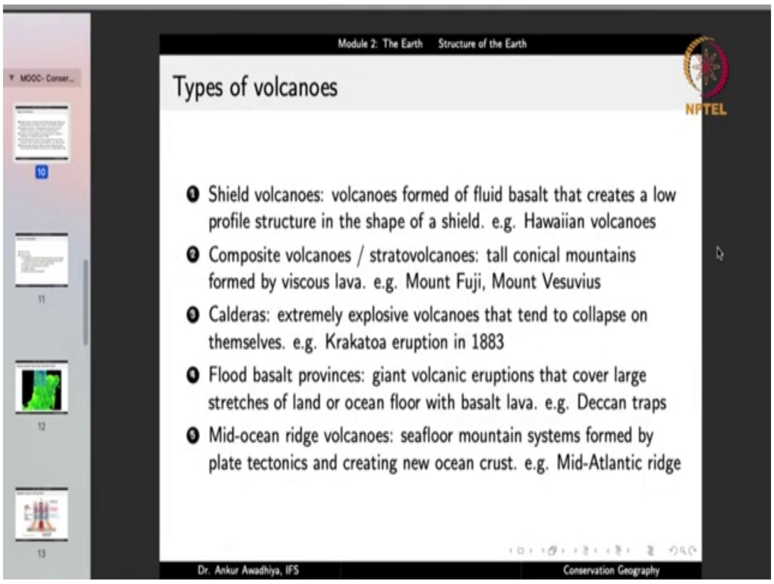

Another type is the Flood basalt provinces. They are giant volcanic eruptions that covered large stretches of land or ocean floor with basalt lava. And a good example is Deccan traps in our country. And in the case of Flood basalt provinces, here again, you have basalt and basalt is a basic magma and it is having a very less viscosity, so it can spread to very large areas. So, if the viscosity is high, then you will have the formation of a cone as a stratovolcano.

If the viscosity is less, then it will probably form a shield. If the viscosity is even lesser, then the magma will spread to very large areas, the lava will spread to very large areas, and it will become in the form of a Flood basalt province. Another volcano is the Mid-oceanic Ridge volcanoes. They are seafloor mountain systems that are formed by plate tectonics, and they are creating new crust.

So, they are on the sea floor, they are in the form of mountain systems. And we will have a look at them in a short while. But what is happening, in that case, is that the magma that is coming out it is creating new crust, which is then moving away from that area. So, you will not find a stratovolcano or you will not find a shield in that area, you will find a very specific structure, in which case the lava that is coming out, it solidifies, and then it moves to other areas.

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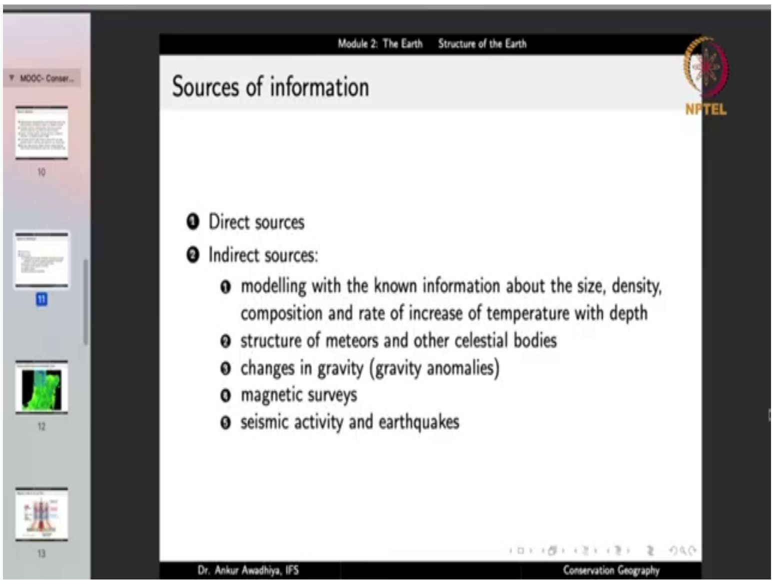

So, those are the direct sources. In the case of indirect sources, we do not get a direct piece of evidence, but we gather information in an indirect way. And good examples include things like modelling, modelling with the known information about the size, density, composition, rate of increase of temperature with depth, and so on.

So, in the case of modeling, what we do is that we take all the direct evidence that we have, and we put it into a model, that is we construct a mathematical framework, or we construct a computer simulation. And we try to plug in all the pieces of direct evidence that we have, and come up with what is the best fit that we can get out of all of these direct evidences.

So, for example, if we know that as we go deeper inside the density increases, so with this we can construct a model of the Earth in which the center is having the highest density and the surface is having a lesser density. Now, with this model, if we assume that the Earth is completely solid, we can use this model to compute things such as the rotation speed of the Earth.

And if it matches with the model, we will say that okay, the model is correct. If it does not match, then we will say no, the model requires some more changes. So, we have to look for some other piece of evidence. So, for instance, if you construct a model of a solid Earth, it does not explain changes in magnetism. And so, we will discard this model. And we will say that no, for magnetism to exist, there has to be some movement inside.

And so, let us try to make a model with a liquid interior. And let us see if it is able to explain different phenomena that are occurring on the Earth. If it explains, then that is fine. If it does not explain, we will look for some other modifications to the model. So, modeling is an indirect source of information. And once you have a model that is a reperesentation of the Earth, you can make use of this model to make certain predictions.

And if those predictions match with their direct evidence, then the model is good. So, these predictions can also serve as data points. So, this is an indirect source of information. Another indirect source is a structure of meteors and other celestial bodies. Now, in this case, what we are saying is that when the Earth formed, when the Earth originated, it did not originate just by itself, there were also other bodies that were formed.

And these other bodies, maybe revolving around the sun, say in the form of asteroids, or in the form of other planets on the form of certain other celestial bodies that are going around. Now, we can have evidence from these bodies. So, for instance, if there is a celestial body that comes into our Earth, it crosses the atmosphere, and then it lands on the Earth, we will say that it is a meteorite.

Now, if there is a meteorite, we can look at its composition. And we can say that okay when the Earth formed, it was also formed of very similar materials. So, this should be the overall composition of the Earth. Or we can look at other planets. And we can make deductions based on the structures of those planets.

Now, in this case, we are not looking at the structure of the Earth, we are looking at the structure of some other celestial body, but this is again an indirect source of evidence because we can make co-relations by saying that okay when the Earth formed, it should also be have formed in a very similar process and so it should be having a similar composition. So, this is another indirect source.

We can look at changes in gravity in different locations. Now, changes in Gravity can tell us what is inside the Earth. So, if there is a certain location where the gravity is more, then that would mean that there is more amount of mass at that location. And by looking at the gravity at different points, we can make a correlation between different locations and the different amount of masses that are inside. So, that is also another way.

Another thing is magnetic surveys. So, we can look at different locations on the Earth and we can look at what is the amount of magnetism, what is the direction, what is the strength of magnetism in those locations. And that can also give us certain information that we can put into our model to understand about the structure of the Earth or we can make use of seismic activity and earthquakes.

Now, we will look at it in more detail in a short while, but in the case of earthquakes, there are certain waves that are generated, and these waves they can pass through the Earth and when they come out at another point on the surface of the Earth, we can make measurements and we can make inferences about what is there inside the Earth.

Now, all of these are indirect sources, because in none of these we are cutting down the Earth and we are seeing what is inside, we are not having our hands on a material that is coming from the inside. So, these are not direct sources, but they are also very important sources the indirect ones because the direct sources are so few and far in between whereas, the indirect sources are much more easily accessible to us because we have a large number of samples of different meteorites that have come to our planet and it is easy to understand them.

We can make measurements of gravity or magnetism at all different locations of Earth, whereas drilling a mine is very expensive, it is very time consuming, and at the same time, we do not have the technology to dig very deep mines. So, the maximum that we can do is a few tens of kilometers, but not more.

Now, considering that the Earth is having a radius of around 6400 kilometers, then 10 kilometers is just looking at the skin of the Earth. So, for the inside information, we have to make use of indirect sources. So, what do these indirect sources look like?

