Applied Seismology for Engineers

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Week – 01 Lecture - 01

Lecture – 01

Music. Hello everyone, this is lecture 1 for the course Applied Seismology for Engineers. Myself, Dr. Abhishek Kumar, I am an Associate Professor at the Department of Civil Engineering at IIT Guwahati. In this particular course, we will be discussing primarily about the structure of the earth in terms of earthquake occurrence and induced damages, why earthquakes are happening, and the factors which are responsible as far as earthquake and induced damages are concerned. Whenever we are discussing earthquakes, the primary concern which comes to our mind is what is happening beneath the earth's surface, which is leading to the occurrence of earthquakes.

Lecture 1: In this particular course, we will be focusing more on the structure of the earth, both in terms of composition as well as physical characteristics, and then we will also be discussing about, because of variation in significant properties of the material beneath the ground surface and up to the center of the earth, what is leading to different processes happening at the surface of the earth and the movement which is finally leading to the building up of stresses and release of these stresses in terms of earthquakes from time to time. We will come back to the stress release as well as the building up of strain energy from time to time, which is leading to earthquakes once again in subsequent lectures.

In today's lecture, we will be focusing more on plate tectonics, continental drift theory. So, these two terms, that is plate tectonics and continental drift theory, will primarily help in understanding the physical phenomena which are happening all across the globe. So, let's talk about the internal structure of the earth. The geosphere is a general term we talk about when we are discussing the rocks which are present in the earth and different materials, minerals which are also present in the earth.

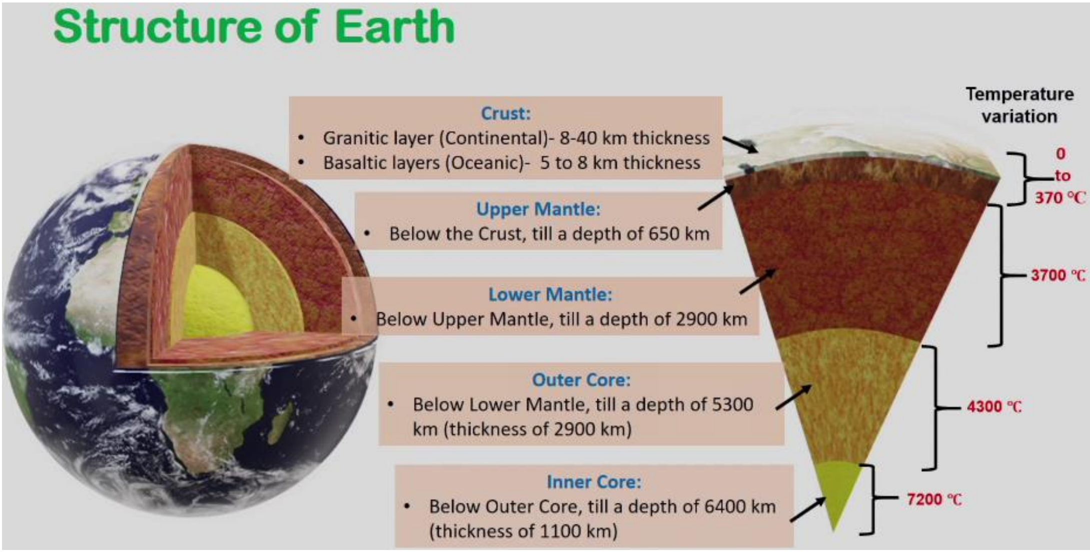
Earth is further, we can categorize into various layers depending upon if we are looking from a composition point of view or we are looking from physical properties of the earth. When we are discussing different layers, that means we are starting from the surface because we live at the surface, we are aware of the soil type, the rock types, physical properties, and chemical properties of the material primarily available on the earth's surface. But in order to understand the various features which are happening across the globe, we have to also understand what is available beneath the surface of the earth and what is composed if you reach towards the center of the earth. What are the different layers? What is the physical composition of these layers? Chemical composition of these layers? Is there any mechanism which is defining the current position and current response of these layers? That we will be discussing.

So, based on the composition, the earth can be divided primarily into three layers. The first one is the crust. The crust is basically the layer on which we are staying. Whenever we are talking about the mass of land available on the continent which is not submerged, we call it the continental crust. Generally, the crust, we have a similar layer of the crust even below the ocean. So that particular layer is called the oceanic crust. As you move from the surface and reach the bottom of the crust, because it's a thin layer on which we are staying or explorations are mainly focused on the crustal medium. Then, once you start moving from the crust, we encounter another material because of the change in the composition of the material by which a particular layer is formed. That layer is called the mantle. So again, the mantle will be starting from the depth of the crust or the bottom of the crust and it will be extending up to significant thickness as you start moving from the surface of the earth towards the center of the earth.

Once the mantle completes the thickness, you will encounter another layer with a significant change in the composition. That layer is called the core. So, in terms of composition, primarily, we can say the entire earth consists of three layers. That is the crust, which is the topmost layer on the surface of the earth. If you move downward, then you will encounter another layer with a significant change in the composition that is called the mantle. The third layer, which is located beneath the mantle, is called the core. Again, based on physical properties, we can further divide the earth into five layers. The first one was based on composition. The second one is based on physical properties. Based on physical properties, we can decide that there can be the lithosphere, asthenosphere, mesosphere, outer core, and inner core. So, while on one side, based on the composition, the earth was divided into three layers, in terms of physical properties, the material strength as well as the physical characteristics in which the medium is available, we can divide the entire earth into five layers. That is the lithosphere, asthenosphere, mesosphere, outer core, as well as inner core. Now, one question that comes to our mind is, on what basis are we thinking that the earth is not having the same characteristics throughout its thickness as we are seeing on the surface of the earth?

That means if you start moving across the globe, you will find somewhere rocks, somewhere weathered rocks, somewhere soil, and somewhere some mineral deposition will also be encountered. Generally, we see there is some limitation in terms of the density of the material. If you talk about the maximum density which is available on the surface of the earth, usually you will find rocks with a density of less than 3 grams per cc. Similarly, the density of water, we encounter water on the surface, water density is also 1 gram per cc. However, if we start looking at the overall density of the earth, we will come to know that the overall density of the earth is somewhere around 5.5 grams per cc. So, this figure itself gives you an indication that we do not have complete information about the material available beneath the earth if you only take into account the densities of the material which are actually visible on the earth's surface. Because the density of the material available on the earth's surface is of the order of 2.8, 2.9, 3 grams per cc. However, the overall density of the earth is above 5.5 grams per cc.

