Plate Tectonics

Prof. Pitambar Pati
Department of Earth Sciences
Indian Institute of Technology, Roorkee

Week - 01
Lecture - 01
Interior of Earth- I

So, friends, good morning. So, today we will going to discuss about this topic Plate Tectonics. So, what this plate tectonics means to you? So, if you see this first slide, the name Plate Tectonics it is associated with three terminologies. One is plate, second is a lithosphere and third is interaction. So, that means it says interaction of lithospheric plate it is called Plate Tectonics. So, before going to understand what Plate Tectonics is, we must understand what is plate? and what is lithosphere? and how they interact with each other? So, first let us discuss about what is plate? So, if you see this figure, these are the plates you all are acquainted about.

So, the similarity between this plate and the plates we are going to discuss is that it is the dimension. Here if you see this plates, here the second dimension or the two dimension are much much more than the third dimension that is called the thickness. And the similarity here, these are the lithospheric plates, different plates are here and this is pacific plate, similarly we have Indian plates, we have Eurasian plates, we have North American plates like different plates. So, the similarity is that this thickness of this plates or the thickness of the lithospheric plates, they are much much smaller than as compared to their areal extent.

So, that means it is a three dimensional body where the two dimension "x" and "y" it is much much more than the third dimension that is the z dimension that is the thickness. So, that's why the term plate is used. Then second term is lithosphere. What is lithosphere means? So, lithosphere in the mean time we can just understand it is the thickness of that part of this earth which composed of the total crust and the upper part of the upper mantle which is rigid and beyond that that is asthenosphere and this mantle other part of the mantle then the outer core then the inner core. So, here the lithosphere means those rigid part of this earth's crust from the surface of the earth to certain thickness or to certain depth.

So, that is called the lithospheric thickness. So, this lithospheric thickness it varies in thickness from 5 to 6 kilometer in the ocean basin and about 40 kilometer and the continental crust and particularly in the mountain region it may be up to 100 kilometers thick. But for example, if you think about the Indian subcontinent we have the Indian plate. So, if you see this dimension its aerial extension, its aerial extension is much much more as compared to its thickness. Suppose for example, we take about 40 kilometer or 50 kilometer.

So, we have thousands of kilometer length, thousands of kilometers of width as compared to only 40 to 50 kilometer its thickness. So, that's why the term plate is used. So, if you see this present day tectonic map of world, this earth it consists of number of plates and some plates are very smaller in dimension like Cocos plate, like Caribbean plate they are very small in size. And in contrast if you see the Pacific plate, the Indo-Australian plate, the African plate, the North American plate they are very large dimension. So, that means I want to say the plates on the earth surface it is divided into number of small segments as well as large segment and all these segments irrespective of their size they are moving with respect to each other and that once they are moving they are interacting with each other and that interaction of called plate tectonics.

So, that means plate tectonics in the sense we can say it is the interaction of lithospheric plate. Now, the question arises if they are interacting what is its use? what is the need of this study? because you see plate tectonics its effect is far extent. So, that means in the future classes we will deal with that what is the utility of studying the plate tectonics. So, this basics about plate tectonics says it is not a new process. So, that means so that doesn't mean that plate tectonics going on nowadays.

So, from the beginning of the earth up to now the plate tectonic process is going on, but the rate of movement of the lithospheric plate is not same throughout. Even In the present day different plates they are moving at different rates. Similarly, in the geological past different plates they have moved different rates and in the present day if you for example, if you talk about this Indian plate before 70 million years it was moving about 16 to 17 centimeter per year, but now it is moving about 5 centimeter per year this is absolute motion. So, there are two types of motion in the due course of time we will discuss one is called relative motion another is called absolute motion. So, this 5 centimeter per year the Indian plate moving nowadays it is the absolute motion.

So, that means different plates they are moving at different rates and in the geological time this rate of movement was not same throughout. Different plates were moving at

different rate and one plate also it is moving in different rate. So, it is occurring from this beginning of the earth that we have discussed now. So, it is not a new process from the beginning of this earth up to now this process is going on. So, if you see this figure here it is today and this is 225 million years.

So, if you see this configuration of this land and sea or the plate configuration here it was Pangaea then it is divided into Laurasia and Gondwanaland then it is divided into different continents and this is the present day configuration of this earth system. So, that means I want to say these plate tectonic it is not a new process that means starting from the 4.6 billion years that is from the beginning of this earth up to now the whole system is moving with respect to each other in different segments. The rate of movement and the dimension of the plates have changed through geological time The rate of movements we have discussed and the dimension of the plate this is also very important. The dimension of plate once I say that means it is x y and z dimensions.