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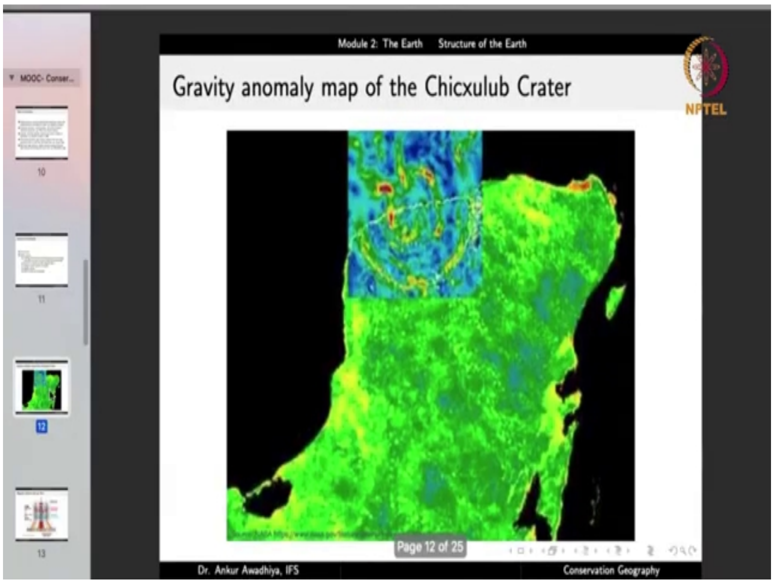

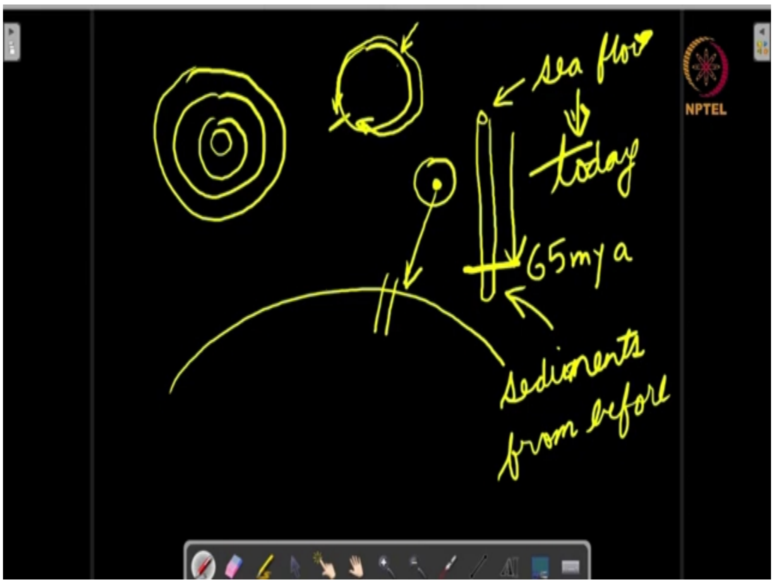

Now, this is a gravity anomaly map of Chicxulub crater, which is right next to South America. Now, this is the gravity map, the gravity anomaly map and what we are observing here is that there are certain locations that are like concentric rings and these rings are having a similar gravity anomaly that is these locations are having a higher gravity that is expected there are certain locations that are having lower gravity than is expected.

Now, this portion is land, this portion is the sea and it is very difficult for us to directly look at what is inside by removing all the sediments and observing it with our direct eyes. But by looking at the gravity anomaly map, we can very easily see that there is something here that is showing a concentric structure.

Now, how can you have a concentric structure, well, you can have a concentric structure, say when there is this Earth and there is a body, a celestial body that comes and it impacts on the Earth. Now, in that case, you will have a crater that gets formed and in that crater, you can have different ridges that get formed. And in the case of this Chicxulub crater, you are observing these ridges.

Now, it is difficult to observe these ridges directly but by looking at the gravity map, you can very easily see that these are concentric circles. And when we take samples from these locations, so what we do is that in these locations typically in the seafloor, we can perform a mining operation, we can draw out cores, what is the core. So, at this location, we will do a drilling and we will take out the Earth in the form of a rod of materials.

Now, at the top, you have the seafloor, which is giving us the information about today. And as we go deeper, we are looking at sediments that were deposited way back. And so, these are the sediments from before. And this is what we had seen in the previous lecture as well, that if you have a water body, there will be sediments that get deposited in the form of layers, and the older sediments are at the bottom and the newer sediments are at the top.

Now, we can also compute the time of these sediments. Because whenever we have these sediments, they will also typically be certain fossils that also get deposited together with these sediments. And with the fossils, we can make a correlation about what was the age of that particular portion of the core.

And so, in this case, what was found is that if you look at, say, around 65 million years ago, you find certain sediments that have a very different composition than the sediments from before that period or after that period. That is, nearly 65 million years ago, there was something that came to displace, before 65 million years ago, what was happening is that there were sediments that were coming out due to the erosion of the Earth.

After 65 million years ago, also you have sediments that are coming through the erosion of the Earth. And so, the composition is similar to the composition of the Earth's crust. But around 65 million years ago, there is a particular segment, where you have composition that is very different. A composition that is having a very large quantity of heavy elements. Now, in the case of Earth, the heavy elements are down in the core.

But in the case of smaller bodies, that would have cooled down much faster, the heavier elements will be found throughout the body. Now by looking at this crater, we came to the conclusion that okay, 65 million years ago, there was certain celestial bodies say in the form of a meteor or in the form of an asteroid that came and impacted on the Earth, it impacted at this location.

And when there was an impact, there was a crater that got formed, we can understand when this crater was formed by looking at the sediments at different locations by looking at the carbon dating or uranium dating. And we also know that 65 million years ago, there was an extinction of dinosaurs. So, we can make a correlation that there was something that happened, probably this Meteor or this asteroid, it impacted the Earth, and it resulted into a large amount of destruction because of it the dinosaurs got extinct.

Now, this is an indirect source of information, because we are not seeing the extinction of dinosaurs, but what we are observing is that there is certain gravity anomaly through which we understand that there is a crater, and then we can make use of direct evidence in the form of the cores, to understand what would have happened at that point of time, and then we also make use of models.

So, what we do is that we have a model, a mathematical or computational model, that tells us that if an asteroid of this size would have impacted the Earth, at this particular speed, what would have been the level of destruction. Now, what kinds of destructions can happen? Well, one, there would be a large tsunami, because this location is very close to the sea. It is half of this crater is on land, half of this crater is in water.

So, when this impact occurred, they would have been a very great tsunami, that is one thing. Secondly, when you have a big impact then probably there would also have been a release of a large amount of energy because of which the forest and the animals that were there in the vicinity that would have died.

Whenever you have an impact on the Earth, then you will be having certain waves that propagate through the surface and through the body of the Earth, those waves would have converged at a location that is diametrically opposite on the Earth. So, that is if you have, if this is the Earth and if you have an impact at this point, you will have waves that go in all directions, but right at the opposite point, they would converge, and here again, there would be probably interference of these waves that would again split up the Earth at this location.

So, probably you will be having certain amount of lava flows in those locations. Now, what is that location, that location is our Deccan traps and if you look at the lava that was deposited in the Deccan traps, that is also around 65 million years old. So, now you can make a corroboration that okay, now, both of these things are fitting together.

So, the model predicts that right on the opposite end of the Earth, you will be having eruptions of volcanoes and you are finding eruptions of volcanoes, then you can make use of direct evidence, the composition of the material that is there at Chicxulub club and the composition there is of very high density of sulphur.

Now, if you have an impact of an asteroid and there is sulphur inside, this sulphur will also be released into the atmosphere. Probably, if the amount of energy is very large, then it would be erupted to even the stratosphere. Now, if you have dust particles like sulphur that come up into the stratosphere, what will happen is that the energy from the sun will not be able to reach the Earth as efficiently, there will be a cooling of the planet.

Now, do we observe a cooling of the planet? Yes, we do observe because after 65 million years ago, for some period of time there was a cooling and how do we know that there was a cooling. Well, we can make use of course from Antarctica and we can see that okay, at this point of time, there was a cooling. We also have evidences of glaciers in different locations that we do not find today.

So, by making use of all of these pieces of information, both the direct and the indirect sources, we can come to the conclusion that okay 65 million years ago, there was a big impact on the Earth at this location, because of which the dinosaurs died, because of tsunamis, because of forest fires, because of cooling of the planet, and so on. So, this is the benefit of the indirect sources.