So certainly, this is indicating firstly that even heavier materials are available on the earth. We do not know whether it is near the surface or at deeper depths. Similarly, because the overall density of the earth is significantly higher than the average density of the medium available or generally encountered at the crustal medium that is 3 grams per cc, that is also indicating that the material which is available beneath the earth's surface is actually dominating in terms of the overall mass or overall density of the earth. So that is also indicating that the material which is not directly visible on the surface or on the crust, that material is also available in huge volume. That's how it is dominating the overall density of the earth with respect to the density of the material you generally encounter at the ground surface. So, this clearly indicates that there are interior layers on the earth which are generally composed of heavier materials. Because the overall density is higher than the material encountered at the crust, we will also see the volume of the material which is available and is belonging to higher densities is also significantly larger in volume in comparison to the medium available on the crustal layers. Now, denser layers generally it is understood that denser layers are available at greater depth. Lighter layers are available near the surface or relatively on shallower depths. Similarly, the densest medium, we will come to know the densest medium, so these mediums are generally located at the center of the earth. Gravity is generally the most driving force which will help in deposition as well as weathering also at times in terms of weathering and deposition and sedimentation of different materials available on the surface of the earth as well as to the deeper layers.



Now, here in this particular picture, we can see, the picture on the left-hand side, you can see, if you see a satellite image of the earth, you will only see clouds, then you will see land mass, and then you will see the ocean or the water bodies which are available on the earth as you see from the top. But if you take a cross-section of the earth or you take a slice out of it, you will see there is significant variation in terms of material characteristics as well as in terms of the physical properties in which the material exists at or near the surface. The same observation continues as you move towards the center of the earth. Now the first layer which we were talking about, that is the crust, it generally consists of thin layers. If you are talking about continental crust or the land mass which is available at the top surface of the earth, we generally call it the continental crust.

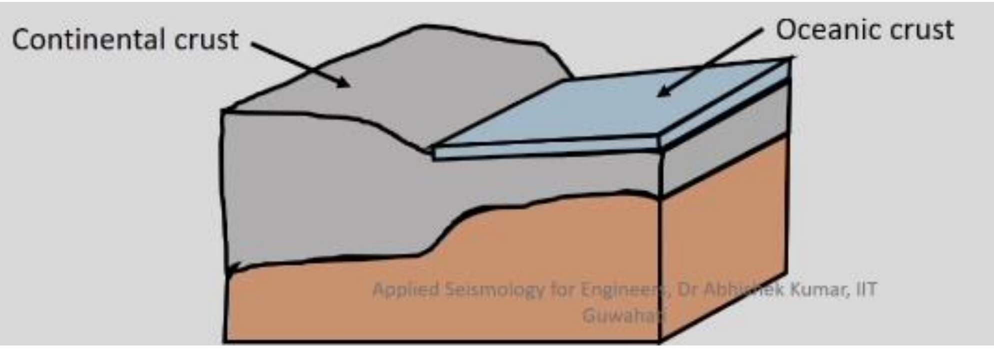
Mainly it has been observed that these continental crusts are granitic in layers, and the thickness of the crystal medium which is available for the continent is of the order of 8 to 40 kilometers. Same way, if you go to the ocean bed, there will be oceanic crust. It has been observed that oceanic crust is dominated in basaltic contents and is having a thickness of the order of 5 to 8 kilometers. Similarly, below the ocean or continental crust, that means reaching a depth of 12 kilometers up to 40 kilometers, you will encounter another layer that is called the upper mantle. So, it is located below the crust and continues till a depth of 650 kilometers. When I say 650 kilometers, that means the measurement of the depth from the ground surface. So, from the surface, the mantle is continuing up to 650 kilometers, and the upper mantle is starting from the bottom of the crust. Similarly, there will be another layer of mantle that is called the lower mantle, which will start after a depth of 650 kilometers and will continue till a depth of 2,900 kilometers. This particular layer of mantle, which is located below the upper mantle, it is called the lower mantle. Now, once you reach a particular depth of 2,900 kilometers, you will again encounter another layer of material, which is located below the lower mantle, and the thickness or the depth in which the material is continuing is up to 5,300 kilometers. Or on average, you can understand the thickness of the outer core itself is almost close to 2,900 kilometers. Bellow, the outer core, that means once you reach a particular depth of 5,300 kilometers, you will encounter another layer of material which is called the inner core. So, the inner core is starting from the bottom of the outer core, and it continues till a depth of 6,400 kilometers or approximately till it reaches the center of the earth. So, you started from the surface and encountered crust, depending upon whether it is on landmass, whether it is under a water body, you will call it as continental crust or oceanic crust. Then you start moving below the crust, you will encounter the upper mantle, which is continuing till a depth of 650 kilometers. Then, followed by that, there will be a significant change in the material composition. You will see another material which is ranging up to 2,900 kilometers in depth, and the name of the material is, or the layer is, lower mantle. Then you will encounter another layer at 2,900 kilometers depth, which will continue for another 2,900 kilometers depth, and that is called the outer core.

In terms of the inner core, the layer is starting from the bottom of the outer core and is continuing till a depth of 6,400 kilometers from the ground surface. Now, if we see in terms of known information about the earth, generally, we try to understand the subsurface medium by using different exploration techniques. Such exploration techniques in terms of soil will be limited to a depth of maybe 50 to 100 meters. If you talk about rocks, depending upon your depth of exploration, 2 kilometers, 3 kilometers. But here we are talking about the layers of the earth starting from the surface and reaching till the center of the earth. So now we can get an understanding of what different layers are available if you start from the surface and reach the center of the earth.

Now let's look at the temperature variation. We see at the surface temperatures of minus 20, minus 25 degrees centigrade to as high as 48, 50, or 52 degrees centigrade. That is relatively the temperature you encounter at the ground surface in different parts of the globe. Let's see how the variation of the temperature is happening beneath the ground surface. So, another photo, which is given on the right-hand side of the slide, you can see in the near surface crust as well as the upper mantle, you will see the variation in the temperature is in the range of 0 to 370 degrees centigrade.

Again, in the lower mantle, you will see the temperature varying from 370 degrees centigrade to as high as 3,700 degrees centigrade. Once you reach the outer core, again there will be a significant jump in the temperature from 3,700 degrees centigrade to 4,300 degrees centigrade. Once you reach the inner core, there will be a significant jump in the temperature. So, in the inner core, the temperature can reach even up to 7,200 degrees centigrade. So, on one side, we are having different layers of the soil, and on the other side, the temperature is not constant throughout. So, temperature is also significantly jumping. We will encounter, as a general understanding, that as you go deeper and deeper, there will be an increase in temperature, as well as a significant increase in the overburden pressure in which a material at a particular depth is going to withstand.