So, x y dimensions that is the area, area has increased or decreased some plates they decreased the area, some plates they gained the area and the z dimension that is the thickness. There are two reasons how the thickness is changed one is called the vertical accretion which is the radiation of heat the earth from this beginning it is radiating heat continuously and it is getting cooled. So, due to this cooling some part of this mantle which is cooled that becomes rigid and welded at the lower part of the crust and that's why the crustal thickness increased. So, if you see this Precambrian tectonics we will deal in future times there the crustal thickness was very less. So, that's why the plate was moving at a higher rate, but with time due to this increase of thickness and due to this decrease in heat radiation.

So, this plate movement gradually decreased. So, that means due to that due to radiation of heat this z dimension increased. Similarly there is a collision there are two plates suppose they are colliding. So, that means that x y direction there is a change. Similarly there is a z dimensional change also their thickness will be increased at the collisional zone.

So, that means the dimension of the plate that the movement rate that is changed from this Precambrian to recent or from the beginning of the earth to recent. Then why it is important? this course why it is important? why plate tectonics is important? The first thing is that it affects our daily life directly or indirectly. Then it is affecting our national economy. So, now how it is daily life for example, had plate tectonics not been there that means we do not have Himalayas and we do not have Himalayas or we do not have eastern ghat we do not have western ghat So, that means the life there would be life in

the plain. So, that means whatever this geographical difficulties are there that means what people are facing due to change in geography that would not be there.

So, it is affecting our daily life. It is affecting our national economy. Why national economy? Because most of the mineral deposit that is governed by plate tectonics. Most of the hydrocarbon deposit governed by the plate tectonics governed by the basin tectonics. So, that means these are the wealth they add our national economy.

So, it affects our national economy. It is affecting our neighborhood relationship. Neighborhood relationship that means I want to say it is the relation between these two neighbors neighboring country for India and Pakistan, India and China. Had it not been hilly terrain probably we would not faced that type of problem that we are facing nowadays. So, it is affecting our national economy.

It is affecting our neighborhood relationship. That means defining a proper border had it been a plan land probably it would be easy define the proper border otherwise we are facing difficulties. Then our food habits it is very much important food habit it is directly or indirectly it is affecting. is affecting. For example, our crop habit it is affecting plate tectonics by affected by plate tectonics because it is affected by soil and soil is affected by the rock types below.

So, rock types it is the product of tectonics. Then climate and environment that means plate tectonics it affects our climate. It is rising Himalayas, it is obstructing the Indian monsoon. So, that it is affecting our crop pattern our agriculture pattern. Similarly if you go to the geological past the plates have moved from warmer climatic regime to colder climatic regime.

Similarly from colder climatic regime to warmer climatic regimes. So, now we have vast amount of coal deposit in Antarctica which is total freeze now which is not possible. Coal deposit it is not possible in cool environment. So, that means due to this climate change now this plate which was or the Antarctic plate which was earlier in the warm and humid region now it is in the cold desert. Now infrastructure development that is very important.

Infrastructure development we do not consider geology and plate tectonics while we are planning that is the blunder we deal. So, that means if we consider this plate tectonics we consider this plate movement we consider the plate movement related structures like fault like fold. So, that means probably our infrastructure will be more safe. You go to the hilly terrain in the Himalayas number of dams are there how safe the dam is?

Whether there is an active fault there, whether there is active thrust there. If we consider it our infrastructure will be more durable otherwise there will be a problem.

So, that means all those systems all those parameters that is directly or indirectly it is affected by plate tectonics. So, before going to study the plate interaction we must understand the plate very clearly. What is the plate? What is its thickness? What is its compositional stratigraphy? And how the composition it behaves during the plate interaction like that. So, to understand that we must go to the beginning of this earth. Now if you see this figure the beginning of the earth we believe it was 4.

6 billion years ago and there are number of theories available for this beginning of the earth. And most the recent theory was here there are two bodies, planetary bodies that is the proto earth and the Theia they collided together and there was a giant impact due to this giant impact the earth and its moon was formed. And it happened 4.6 billion years back.

And if you see this 4.6 billion years time scale we divided into 24 hours. The Homo sapiens it appeared about 23 hours 59 minute 12 second. So that means just 48 second below or before. And here the modern man it is just only 4 second below. So that means our life as compared to this beginning of this earth is about 4 second.

So within that 4 second utilizing our technology utilizing our mind we want to understand the 24 hour clock. What are the different processes that were acting in the geological past? How the process changed with time and what are their product? The process change means the product will be different. So the process product relationship in the plate tectonics that in the terms of plate tectonics we want to understand. But one theory probably you have heard earlier it is called theory of Uniformitarianism. that is that means the present process it leads to the past process which failed here.