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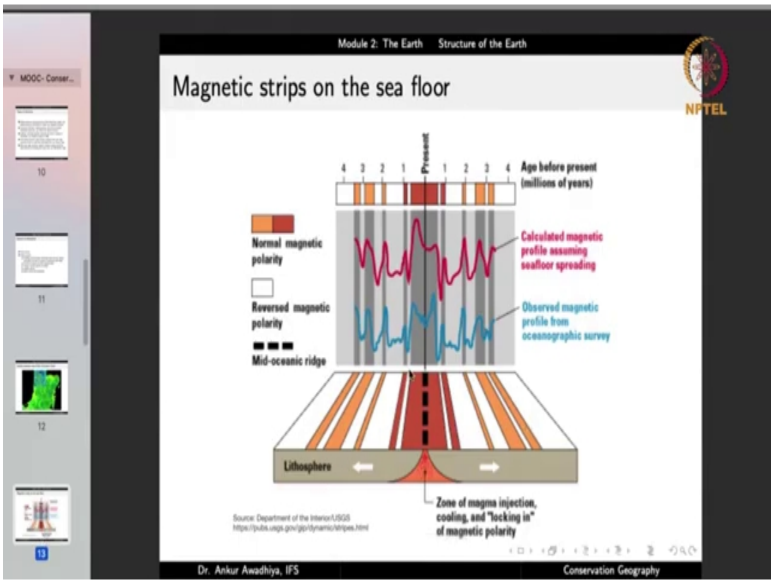

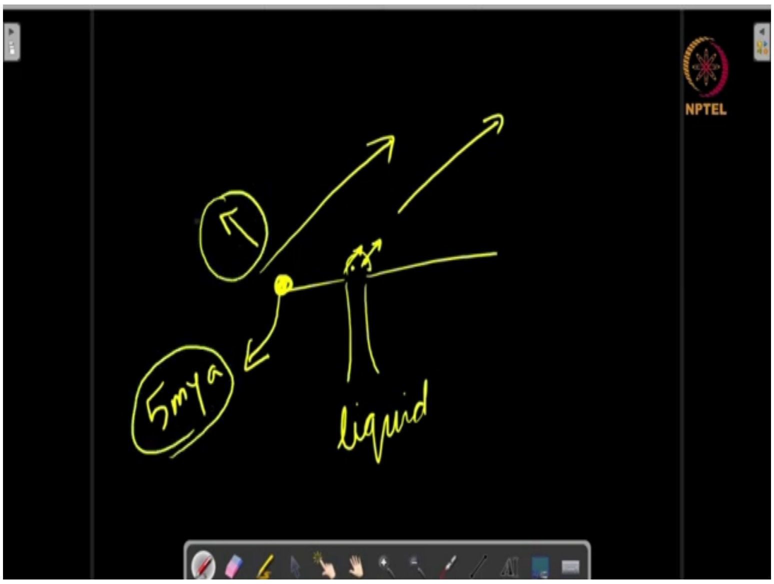

Another indirect source is the magnetic strips on the seafloor. So, if we do a magnetic survey will find that there that different locations have different magnetic properties that are stored in them. So, what happens is that when you have lava that is coming out, now lava is liquid. Now, when it comes to the surface, it solidifies. Now, this lava might also be having certain magnetic materials.

Now, we know that the Earth's magnetism is not constant, it changes with time. The poles, currently we have the magnetic south pole at our geographical north pole and the magnetic north pole at the geographical south pole. But at some point, in the past, the poles were at very different locations.

Now, we can whenever there is the solidification of the lava on the surface, what happens is that you have a magnetic field in a certain direction and the magnetic materials in the lava they also align themselves in that direction and then when the lava freezes, then there is no more changes that can happen.

So, if you have a location and you can compute that this location was say 5 million years old. And at this location, you have a magnetic field that is like this. So, in that case, you will say that okay, 5 million years ago, the magnetic field was in this direction and this is what we are observing on the seafloor.

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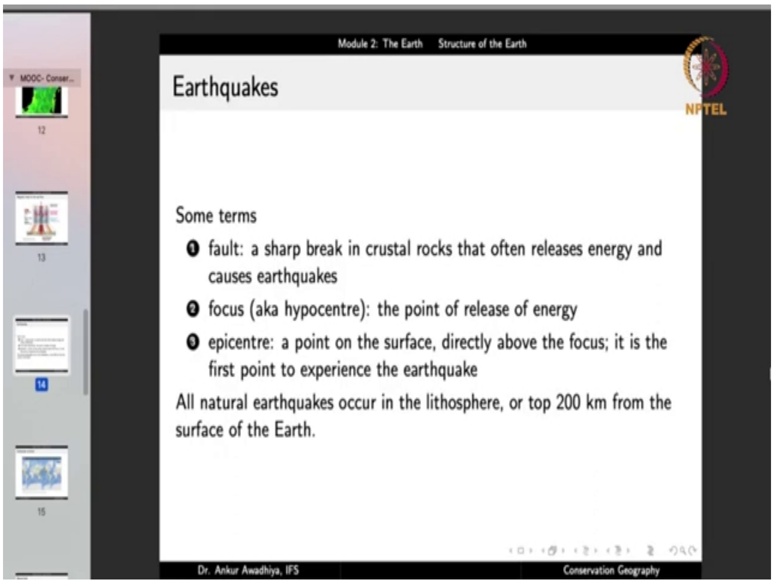

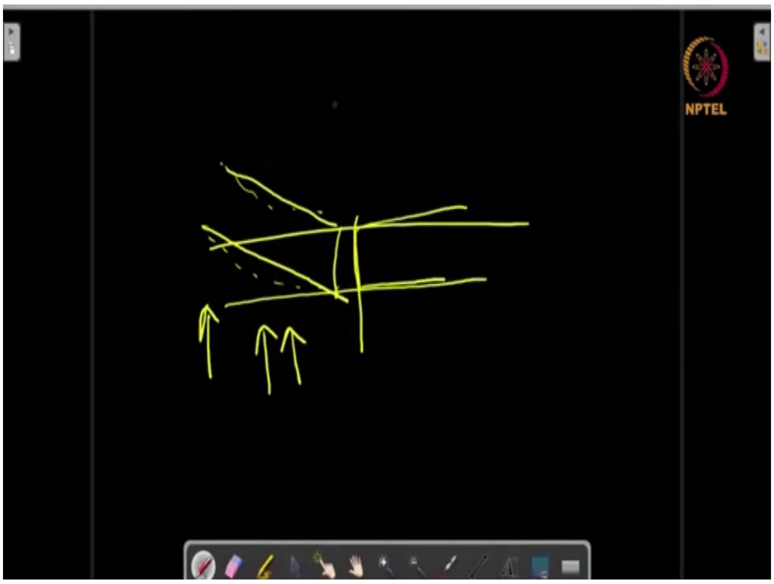

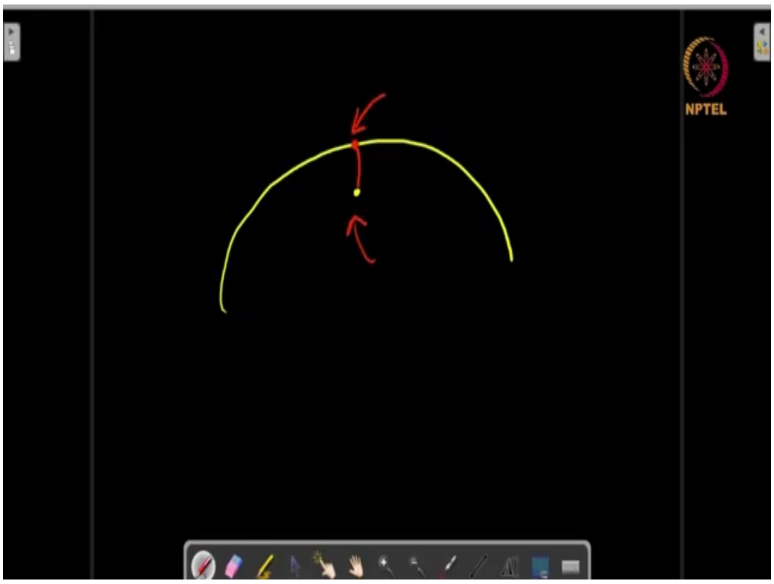

Another indirect source is the earthquakes. When we talk about earthquakes, there are certain terms that we should know. The first is fault. A fault is a sharp break in crustal rocks, that often releases energy and causes earthquakes. So, when we talk about faults, what we are talking about is that there is a rock that breaks in a certain location, and when there is this breakage, there will be a release of energy.

Why? Because suppose you have a piece of rock like this, and you were having pressure on one side, because of which this rock was bending like this. Now, the rock because it is a very strong material, it was able to withhold this pressure, it was able to sustain this pressure, but it will give up at certain amount of pressures. And when that happens, there will be a breakage at this location.

And now you will be having a rock that is like this, and it has broken at this location, and you have the rest of the rock like this. Now, once that happens, all this pressure that was being stopped by this rock that is now out in the open. And so, there is, there will be a huge amount of energy that will get released. So, this is a fault, a sharp break in crustal rocks, rocks in the crust, that often releases energy and causes earthquakes.

Now, when this energy is released, there will be shaking of the ground, they will be certain waves that get generated. And they will start to move and this is what we refer to as an earthquake. The point where the release of energy happens the point where the rocks break is the focus, also known as the hypocentre. And in a number of cases, the hypocentre will be at a location that is below the Earth's surface.

So, probably the rocks broke at this point. And there will be a point that is right above this point. And this point will be called as epicentre. So, this is the hypocentre and this is the epicentre. So, you have fault, focus, or hypocentre and epicentre. Epicentre is a point on the surface directly above the focus.