Now the crust, as we discussed, depending upon the position of the crust, if it is on landmass, it is called as continental crust, and then if it is under the ocean, you call it an oceanic crust. A continental crust is generally much thicker, up to a thickness of 75-80 kilometers, and is composed of relatively less dense granitic rocks. The density of such rocks is in the range of 2.7 grams per cc and is strongly deformable. Some of the oldest rocks which are available on the planet belong to the continental crust and at times can have an age of billions of years. Oceanic crusts are relatively thinner in comparison to continental crusts, usually in the range of 8-10 kilometers thickness, and are mainly composed of basaltic rocks of volcanic origin. Usually, these are heavier than continental crusts. So, where the continental crust was having an average density of 2.7 grams per cc, the oceanic crust, on the other hand, can have a density higher than that. Comparatively, the oceanic crust is non-deformable and geologically younger, usually 200-300 million years of age in comparison to the continental crust, which at times you will encounter of billions of years of age.

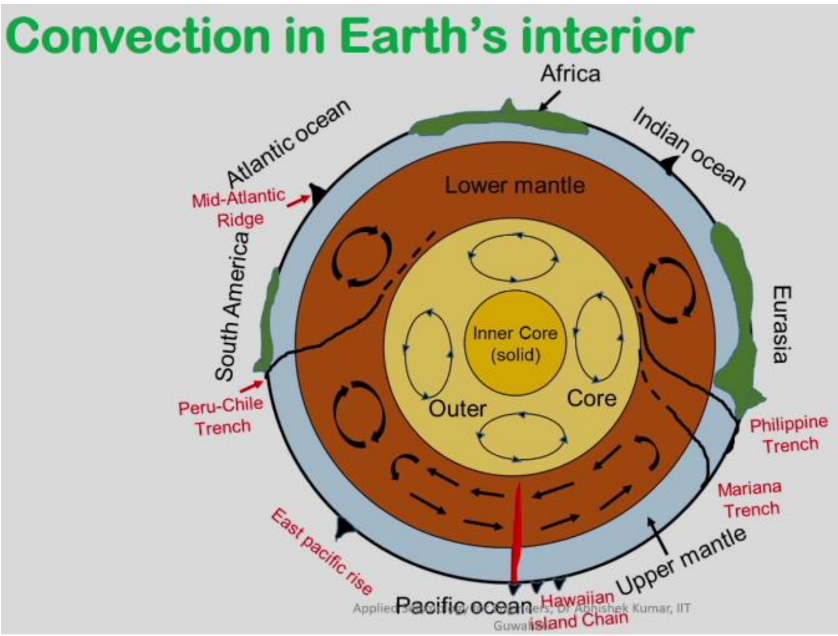


You can see in this particular picture also, on one side you are having a landmass and on the other side you are having the ocean, so whatever is located beneath the ocean is a part of the oceanic crust, and whatever is available on the continent is a part of the continental crust. Now let's go to the second layer, that is, the mantle, which is existing below the base of the crust and continues till the top of the outer core. As the name suggests or as the position of the mantle is, it basically covers the core. The thickness of the mantle overall, including the upper mantle and lower mantle, is 2,900 kilometers thick, and it constitutes 82% of the earth's volume. So, depending upon the thickness of the mantle and its position, which is basically in between the crust as well as the core, we can understand that a significant portion of the earth's volume as well as the earth's mass will be dominated by the mantle. That is the reason almost 82% of the entire volume of material on the earth is the cause of the mantle. Similarly, if you talk about the mass of the earth, 68% of the mass of the earth is solely coming from the mantle. Again, mantle, if you discuss in terms of composition, it consists of rocks primarily made from silica and oxygen. Also, there is iron and magnesium present in abundance if you talk about the material which is available in the mantle. Fragments of mantle are at times brought to the surface during volcanic eruptions. So, there are volcanic eruptions as a result of which the material which is available in the mantle will come onto the surface. We will see what is the governing mechanism in terms of volcanic eruptions as well as other features on the surface of the earth in the coming slides. So, the material from the mantle will come through volcanic rocks or volcanic eruptions and get settled on the ground surface. Because of the presence of overlying rocks, as you are moving deeper, on one side, there is an increase in the temperature, and on the other side, there is an increase in the overburden pressure. So, you can see here the density increases with depth, starting from 3.2 grams per cc in the upper mantle to as high as 5 grams per cc at the interface between the mantle, lower mantle as well as the core. The next layer which comes into the picture is the core. So, the core is extending to a diameter of 7,000 kilometers. We discussed the mantle, which is having a thickness of 2,900 kilometers. So, after reaching a depth of 2,900 kilometers, there will be the core, starting from 2,900 kilometers depth, continuing to 6,400 kilometers depth, and then that will continue because it is the center part of the earth. So, on average, the core is extending to a diameter of 7,000 kilometers. The density in the core, similar to the mantle, also increases with depth. The average density of the material available in the core is 10.8 grams per cc. In terms of volume, the mantle was contributing close to 80% of the earth's volume, but the core, though the density is very high, is only contributing 16% of the earth's volume.

In terms of mass of the earth, we will see that close to 32% of the contribution of total mass of the earth is coming from the core itself. When we talk about the core, it is further divided in terms of physical characteristics as well as chemical composition into two layers primarily. That is, the first one is outer core, which is extending between 2900-kilometer to 5100-kilometer depth. So, the outer core, which is starting from the base of the mantle at 2900-kilometer depth and will continue till a depth of 5100 kilometer, usually is consisting of an alloy of iron and nickel, with temperature varying from 4000 to 5000 degree centigrade and is usually available in liquid form. This also results in the cause of convection current or generation of convection current. So, there is an outer core, because of variation in the temperature between the top of outer core and the base of the outer core that will lead to the development of convection current, and being material which is magnetic in nature, when this material is undergoing rotation, this particular outer core or movement of material in the outer core will also result in the development of earth's magnetic field. Depending upon the direction of rotation of the inner core with respect to the convection current, which is generated in the outer core, even the possibility of shifting in the magnetic poles, the configuration of magnetic poles, magnetic north and magnetic south is also a possibility. This leaves a record on the rocks in terms of paleomagnetic values, that means shifting in the magnetic poles or the configuration of magnetic poles whenever there is a shift, and when, if there is any magnetic material which is undergoing some kind of densification or solidification, usually the magnetic content of that material will align with respect to the north and south magnetic poles available at that particular time. So, such understanding or the orientation of the magnetic minerals in those rocks will also help in understanding the movement or in understanding whether the present configuration of the mineral is actually belonging to that particular geographical location, or that particular mineral rock deposition has moved from its parent position and has been redeposited somewhere else.