So that that means presently what is happening it may or may not it was happening in the geological past. And if it was happening maybe of different rates. So the planet earth it is believed to have formed by the accretion of the primordial solar material similar to the composition of chondrite that is very important to understand, what is chondrite? So chondrites are nothing it is the stony non-metallic meteorites that have not been modified due to melting or differentiation. If you see this figure here there are undifferentiated bodies and there are differentiated body. And the earth it was formed by a differentiated body that means we have core, we have mantle, we have crust so that means we have compositional stratigraphy if you are moving from this surface to the inner side or the interior of the earth.

But there are certain bodies, there are certain meteorites which are now we are able to understand that have not been differentiated from their beginning. So that means they contain their original identity. So that means those are very important to understand how the crust system, how the solar system or how the earth system it was evolved from the beginning. So now you see this is the chondrite and chondrite means it is Chondrules. The chondrite terminology it derived from Chondrules.

Chondrule means if you see this the rounded bodies, these are rounded, the rounded shapes they are called Chondrules. So from these Chondrules the chondrite terminology was derived. So those are the undifferentiated non-metallic meteorite and which has not been undergone any types of differentiation or metamorphism or change permanently. Arguments based on this radioisotope like hafnium and tungsten that believe this earth was accreted for about 10 million years and the core formation it was continued about 30 million years. So there are different theories there available defining this core formation or this earth's layer formation and this most acceptable theory was here given by Safronov's.

That's model says first if you see this four figure 1, 2, 3, 4 it says the first one it is the melted iron layer between the protomantle and the primordial core. Here is the primordial core and this red layer it is the melt of metal or the molten layer of the metal. So with time it was totally revolving, it is rounding. So that means if you see here the second one the primordial core it is cracking. So due to this rotation this primordial core there are cracks developed and through these cracks the molten material they started going inside through these cracks.

So now further once this crack allowed to pass the molten material inside so there is mixing, intermixing. So now you see this primordial core and this mantle material or the molten metal material then intermixed and further rotation then they differentiated. So due to differentiation this primordial core which was relatively lighter so now they are coming to this periphery and the heavier material or the metals they are occupying at the core. So this was the theory which was proposed by Safronov and it is most acceptable till now. So now the question arises why this hafnium and why this tungsten isotope was used because of this half life period.

If you see hafnium it has 34 isotopes starting from 153 to 186 and there are 5 stable isotopes here that is 176 to 180 but the radiative isotope of half life ranging from 400 millisecond to 2 beta years. So this is important. So that's why it can date up to long range events. So that's why this hafnium it was used there. Then another is the tungsten

it consists of 4 stable isotopes and one very long lived radio isotope that is tungsten 180.

So theoretically all 5 can decay into isotopes of element 72 hafnium by alpha emission. So the only 180 which is the longest long-lived radio isotope has been observed to do so at a half life of this much years of some million years. So that's why due to their high half-life period these are being used to detect the earlier or these ancient events precisely. During this early accretion of this earth it was hot because due to accretion it generates enormous amount of heat.

Accretion that is adhesion, collision. So this accretion it created enormous amount of heat. Then radioactive decay. So radioactive decay that means we have radio isotope like uranium, thorium they are continuously radiating, they are creating heat, they are generating heat so that was there. Then formation of the iron nickel core. So once there is a rotation there is intermixer and there are metallic material which are going inside so that due to friction they are creating some heat.

And bombardment of the terrestrial bodies at the initial time there are many more bombardments at present day compared to the present day. So these are the reasons the earth was very hot. And another rock probably you have heard this term that is called Komatiite. The Komatiite it was erupted or it was formed during the Archean time.

No Komatiite was recorded after Archean time. So this is due to this radiation of the heat and the cooling of the mantle because Komatiite formation it needs enormous heat. So now this earth mantle has not that much heat it can generate Komatiite lava. Second thing that Komatiite suppose it is forming there at the mantle level. So it has to come to the surface because Komatiite it is an ultra-mafic volcanic rock. It has to pass through this crustal layer or the lithospheric layer so there will be contamination within that magma.

So if the Komatiite magma is forming and by erupting to this crustal level there will be contamination. So that means its composition will not there of that much. That means whatever the composition at the ultra-mafic composition it will not retain its ultra-mafic composition while erupting to the surface. Second thing that heat loss. Suppose in the Precambrian or this Archean time or there is the beginning of this earth crust was very thin.

So the magma was generating at this level and it has to puncture only this much distance so it was erupting here. So there is less heat loss but nowadays the heat loss will be more. So that's why nowadays there is no Komatiite being formed. So the energy

released by sinking iron and nickel to form the core generated sufficient heat to melt the large fraction of this earth.