And it is the first point to experience the earthquake because this is the point on the surface of the Earth that is closest to the focus. And so, the earthquake will first be felt at this point. All-natural earthquakes occur in the lithosphere, litthos is rock, so this is the rocky sphere or the solid portion because typically you will not have breaks in the liquid portions or the viscous portions. So, all-natural earthquakes occur in the lithosphere or top 200 kilometres from the surface of the Earth.

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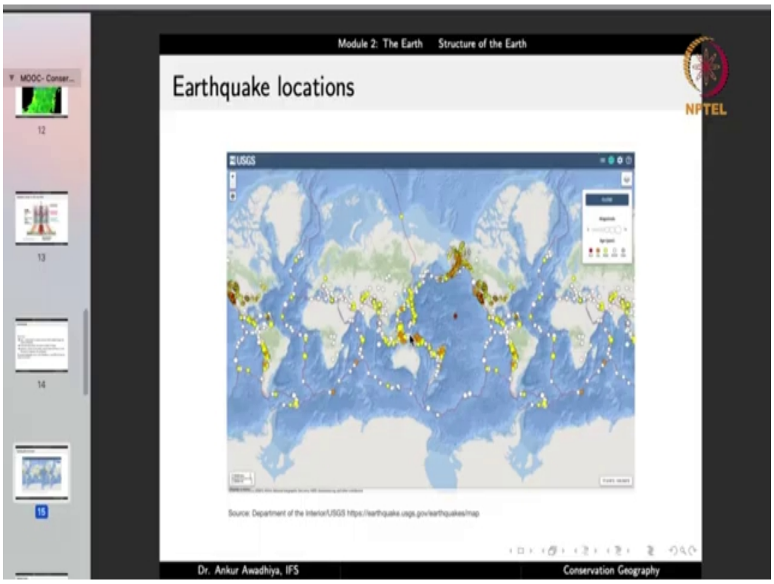

Now, if you look at where the earthquakes occur, if you plotted the earthquakes, this is the kind of chart that we will get. So, one thing is very obvious that there are certain locations where the earthquakes are much more frequent than other locations. So, like if we look at the Sahara, there is hardly any earthquake, but if we look at say Japan, there are a large number of earthquakes.

So, there are certain locations that have more number of earthquakes and there are certain locations that have less number of earthquakes. Also, there are certain locations where the earthquake intensity is higher, there are certain other locations where the earthquake intensity is lowered. The third thing that we can see from this curve or this map is that the points that have the earthquake, they are connected to each other. So, we can say draw a line like this.

So, there is something in these locations, that is resulting in a large number of earthquakes and typically a large number of large intensity earthquakes that are occurring at these locations. Now, this is another indirect source of evidence that we have, because if we have earthquakes at only these locations, what is so special about these locations, that can tell us about what is there inside the Earth. Now, when we talk about faults, there are different kinds of faults.

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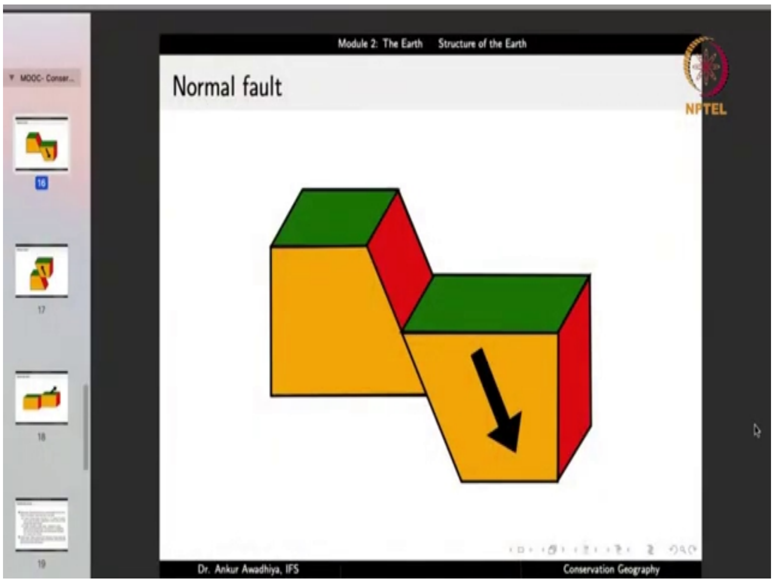

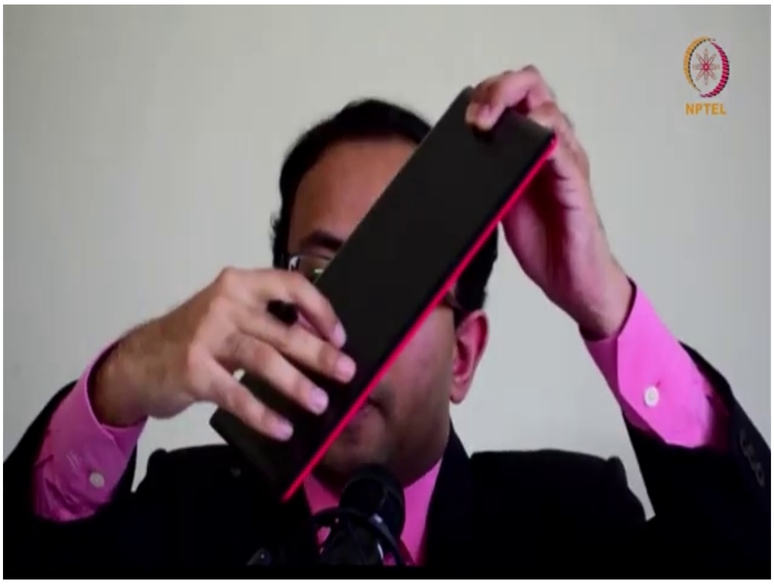
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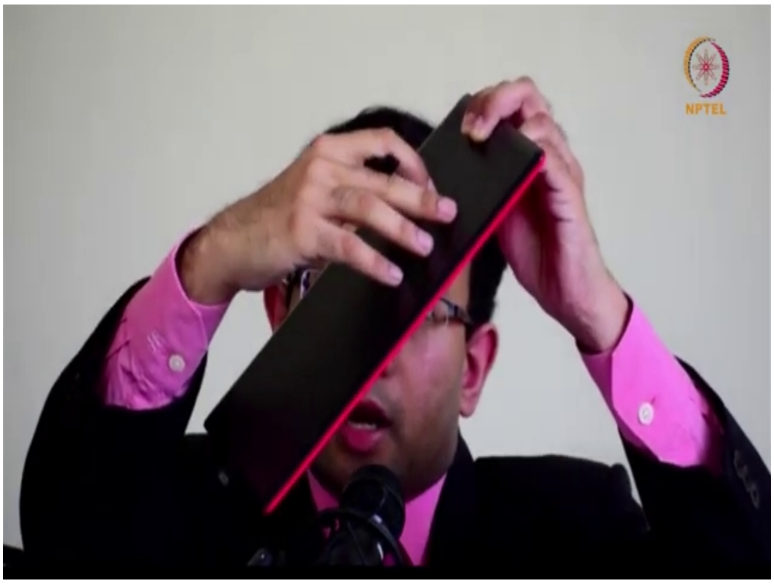
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NPTEL
Normal fault

The first one is a normal fault. Now, in the case of a normal fault, if this was a piece of rock and this is the fault plane, that is the plane at which the breakage has occurred, and in this case, the top portion is going down. Now, you can understand this by considering, say how gravity works.

Now, if you have a surface that is something like this, so if this is your fault surface, and if the portion that was here on the top, if it is going down, then we will say that this is a normal fault, the top portion is going down. On the other hand, if the breakage occurs, so that the top portion is going up like this against the gravity, then we will say that this is a reverse fault. So, this is a normal fault.

And typically, when we look at normal faults, we will find things like this. So, this is a model of a normal fault, thanks to our friends from the US Geological Survey, and what this model is showing us is that earlier you had this whole piece of rock, this is the fault plane and after this fault, the top portion that is the portion on this side, it is going down and this portion has gone up.

So, this looks very similar to what we would have observed in the case of say a piece that is falling due to gravity. Now, how do we know that this fault has occurred at this place. Well, we again make use of the principles that we have seen in the case of stratigraphy in the last lecture.

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If there is say a marker bed, so if you have a bed like this, then this bed should have continued like this, but you are observing that the bed continues till this point, and then it starts from here. So, there must be at some point of time, you should have a situation where both of these were together.

So, this portion was up here and because of the fault, it has gone down. So, by looking at these marker beds, we can make an inference that yes, there was a fault that happened and what was the kind of fault that we saw here. So, this is the normal fault.