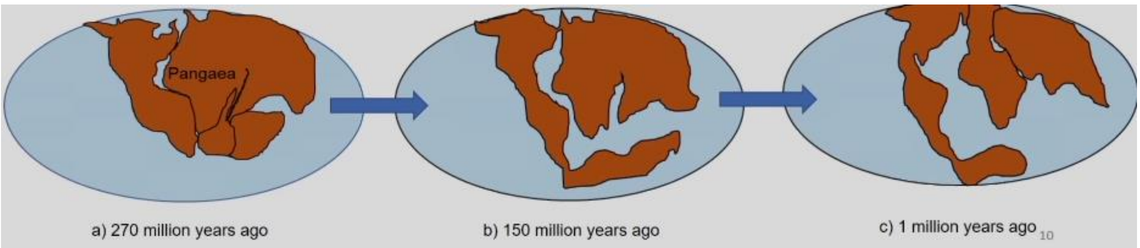
So, generally, in terms of when we are interested to find out movement of the landmass, which will come under plate tectonics, so we can get supporting information whenever we start exploring the magnetic properties of the depositions. The next layer which will come into the picture, is inner core. So, inner core, as the name suggests, is the innermost part of the earth, earth being spherical, the center part of the earth, that is the inner core, that is the innermost part of the earth, it is extending from 5100 km depth to 6400 km depth. So, starting from the base of the outer core, which is ending at 5100 km depth, and reaching up to a depth of 6400 km, that means reaching at the center of the earth, that is the radius of the inner core, and this is a solid ball, mostly composed of iron, having a temperature of 5000 to 7000 degree centigrade. Even though the temperature is very high in the inner core, because of overburden pressure of the layers, that is outer core, lower mantle, upper mantle, crust, the material which is available in the inner core still remains in solid form. In the outer core, if you look at the material, the material was available in liquid form. Now, the classification based on physical properties. So far, we have discussed the classification based on the composition of the different layers, which are available beneath the ground surface, starting from the crust, then we have upper mantle, lower mantle, outer core, inner core. If we discuss or classify the earth in terms of physical properties, we will see five layers, that is, the first one is lithosphere. It consists of the rigid outer layer of the earth, including the crust as well as upper mantle.

The thickness of the lithosphere varies from as low as 10 km in the oceanic region to as high as 300 km in terms of continental regions. Primarily, this is because of the inclusion of the upper mantle. Similarly, if you discuss the asthenosphere, this consists of soft rocks in a molten state, which can be deformed easily. The chemical composition of asthenosphere is the same as that of lithosphere, but there is slight modification in terms of mechanical properties. The third layer which will be encountered is mesosphere. At this particular great depth, the higher-pressure effect dominates the effect of higher temperature, and thus again, you will encounter that the material is stronger as well as more rigid in terms of mesosphere. So, basically, it is the zone between asthenosphere, that is located consisting of primarily the molten material, and the core. Again, in terms of physical properties also, because the outer core is located in liquid form and the inner core is available in solid form. So, the last layer, that is, core, in terms of physical properties also, you can divide it into outer core as well as inner core. So, the ground surface is basically consisting of solid material, then you are having liquid material in the upper mantle as well as in lower mantle with different driving phenomena, and then you are having outer core that is again molten state, having temperature in the range of 4000 to 5000 degree centigrade.



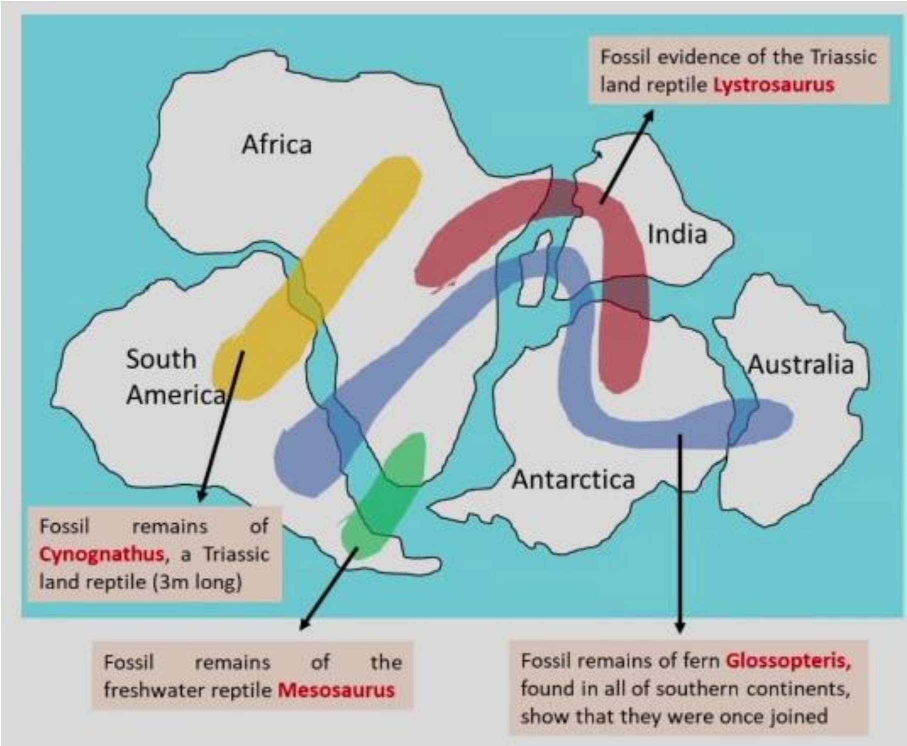
Then you will encounter another part of the core, that is, inner core, which is solid of iron, and it is continuously under rotation. Now, here in this particular picture, we'll come to know about different layers. So, you can see over here where there is Africa, there is Eurasia, there is South America, you are actually able to see the continental crust. At the same time, we are having different oceans also, where you are able to see the oceanic crust also. Then you start moving from the crust, then you will encounter the upper mantle, and then within the upper mantle, across the globe, you can experience Philippine trench, Mariana trench, mid-oceanic ridge, mid-Atlantic ridge. These are some governing, dominating regions where whatever is happening between the crust and the mantle can be visually identified. Again, if you start from the surface, so after the upper mantle, there will be lower mantle, as can be seen over here, there is significant variation in terms of temperature between the top of lower mantle, as well as the bottom of this lower mantle layer. As a result of this particular variation in the temperature between the top and the bottom of the same layer, there will be the generation of convection current. So, what happens, the material which is close to the surface or close to the top layer of a particular layer, the material is relatively in a cooler state because near the surface the temperature is relatively low. As a result, the material becomes heavier, it will start sinking. When it is moving downward or sinking within or starts moving towards the bottom, the material will experience an increase in temperature. When the material experiences an increase in temperature, the material will expand. As a result, there will be a reduction in the density of the material, so that the material, which at one moment was going down with an increase in temperature and reduction in the density, the material will also start coming to the surface. Once it comes to the surface, again, there will be solidification in the material or reduction in the volume or increase in the density, the material will start again sinking because as you reach near the surface, there is a reduction in the temperature. The material is getting cooler. So, the material is getting cooler, it is coming to the surface, becoming heavier, it starts sinking. As it is sinking, the material will expand, reduction in the density, material becomes lighter, and then it will start moving towards the surface. So, the process of solidification, cooling, expansion, heating keeps on happening. It's a continuous process, as a result of which there is a continuous current which is developed in the material, which is primarily located in its molten state or in liquid form. So, the same can be witnessed in lower mantle, in upper mantle also, in outer core also, and definitely not in inner core because that is a solid material. So, the convection current which is generated in different layers, that is, upper mantle, lower mantle, outer core, each of these, because the material is primarily in liquid state and there is significant variation in the temperature between the top of that particular layer and the bottom of that particular layer, the generation of convection current is a continuous process. As a result of this convection current, the material which is in contact with the layer above that particular layer in which the convection current has been generated, what will happen, this layer or the material which is undergoing rotation, the material which is at the bottom most portion of the upper layer, that means if you are talking about upper mantle, so the material in upper mantle, which is undergoing convection current, it will basically induce a kind of push into the bottom of the crest, as a result of which this particular layer starts moving.