So this is another source of heat generation. The magnetic field is generated by convection of the molten metallic outer core which must therefore have been preserved at that time. So that means I want to say these earth's magnetic field nowadays we see it is there due to this rotation of this earth's outer core it was existing that time. So that means it says the earth's outer core was present that time. So if you see this figures, so here the bombardment it is seen here impact craters we have impact crater nowadays that is Dhala impact crater, Ramgarh impact crater, similar lunar lake in Maharashtra impact crater. So that means these are the live example that this bombardment extra-terrestrial bodies, bombardment was there.

And if you see this metal silicate partitioning we have metallic drops or this metallic bodies which are differentiating and it is going down being it is heavy it is going down. So during movement through this medium it was having some frictions with the surrounding and it was creating heat and the dense metal phase sank towards the early core. So finally, we are collecting the metals from the surrounding and enriching the core here. And finally, what we are getting it is the core which is mostly nickel and iron then we have outer core which is melt at the molten stage then we have mantle which is viscous then we have crust that is the solid part and some part of this mantle due to heat radiation they are cooled down and that is welded at the base of this crust and finally, we created the lithosphere. This much thickness that is the lithosphere which is playing major role in the plate tectonics.

So it means before going to understand what plate tectonics is? what is its effect? how the plates are interacting? we must very clearly understand what is a lithosphere and why it is formed and what is their different compositional stratigraphy at different places. So some fundamentals before going to real plate tectonics the earth formed about 4.6 billion years ago, interior of the earth is not accessible. So interior of the earth it is not directly accessible. We indirectly study the interior of the earth by seismic method and by this deep crustal xenolith.

So, you probably heard about this term xenolith it is the crustal or the deeper rocks they are coming to surface or near surface during magmatic eruptions. So, these are called xenolith so that means they are giving us the direct information what the different rock types which are lying below. So the deepest well about 12 kilometer or 14 kilometer deep from the earth surface. So that means the deepest well we could drill for oil drilling

about 12 to 14 kilometers that means we have direct data of 12 to 14 kilometer at some places, but maximum places it is inaccessible. So that's why we have indirect evidences like seismic by that we can study the interior of the earth.

Direct evidence of the deeper earth materials are found in the deep sea volcanoes and the xenoliths. So here at the mid-oceanic ridge the mantle material is erupting and we have this direct study for the rock types in the interior of the earth. Similarly from volcanoes it is taking the material from inside so we have direct evidence what is happening inside. So these are the direct evidence along with this drill wells that we can study directly what is happening at what depth, but beyond that earth's radius have 6370 kilometers.

So out of that we could have assessed about 12 to 14 kilometer. So beyond that we do not have direct knowledge. So up to certain depth we can study by this xenolith by the volcanoes, but beyond that we do not have. So that's why indirect method like seismic we are using very efficiently to study the interior of this earth. So this earth's cross-section you see it is the crust then we have this asthenosphere then we have the mantle, then outer core, then inner core and the crust it has two types one is called the continental crust another is called oceanic crust. The oceanic crust about 5 to 6 kilometer thick and this continental crust about 40 to 50 kilometer thick, but in the mountainous region like the Himalayas, like the Alps it is about 100 kilometer thick.

So our main aim will be confined here at the lithosphere that means the crust as a whole and the upper part of the upper mantle upper part of this upper mantle which is rigid and which is solidified and welded at the base of this crust this total layer is called lithosphere. So interaction of lithospheric plate that means this much thickness of this earth it is moving like curved caps on the earth's surface like curved caps on the earth's surface they are moving in different directions they are interacting with the neighboring plates and finally due to the interaction we are getting the dimensional change, we are getting the mineralization, we are getting the metamorphic minerals, we are getting these volcanics, we are getting the volcanic that means igneous minerals like that. So we are generating these sedimentary basins for petroleum hydrocarbon So that means whatever this wealth or this geologically important subjects like structural geology, like economic geology, stratigraphy and petroleum geology all those things they are dealing with the plate tectonics. So plate tectonics it is an integral part that means we must have to study. So here once we are going inside the earth so this is the crust, this is the continental crust and this is the oceanic crust and the crust is divided into two, one is the upper crust and the lower crust and here this is the conard discontinuity.

It divides the upper to lower crust. Similarly from crust to mantle the discontinuity is there that is called Mohorovičić discontinuity or Moho discontinuity and then this is the upper mantle and then this is the lower mantle this is core-mantle boundary this is the outer core and this is core-mantle boundary that is called Gutenberg discontinuity. Then this is the outer core and inner core that is Lehmann discontinuity then this inner core it is solid. So if you see this seismic wave path the P-wave velocity path here the velocity it is gradually increasing and increasing and increasing and finally, it is reaching here. So this is called Preliminary Reference Earth model or it is called PREM model.

So preliminary reference earth model this is called PREM model. So first this PREM model was derived based on the seismic velocity P wave velocity and later on there are number of modification with this models and finer to finer details now available from the crust to the interior of the earth. So thank you very much we will meet in the next class.