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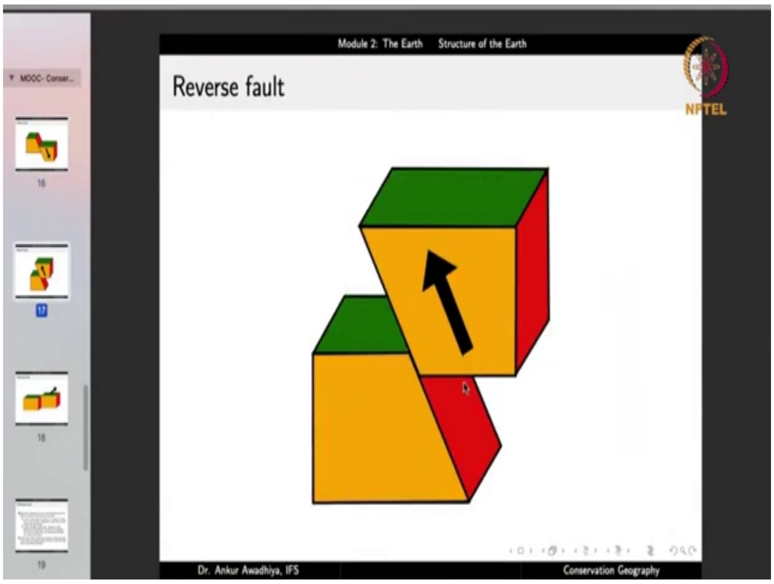

Another fault that we have is the reverse fault, now in the reverse fault the piece that was here it is going up. So, this is how a reverse fault looks like. So, this is the fault plane, and this portion, it has gone down and this portion has gone up. So, this is a reverse fault.

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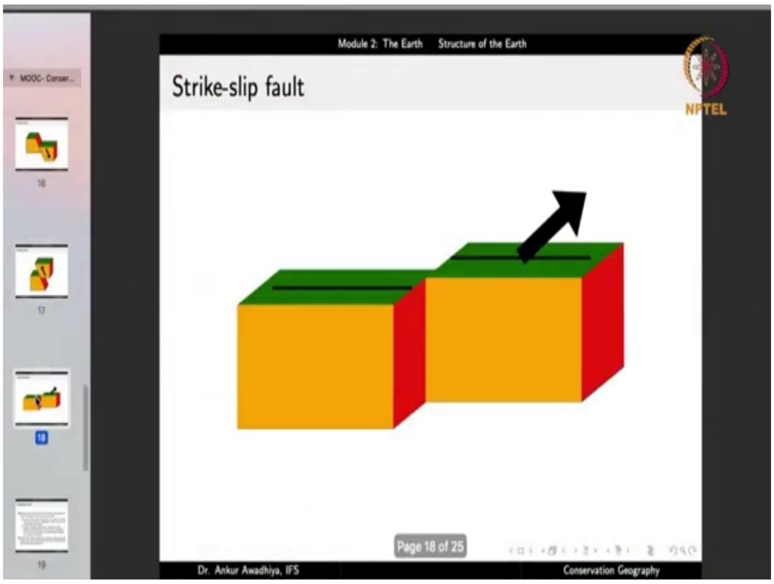

We also have another fault which is known as a Strike-slip fault, now in the Strike-slip fault the rocks they slide past each other, so there is no upward or downward movement, they are just moving past each other and this is how the strike-slip fault will look like. So, here you have the rock and it is still horizontal.

So, there is no vertical movement in it, but if you look at it like this, you will find that okay, earlier you had a river that was flowing like this. Now, in the normal circumstance, it should have flowed like this only, but what we are observing is that it is flowing like this, then there is a sharp movement, and then it continues its movement.

So, this gives us an indication that okay, this portion should have moved. So, earlier this point, it has now shifted to this location. So, this movement is because of a moment on the fault plane and this is a Strike-slip fault. And you can have Strike-slip fault in both directions right and left.

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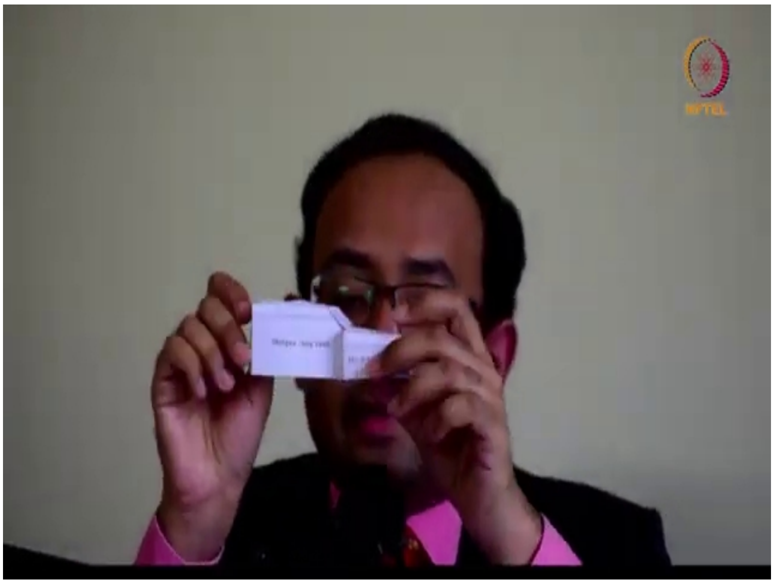

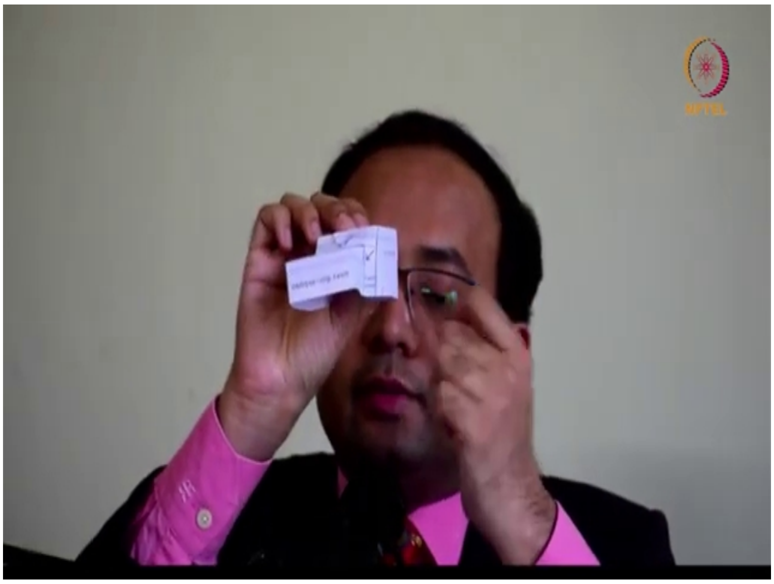

And in certain cases, we also have an oblique-slip fault. Now, in the case of an oblique-slip fault, you have a moment that is up or down and also a moment that is sideways. So, in this case, this portion, this portion, it has gone down and it has also moved sideways. So, this is an oblique-slip fault. Now, in a number of cases, these faults may also occur in combinations.

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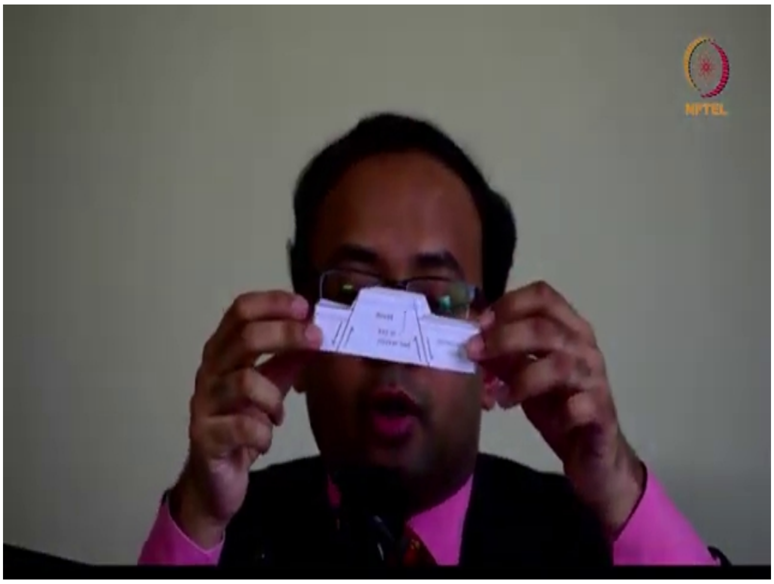