So, there was a crest, and because of convection current generated in the mantle, it started pushing the material. This particular material is also quite rough, and then this particular convection current, which is also developed in a particular material, is undergoing continuous motion, as a result of which the crest started moving. Now, depending upon the direction and the dominating forces which are controlling the convection current at a particular location, that will define whether the landmass, the particular landmass, will be moving towards the adjacent landmass or moving away from the adjacent landmass. So, the variation in the temperature and expansion and solidification in the material subsequently, is responsible for the development of convection current. If we talk about the magnetic field of the earth, you can see over here that in the outer core as well, there is development of convection current, as a result of which, when the material, which is metallic in nature, starts moving, there will be development of a magnetic field, which we can witness at the surface by means of a magnetic needle orienting towards magnetic north and magnetic south. So, depending upon the rotation of the inner core with respect to the outer core, that can define the configuration of the magnetic north and magnetic south poles, which, as per existing information, shuffling of magnetic poles also possible.



Now, when we discuss in terms of convection current, the primary objective was to find out what are the driving forces, from where these driving forces are generated, such that these forces are basically pushing the top surface of the earth. So, this is the reason for the continental drift theory. It was a theory, so starting from different researchers, Ortelius, Christoph Lilienthal, Alexander von Humboldt, and many more, proposed that the landmass on which we are staying is not fixed at a particular location but is under constant motion. The primary reason was the exact matching of the coastlines of two landmasses which are, in current configuration, thousands of miles apart. In the year 1915, Alfred Wegener, a German geologist, proposed the theory of continental drift, suggesting that because of the exact matching of coastlines between landmasses, which in the current configuration are far away from each other, because of this exact matching, he proposed that the landmasses are in continuous motion. So, somewhere in the past, all these landmasses might have been in close proximity to each other, and because of convection current, which is not part of the continental drift theory, the landmasses started moving away from each other.

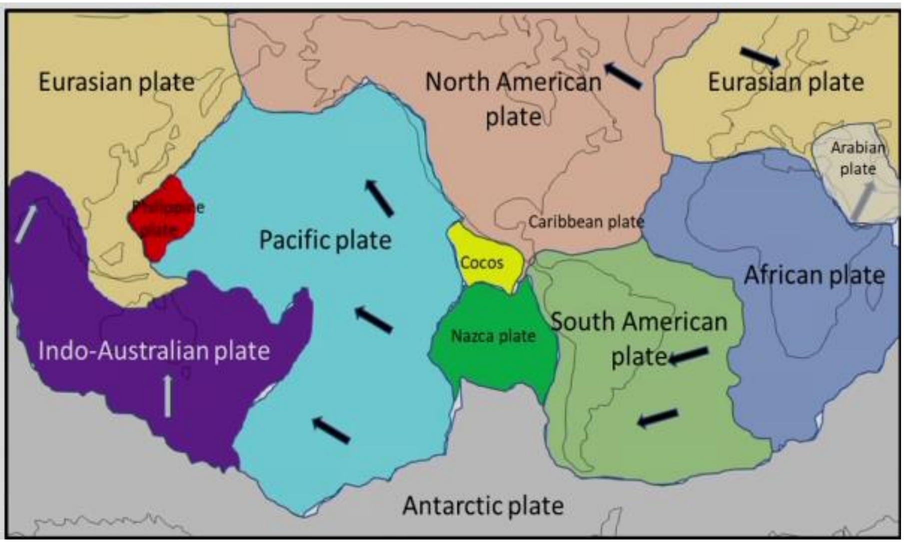
Please note here that the continental drift theory only tells that landmasses are moving away from each other or there is relative motion between the landmasses. It never tells the reason for such movement. It completely explains that motion is happening. It also tells that the entire landmass, almost 250 million years ago, was a single continent called Pangea, and then later on, it started breaking into pieces and started moving. So, if you see these three pictures, which are shown at the bottom, you can see what the configuration was almost 270 million years ago, then almost 150 million years ago. So, you can see, with respect to 270 million years ago, some landmasses had started moving. Again, the third part or Figure C will tell you the current configuration almost one million years ago. So, you can see here, whatever landmasses in the first picture of Picture A were together, they started moving, and then you can see there is significant movement starting from 270 million years ago to one million years ago. The movement, depending upon the governing factors, can be of the order of 2 millimeters per year, 3 millimeters per year. So, the process is happening very slowly, and it has been continuously happening for millions of years. Now, when we say the continents are moving, certain evidences are also there which support that the theory suggested by Alfred Wegener in 1915 is actually supported by physical evidences. Some of the evidences include similar animal and plant fossils on landmasses which are not adjacent to each other, at least in the current configuration.