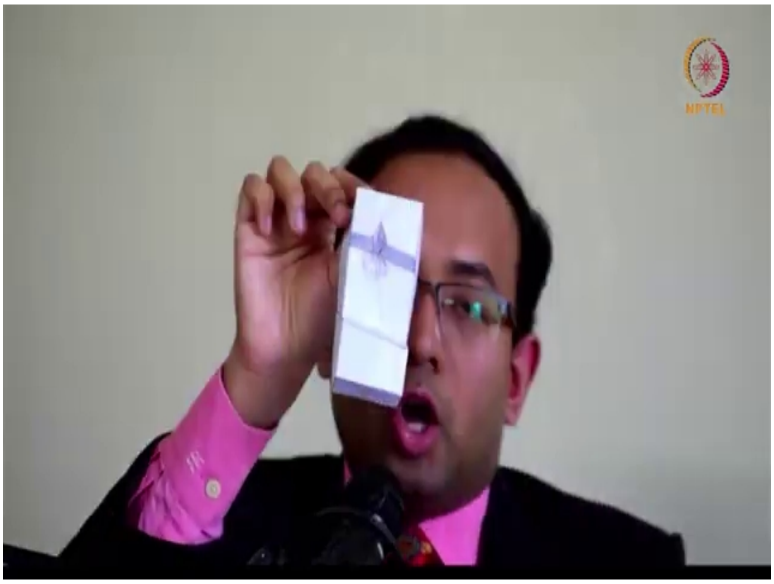

And when you have a combination, you can have a thing such as a horst. Now, this is an example of a horst. Now, in the case of a horst what is happening is that the central portion, it has gone up and side portions have gone down. So, this is now resulted in a portion that is protruding out you can have a thing that is just the opposite, which is known as a graben.

Now, in the case of graben the central portion has gone down and you have these two projections that are left on the top. Now, typically, these faults happened right in an instant. So, they are instantaneous things. So, if you had a river that was flowing like this, suddenly this portion, the central portion it has gone down. So, now you will have things such as a waterfall or probably there is a such a steep fall of water that it also results in the deposition of a large amount of sediments at the bottom.

So, by looking at these structures, we can make an inference that okay earlier this portion was a flat rock, as we can also see by looking at the key marker beds, but then this portion the central portion it went down, we know this because this marker bed is now at a lower position whereas, it should have been continuous and we also know this because of this deposition of sediments here. So, these are the different kinds of faults.

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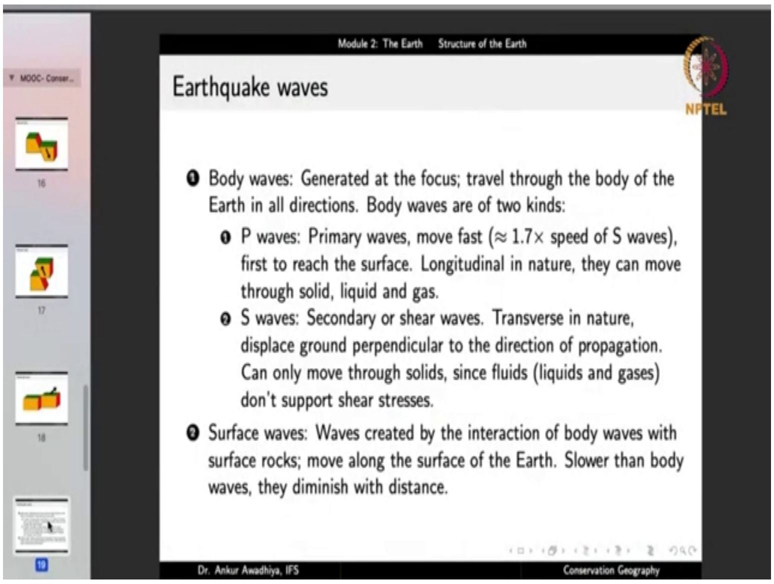

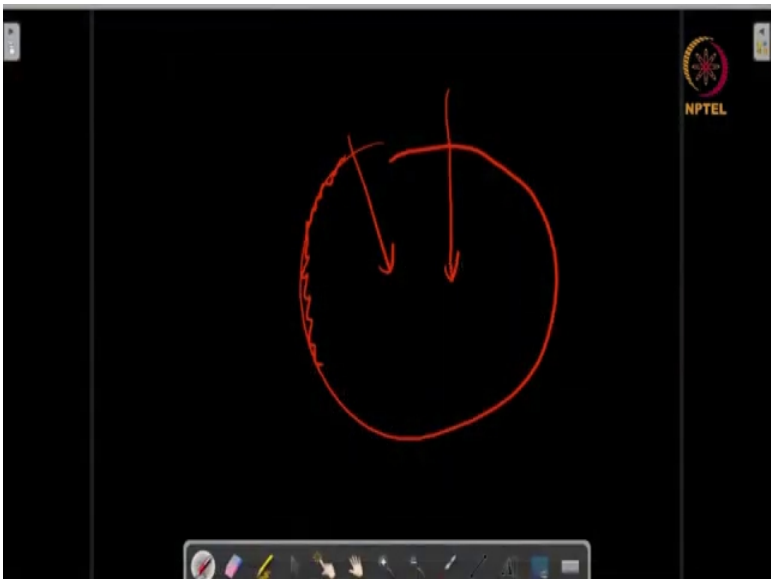

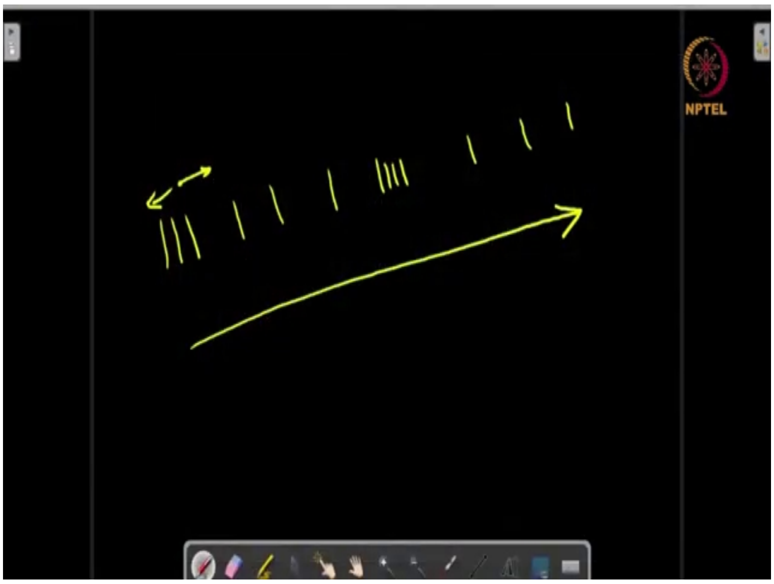

Now, when there is a faulting, there is a release of energy, and this release of energy moves in the form of earthquake waves. Now, earthquake waves are of different types, we have three main classes of earthquake waves. So, we have the body waves and the surface waves, and the body waves are subdivided into P and S. So, body waves are those waves that move through the body of the Earth.

So, if we consider the Earth the body waves will pass through the body of the Earth, whereas, the surface waves will only move along the surface of the Earth. So, that is the difference between body waves and surface waves. Body waves are generated at the focus, they travel through the body of the Earth in all directions, and they are of two kinds, first is P waves or primary waves, they move fast around 1.7 times the speed of S waves are the secondary waves and they are first to reach the surface.

Why? Because they are the fastest waves. Now, because they are the fastest ones, they are the first to reach and because of that, they are the primary waves. They are longitudinal in nature. Now, what do we mean by longitudinal in nature, it means that they move just like sound waves. So, you will have a portion that is of a greater density then you have a portion of lesser density then again, a portion of greater density, then again, a portion of lesser density and so, on.

So, essentially the movement of particles is occurring in the same direction as that of the propagation of the wave. So, the wave is moving in this direction, the particles are also moving parallel to this wave propagation direction. So, these are the primary waves. They are longitudinal in nature, and they can move through solid, liquid and gas just like sound.

So, sound can move through air and the P waves being longitudinal in nature, they are very much like sound waves, they can move through air, they can move through solid, liquid, or gas. Then we have the S waves or the secondary or shear waves, they are transfers in nature.