So, you can see on this particular picture the western part of Africa and the eastern part of South America; you can see the coastline is approximately matching or fitting into each other. Similarly, the southwestern part of India and the eastern part of Africa, the coastlines are matching. Similarly, you can see the configuration with respect to India and Antarctica and then Antarctica as well as Australia. So, it's not only in terms of exact matching of the coastlines, but at the same time, plants and animal fossils which were located or found in the eastern part of South America are matching exactly with the western part of Africa. So, if you see in the current configuration, Africa and South America will be thousands of miles apart. But in support of that, the coastlines are exactly matching as well as the fossils of animals and plants which are located or found in South America also match with Africa. That suggests that in the past, these two landmasses, and similarly other landmasses, were in close proximity to each other, as was suggested in the previous slide as Pangea.

So, matching of coastlines, similar animal and plant fossils, which are found in different parts of closely matching coastlines across the globe, is evidence. The third pieces of evidence are the distribution of glacial sediment. So, the characteristics of sediment which are found in different parts of the globe, in different continents, also follow some similarity. The last part is similarity in magnetic anomalies. As we discussed, whenever magnetic material is undergoing solidification, the material from the deeper layer comes to the surface by means of volcanic eruptions, and at the time of deposition and solidification, the magnetic minerals will orient themselves with respect to the magnetic north and south pole configuration at that particular location and at that particular time. If that particular material or that particular location is under continuous movement, what we will see after several thousand years is that the material might have moved with respect to its initial position of deposition to some other distance. Now, if you see, as per the new distance, the configuration of the material in terms of position as well as in terms of orientation of the mineral with respect to the magnetic north and south, there will be some anomaly. So, it has been observed that because of the magnetic minerals which are available in different continents, the magnetic anomaly is also finding some kind of similarity. It is also suggested that the magnetic minerals, which were deposited in one part of the continent where the coastal boundaries, also match with the adjacent continent, the magnetic anomaly or the characteristics of the magnetic mineral do not match with the current configuration but are matching with respect to each other. So, going ahead with these evidences, that is similar animal and plant fossils, matching of coastal boundaries, distribution of glacial sediments, and similarity in magnetic anomalies which are found in different continents across the globe.

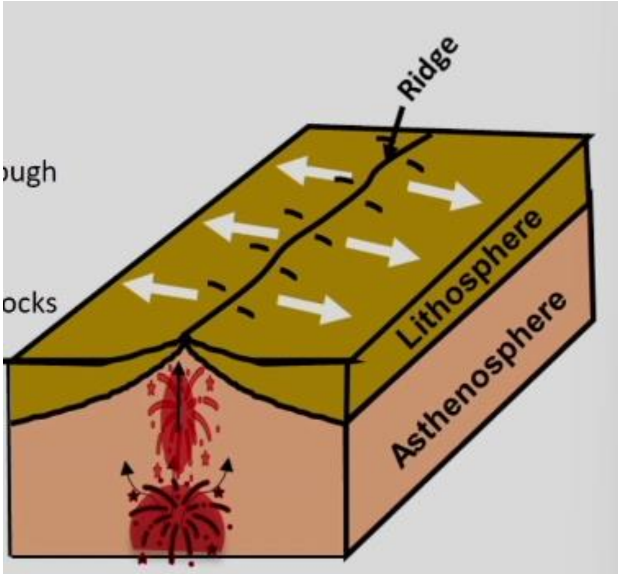
One observation which collectively comes to mind is that definitely, in the past several hundred million years ago, the landmasses which in the current configuration are wide apart from each other must have been in close proximity to each other. Later on, when the convection current or the theory of plate tectonics came into the picture, we can also understand what the governing factor is which is responsible for the movement of these landmasses which are spreading maybe thousands of kilometers in length and width and are under continuous motion even in the current configuration. So, if one is interested to know the rate and direction of movement, often we can refer to GPS-based measurements or satellite-based measurements and then we can get to know which part of the globe is moving in which direction and at what rate per year. So, as per the plate tectonics, we can suggest that the surface of the earth, which consists of continental as well as oceanic crust, is basically consisting of a large number of intact blocks or plates, and these plates, by means of convection current, keep on moving with respect to each other. In general, we can see seven major plates are there.



So, in the figure which is given on the right-hand side, we can see that the entire globe can be divided into seven major plates, starting with the Eurasian Plate, Indo-Australian Plate, Pacific Plate, North American Plate, South American Plate, and African Plate. Later on, because of the development of stresses within the plates, we can see subsequently 14 subcontinental-sized plates. So above seven plates and, in addition to that, you are also having some subcontinental plates like Philippine plate, Cocos plate, Nazca plate, Jhondefuka plate, Arabia plate, Scotia plate, Caribbean plate. So, in total, you are having 17 major plates and 14 subcontinental plates in which the entire globe, or the surface of the earth, can be divided into. Most of these plates now—the arrows shown here are showing you the relative motion of these plates. If you see the Indo-Australian plate, on one side it is moving towards the Northeast, and if you go to the southern part of the Indo-Australian plate, it is moving primarily in the northern direction. So, this movement is basically governed by the convection current in the layers below the crust.

And similarly, in other parts, like the South American plate, you can see it's moving towards the West, the North American plate is moving towards the Northwest, the Eurasian plate is moving towards the Southeast, and subsequently, in different parts of the globe, you can see there is relative movement; not all the plates are moving towards each other but in different directions. That gives confidence that these plates were in contact with each other, and then, whenever two plates are coming in contact with each other, that possibility also is there. Now, we have seen that there are different plates which are moving away from each other, towards each other. So, places where the two plates are coming in contact with each other, such locations are called plate boundaries. So, you are having one plate, maybe the Eurasian plate, and you are having another plate, like the Indo-Australian plate, and wherever these two plates are coming in contact with each other, those locations are called plate boundaries.

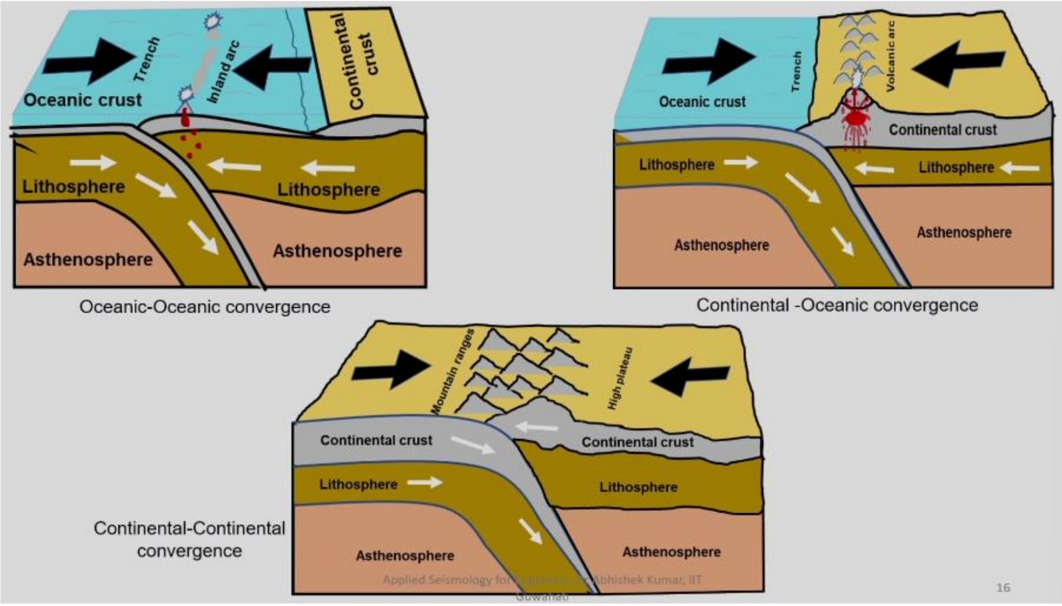
So, this is one plate, this is another plate, these two plates are coming in contact with each other, and then this boundary, which is the interference medium between the two plates, this particular medium is called boundaries or plate boundaries. Now, depending upon whether the two plates are moving towards each other, or when the two plates are moving away from each other, or where there is slight pass or relative motion between the two plates, these plate boundaries can be categorized into three categories: that is, divergent plate boundary. As the name suggests, divergent means the two plates are diverging away from each other. The second one is convergent plate boundary. As the name suggests, the two plates are not moving away from each other but rather they are converging or moving towards each other. So, in the divergent plate boundary, the plates are moving away from each other; in the convergent plate boundary, the two plates are moving towards each other. Then, not every time across the globe will you see that the plates are either moving towards each other or away from each other, but there might be positions in order to understand or to maintain the rate of divergence or convergence, different rates of divergence and convergence, there might be some locations which will experience a form of pure shear. So, two plates are there, and if you see in plan, the two plates are moving not towards each other or away from each other, but there is relative motion between these two plates, so this is the movement in plan. The two plates are moving away from each other, so at the boundary, you will see a form of pure shear, and such boundaries are called transform plate boundaries. So, you are having a divergent boundary moving away from each other, a convergent boundary moving towards each other, and a transform plate boundary where there is a slide past or relative motion in plan.



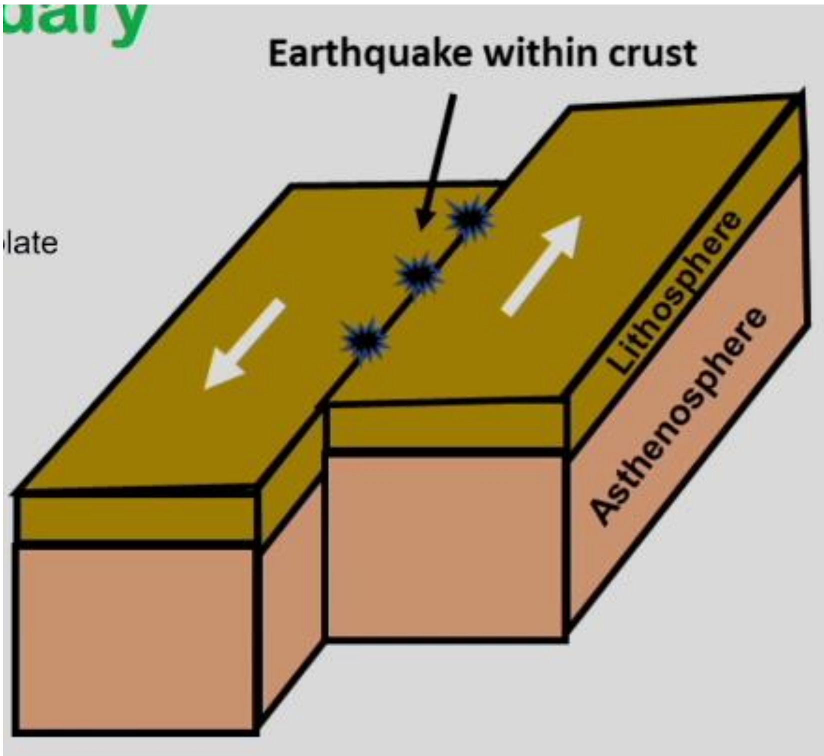
So, divergent plate boundary, as the name suggests, you can see because the two plates are moving away from each other, it creates a space through which the material from deeper layers—so, this is a divergent plate boundary when the two plates are moving away from each other—it will create a space through which the material, which is available at deeper layers, will come onto the surface and will start depositing. Now here, when the material comes onto the surface and starts depositing, that means when the two plates moved with respect to each other, some other material from the deeper depth came and started depositing here, so you will end up creating new land masses in the case of the divergent plate boundary; that is why divergent plate boundaries are also called constructive boundaries. You are constructing basically new land mass; it is also called an extensional boundary because the two plates are extending away from each other, so you can call it a divergent, extensional, or constructive plate boundary. In the divergent plate boundary, when you are discussing, you will mostly see the two plates are moving away from each other, most commonly at oceanic plate boundaries. So, two oceanic plates are there, which are moving away from each other, as a result of which you can see the new land mass is continuously getting created, or the molten material is coming onto the surface from the deeper layers and getting solidified. A critical example of a divergent plate boundary, primarily for the oceanic crust, is the oceanic ridge; this allows the flow of material from the bottom or from the mantle onto the surface through the rifts or valleys. Now, the two boundaries or the two plates were moving away from each other, the material through rifts or valleys came onto the surface and started depositing over here, and this plate is moving, so you will see this was the boundary and this is the plate which is continuously moving, so material from the bottom, when it comes to the surface, it gets solidified and it is under continuous motion. So, you will see the material which is deposited now, after maybe several hundreds of years, you will see slightly the material has moved away from the divergent plate boundary, and then at this particular place, there will be new material which is getting deposited. So, based on that analogy, we can see the material which is deposited very close to the divergent plate boundary will be relatively younger because it has been deposited in recent time with respect to another material which was also deposited at the plate boundary, the same plate boundary but several hundreds of years back, because that material might have reached far off from the divergent plate boundary. So, the material which is close to the divergent plate boundary is relatively younger; material which is away from the plate boundary is relatively older because this particular divergent plate is in continuous motion. So, this allows the flow of material from the mantle to the surface; rocks which are close to the divergent boundaries are relatively younger in comparison to the rocks which are away from the divergent plate boundary.