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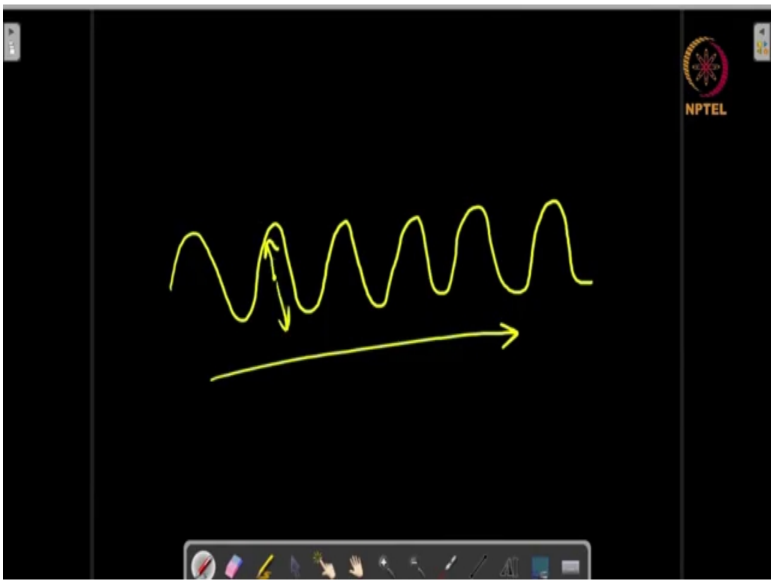

Meaning that they are very similar to the waves that get generated on the surface of water. So, if the wave is moving like this, the movement of particles it occurs up and down, that is perpendicular to the direction of the wave. So, these are transverse waves, they displace ground perpendicular to the direction of propagation.

So, if the direction of propagation is like this, the ground will be displaced like this perpendicular to the direction of propagation. They can only move through solids because fluids that is liquids and gases do not support the shear stress. Now, in this case, we are talking about the body waves.

So, they are moving throughout the body of the Earth, but they will only move where you have solid if there is a fluid then it will not be having shear stresses it will not be able to be bear shear stresses, and so, the S waves will not be able to move through them. So, this is a very important property of the S waves. And this can help us get information about what is inside the Earth.

The third ways are the surface waves that move on the surface of Earth, they are created by the interaction of body waves with the surface rocks, they move along the surface of the Earth and they are the slowest of the waves, they are slower than the body waves, and they diminish with this distance. So, the fastest ones are the P waves, then the S waves and the slowest are the surface waves.

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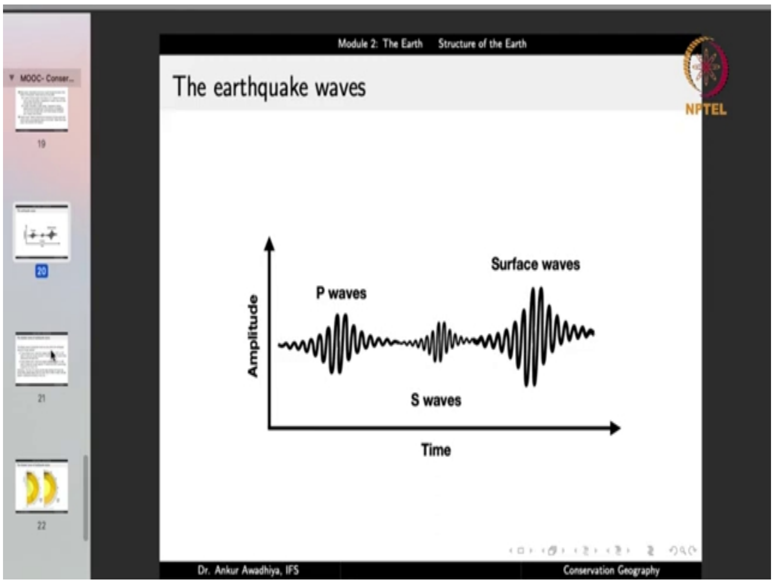

So, if there is an earthquake, if we plot amplitude versus time, the first waves to reach will be the P waves. Next, we will have the S waves and at the last will be having the surface waves.

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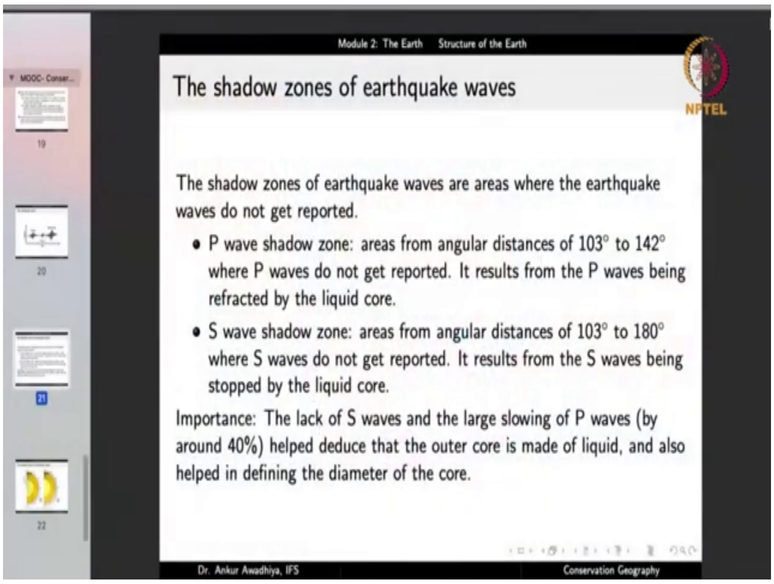

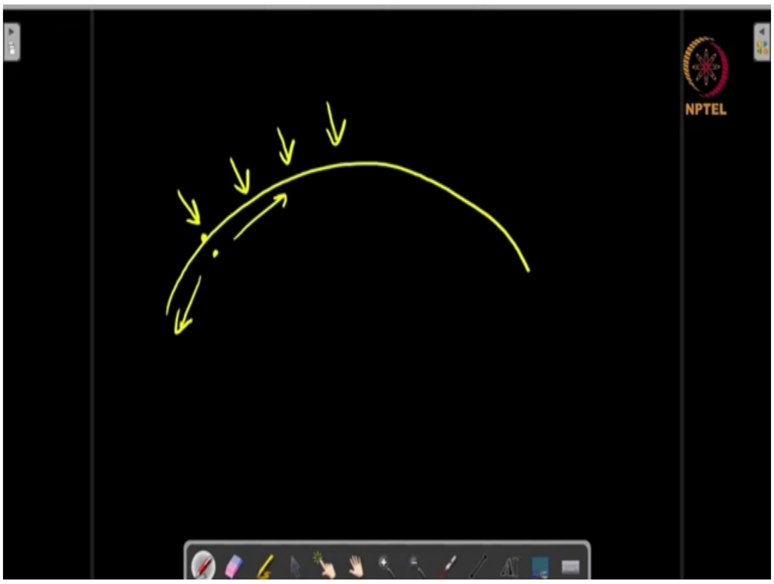

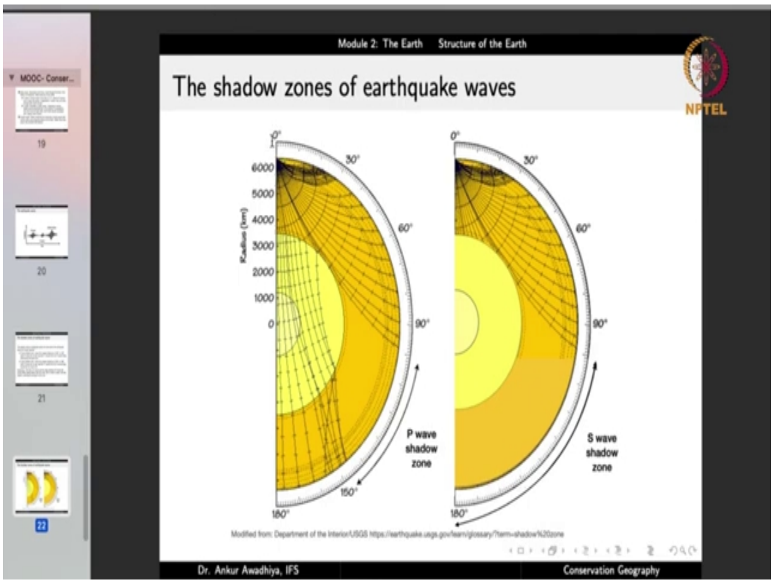

Now, why are these important? These are important because whenever you have an earthquake and whenever these waves move through the body of the Earth, you can make a reading of the amount of earthquake intensity at different locations on the Earth. That is, suppose, you had, suppose, this is the focus, this is the epicentre and you have the waves that are moving in different directions.

So, you have waves that are moving like the centres. So, you can measure the earthquake at this point, but you can also measure the earthquake at this point and this point and this point and so on. Now, when we do such measurements, now these measurements are only possible because these waves are propagating throughout the Earth. So, we can make these measurements at different locations.

Now, when we do these measurements, it turns out that at certain locations, we can make the measurements, but in certain locations, we do not get any of these waves. Now, why is that so? Now, the locations where we do not get the ways are the shadows zones, the shadows zones of earthquakes are the areas where the earthquake waves do not get reported. So, that is there is no displacement that is recorded in those locations.