Usually, a divergent plate boundary is responsible for shallow-focus earthquakes. What is a shallow-focus earthquake we will discuss in coming slides, and generally, such shallow-focus earthquakes are of low magnitude also. Some more examples of a divergent plate boundary: mid-Atlantic ridge, Pacific and Antarctica ridge, Red Sea ridge. So, each of these is giving an example of a ridge where the two plates which are moving away from each other because of the ridge, the material is coming onto the surface and getting solidified; they result in the formation of new landmass, that is why this is called a constructive plate boundary or an extensional plate boundary. The next one is a convergent plate boundary. As the name suggests, that means either the two plates are moving towards each other, or even one plate is moving under the other plate; this is called as convergent plate boundary. That means there is no movement away from each other, but whatever movement is happening at the plate boundary, it is towards each other; that's why this boundary is also called a destructive boundary. So, if you see, there are two plates which are moving towards each other; when these two collide, this particular landmass actually is going under this particular layer because if they are striking, one has to consume and one has to maintain, so that's why this is called as, because it's undergoing consumption. When we were discussing divergent plate boundaries, new landmass was being created, so you call it constructive. In the convergent boundary, because one landmass is continuously moving under the other boundary, you call it as destructive plate boundary, so convergent plate boundaries are also called destructive plate boundaries. Usually, such boundaries are called when the two tectonic plates are moving towards each other and collision takes place.

Usually the younger and softer material or the plate boundary which is relatively softer, that will bend and start subducting under the older and relatively stiffer material, so you can see over here the material, two plate boundaries are there, whatever boundary is relatively younger and softer, that will, at the time of collision, start bending or subducting under the older plate and it is going down, so you can see over here the younger plate is actually undergoing some kind of destruction, or the landmass of the younger plate is actually getting consumed at the convergent plate boundary. As a result of higher-pressure friction, now this material, which started moving under the older plate, this material, when it starts moving down, will also be subjected to high pressure as well as temperature, as a result of which many a times the material will undergo melting at the convergent plate boundary. Now, depending upon what are the two plates, whether one plate is ocean, one plate is continent, then you call it as continent-ocean convergent plate boundary. When two plates moving at the convergent plate boundary are both oceanic plates, then you call it an ocean-ocean convergent boundary or oceanic-oceanic convergence. A critical example is the mid-oceanic range. When continent and oceanic convergence is there, then you call it continent-oceanic convergence; an example is the western coast of South America. When continent and continent are converging, a critical example is the Himalayas and the South Alps. So, the two plates are moving towards each other, the younger plate is subducting under the older or relatively stiffer medium, and when the material reaches a certain depth, you will experience that the material is undergoing melting, that is why the convergent plate boundaries are also called destructive plate boundaries.



Here are some of the pictorial views of oceanic-oceanic convergence. In the first one, you can see one ocean is subducting under the other ocean, definitely an example of convergence plate boundary, and when the material undergoes or subducts under the other plate, there will be friction, there will be melting of the material, and sometimes this molten material will come onto the surface through volcanic eruption. So, you can also see some kind of volcanoes, a continuous chain of volcanoes, or a continuous chain of mountains at the convergent boundaries. So, when oceanic-oceanic crusts are undergoing convergence, you can see over here the first figure, it is basically showing you some kind of volcanic eruption, and the molten material from the bottom is coming onto the surface. Second one, continent-ocean convergence, so continental crust is there, and oceanic crust is there, oceanic crust is bending under the continental crust, as a result of which again there will be friction, there will be melting of the material, when this molten material comes onto the surface you can again experience some kind of volcanic eruption, because in the second case the volcanic eruption is happening at the surface, it will be more evident, or you can clearly witness it. In the first one, when the volcanic eruption is happening under the ocean, so everything will be submerged within water, and then that's how it will be happening. The third one is continent-continent convergence, so here you can see there is no ocean, only both side land masses are there, so while on one side the land mass will go down and will start melting, on the other side the land mass initially, when these two came in contact, then slightly the younger material starts bending down, the other material experiences some kind of rise, and then over the period of time when this process of convergence between two continental plate boundaries continues for millions of years, you will see a continuous chain of mountains, a critical example is the Himalayas and the South Alps, so these two are critical examples of convergent plate boundaries when the two continental plates are converging towards each other.



The next one, or the last one kind of plate boundary, as we discussed, so on one side when we are having convergent plate boundary, somewhere there will be divergent plate boundary, so consider two plates which are away from each other but are converging or diverging at different rates, so certainly there might be some locations where there is, in order to balance this particular difference in the rates of divergence or convergence, there will be some zones which are undergoing pure shear, so this particular pure shear is a critical example of a transform plate boundary. There is no consumption of the material because none of the plates are moving or subducting under the other plate. There is no construction of the new land mass because the two plates are not moving away from each other in order to bring the material from the bottom onto the surface, so neither it is constructing nor it is destructing. That's why this kind of plate boundary, that is, transform plate boundaries, are also called conservative plate boundaries. So, these generally transport strain between the ridges or subduction zones. As I told you, when two plate boundaries are there with different rates of convergence or divergence, certainly in between there will be a transform plate boundary, connecting the abruptly ending ridges to other faults or ridges. A critical example here is the mid-oceanic ridge.

So, summarizing whatever we have discussed in today's class, though we have some information about earth based on whatever we are seeing in and around ourselves, as you start exploring the overall characteristics, whether in terms of mass, or whether in terms of volume, it gives an indirect hint that there is something denser, there is something which is denser and in addition consists of larger volume existing beneath the ground surface. Then, based on that we found out that overall, in terms of composition, three layers are there: crust, mantle, and core. In terms of physical properties also, five layers are there. Then we saw, because of significant variation in the temperature as well as overburden pressure, some layers are in solid state, some layers are in liquid state. Further, we saw because of significant variation in the temperature between the top and bottom of the same layer, there will be development of convection current, this convection current particularly in the upper mantle will result in the push of the crust, or that's how you can see different land masses which are available across the globe are in continuous motion with respect to each other.

The theory of continental drift suggested that the land masses are in continuous motion with respect to each other. Plate tectonics suggested that these land masses are by means of convection current, are actually in constant motion with respect to each other. Then we saw, when these land masses are in motion with respect to each other, depending upon whether the two land masses are moving away from each other, towards each other, or are experiencing pure shear, you can have divergent, convergent, or transform plate boundaries. So, in the next class, we will continue more about what is happening beneath the ground surface and how it is contributing to earthquake occurrence, and subsequently, we will discuss more about the topic. Thank you, everyone.