And we have two different kinds of shadow zones, we have the P wave shadow zone and the S wave shadow zone, P wave shadow zone is areas from angular distances of 103 degree to 142 degrees, where the P waves do not get reported. And it results from the P waves being refracted by the liquid core.

So, what is happening is that if you have an earthquake at this point, you will have the body waves in the form of P waves that are moving throughout these materials. So, it can move through solid it can even move through liquid, but when there is a movement of the waves in these different materials, then because of different densities, because of different properties of these materials, the speed of the waves will be different, very similar to the refraction of light, when it moves from air to water to glass and so on.

So, there will be a refraction of these waves that occurs. Now, because of these refractions, the waves change their directions. So, the waves from this point they will move like this, like this, like this, like this, but the waves that have come to this liquid portion, they are then refracted and then they move like this. And so, in these locations, you do not get any waves.

So, you can make measurements from here to here and you can make measurements from here to here, but at these locations, you do not have any earthquake that gets reported. Then, we also have the S wave shadow zone, these are areas from angular distances of 103 degrees to 180 degrees, where the S waves do not get reported, it results from the S waves being stopped by the liquid core.

Now, we saw that the S waves can only pass through solids, they cannot pass through liquids or gases, because they do not sustain the shear stresses. Now, in the case of S waves, as soon as a wave reaches to the liquid portion, it stops there, it cannot pass through the liquids. And so, you will find that the S waves move like this, they just touch the surface of the liquid portion, they come to this point and from here to here you have the S wave shadow zone.

Now, today, we know that in the interior of the Earth we have a liquid portion, but when we did not know that, how did we come to know that the interior has a liquid portion by looking at these different waves because we knew that the S waves will not be able to pass through the liquids. So, by looking at the shadow zones of P and S waves, we can make a correlation about what is the size of the liquid portion. We can also make an inference about the composition of these different layers by looking at the P waves and how they are getting refracted.

Now, here again, it is important to model things because if you come up with a hypothesis that okay, inside at this depth, you have a liquid of this density, then we can make a computation about how the P waves will get refracted at that particular location. And when we do the model, we can compute whether the model is able to represent what we see or not. If it does not match with the reality, we will make certain changes in the model.

And with this iterative process, we can come up to the conclusion that okay there is a liquid portion of this size and this density. So, the importance of the P and S waves is that the lack of S waves and the large slowing of P waves by around 40 percent help deduce that the outer core is made of liquid. And it also helped in defining the diameter of the core.

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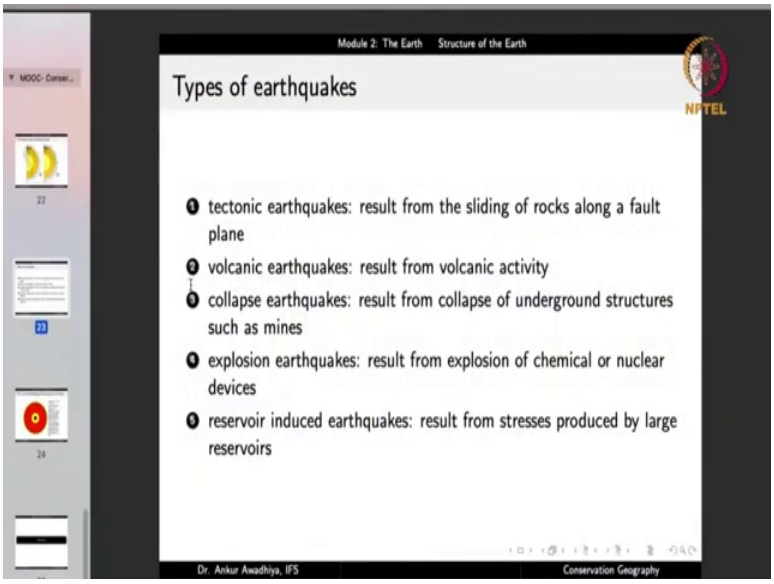

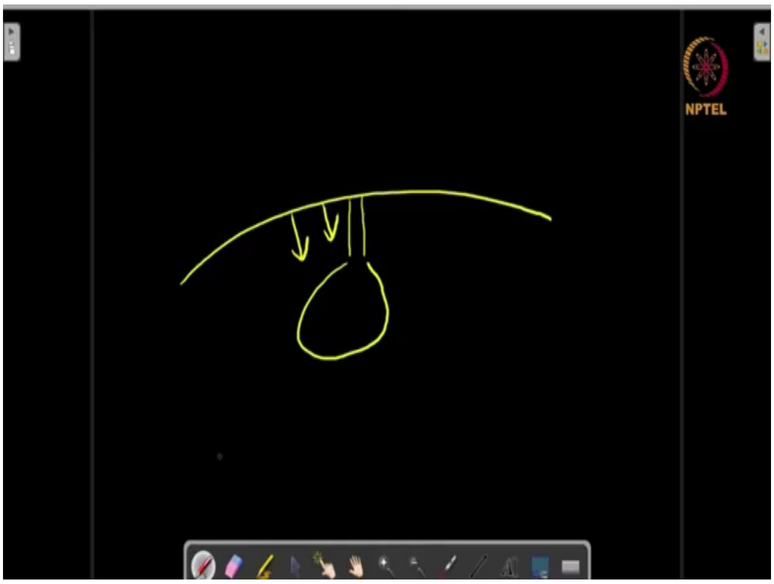

Now, earthquakes because they are so important, it is also important to note that we do not have only one type of earthquakes we have different kinds of earthquakes, which give us a very large quantity of data to make use of in understanding the structure of Earth. So, we can have tectonic earthquakes that result from sliding off rocks along a fault plane.

As we have seen before, that if there is a fault, because of tectonic movements, now tectonic movements are the movements of different plates that we will see in one of the later lectures. And whenever there is a movement of plates, it generates tremendous stress and when the rocks break, it gives rise to earthquakes. Along with tectonic earthquakes, we also have volcanic earthquakes that result from volcanic activity.

So, when there is a big explosion, because of a volcanic eruption, that can also generate waves that will move through the Earth, and that will move through the surface. We can make use of the volcanic vibrations to also get more and more data, we have collapse earthquakes that result from collapse of underground structures such as mines. So, essentially, if you have, if this is the Earth, and if there is a mine.

Now, suppose this mine collapses, that is all this portion comes down when there is a collapse, that will also generate certain waves, and that will also result in certain vibrations on the Earth, we can make use of those vibrations as well. We also have explosion earthquakes that result from explosion of chemical or nuclear devices. And we also have reservoir-induced earthquakes that result from stresses produced by large reservoirs.

Now, typically, the number of earthquakes that we have is so large that we get tremendous amount of information. But in certain cases where we want to do certain experiments to understand the earthquakes at certain locations, we can even generate those earthquakes by doing explosions, through say detonation of bombs or we can make use of the testing locations of say, traditional weapons or the nuclear weapons, and we can get data about these different waves that move to the Earth.

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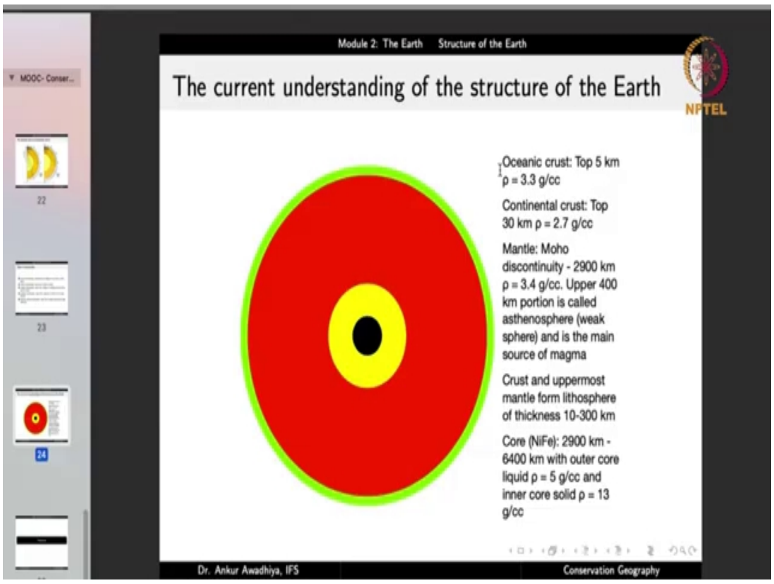

Now, with all of these direct and indirect evidences, we can compute what is inside the Earth, what is the structure of the Earth. And we saw that the outer core is made of liquid, the inner core is solid, the density goes on increasing as we go down, the temperature goes on increasing as we go down. The crust is having a material that is very light.

And this is the structure of the Earth. So, this is the current understanding of the structure of the Earth. We have oceanic crust, continental crust, mantle, and the core, the core is divided into the outer core and the inner core. So, that is all for today. Thank you for your attention. Jai Hind!