Plate Tectonics
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Week - 01
Lecture - 03
Interior of Earth- III

So, friends good morning. So, if in the last class you can remember we were talking about the internal structure of the Earth So, before moving to actual plate tectonic concept we must very carefully understand what is the internal structure and particularly the crust. Because if you remember I was talking about the whole crust as well as the upper part of the upper mantle which is collectively called lithosphere, it is interacting with another lithosphere during the plate interaction. So, that is why understanding the lithosphere and particular the crust it is very much essential. And once I talk about the crust it is the continental crust as well as the oceanic crust. and the continental crust which was formed during the Archean it is not changed much.

However, the oceanic crust which was formed that time it is undergoing many time changes. So, that means the oceanic crust is new as compared to this continental crust. So, that's why understanding the continental crustal composition as well as the oceanic crustal composition it is very much essential to understand the plate tectonics and their product during the plate interaction. So, the continental crust it is mainly represented by the precambrian shield.

So, now the question arises what is precambrian shield? So, this term is highlighted here. And in the next slide we will talk in detail what is shield and what is its significance in plate tectonics. Rocks in the shield may range in age from 0.5 to greater than 3.5 giga annum.

So, that means this age it says we are in the precambrian domain. And here it is clearly mentioned that this continental crust mainly represented by the precambrian shield. So, that means when this earth was formed there was convection system and this Quartz-feldspathic material mostly the felsic material they are separated out and form the upper layer as foams just floating on the water. So, now you imagine suppose there is a felsic material which is floating on this magmatic system due to convection and similarly another magmatic system that means another floating material that felsic material is floating here. So, they are amalgamed together and that is forming the continental crust.

So, that means the dimension of the continental crust that increased due to this lateral accretion this is called lateral accretion that means laterally they are accreted they are added together it is called lateral accretion. So, due to lateral accretion the dimension of the continental crust increased. Similarly due to heat loss the crustal thickness gradually increased. So, that is why the continental crust it was changed its dimension both in two dimension as well as the third dimension that is the thickness with time and all that happened during or just after the formation of the earth. So, that's why the continental crust it is mainly representing the pre-cambrian shield and what is the shield in the next slide we will talk in detail what the shield is? Metamorphic and plutonic rock types dominant so that means the pre-cambrian shield or the continental crust most part it is dominated by the metamorphic rock and plutonic rock.

Plutonic rock you know that this magmatic system when this rock is intruded deep inside this earth that is called plutons granite it is a plutonic rock basalt is a volcanic rock, rhyolite is a volcanic rock. So, that means it is the metamorphic rock and the plutonic rock they dominant the earth's continental crust In the temperature-pressure regime recorded in exposed rock suggest burial depth ranging from 5 to 40 kilometer. So, that means it says if the continental crustal thickness as we believe to be around 40 kilometer. So, the earth's crust which was formed that time it has undergone metamorphism up to 40 kilometer depth and that rocks now it is exposed to the surface. Now the question arises if it was formed around 40 kilometer depth how it is near surface or at the surface they are exposed this is called crustal exhumation.

Crustal exhumation means the rock which was earlier inside due to this tectonic movement they are coming to the top surface that is called exhumation process. So, once upon a time the rock which was metamorphosed at the depth. So, due to this crustal exhumation they are coming to the surface or near surface and exposed for the study. 11 percent volume of the total crust it is composed by the shield area. Then it exhibits very little relief they have remained tectonic stable for long period of time.

So, in that case I can say it is the Archean-Proterozoic boundary. So, that means if you go to this peninsular India this is the Indian shield. So, mostly the rocks are exposed it is composed of granitic gneiss, granodiorite, migmatite like that. So, here the shield concept and the craton concept you can understand very well. Now you see these are the rocks, basement rocks that means it is mostly composed of granitic gneiss, migmatite like that and they are highly metamorphosed.

If you see this rock it is migmatised, gneissic appearance is there, migmatite bending, gneissic bending is there that means there are high grade metamorphic rock. So, it is representing here and periphery of this system periphery of this basement it is covered by the sediments. So, the whole system that means this basement rock as well as this cover sediment this total system is called craton. So, craton is divided into two parts or the two component. One component is your shield where this pre-combined rock is exposed to the surface and the platform cover at the periphery at the low lying areas where the sedimentary rocks are occupying.

So, this total system is called craton. If you see here this Indian context we have different craton like Dharwar craton, we have Bastar craton, we have Bundelkhand craton so like that. So, that means these cratons are nothing it is the rocks that were geologically or tectonically stable from this Archean-Proterozoic boundary that means no significant tectonic deformation has been recorded after this Archean-Proterozoic boundary. So, that is why it is called tectonical stable that is the craton. Isn't it? So, craton where this basement rocks are exposed to the surface that is called shield and this sedimentary cover that is called the platform cover or it is called supracrustals.

So, here in this craton you can see here these are this pre-cambrian shield rocks and here it is exposed and all other parts that are covered by sedimentary rock. So, that means this whole system is called craton but this exposed part it is called the shield area. So, if you see world map there are two types of region. One is called shield area another is called mobile belt. So, here if you see these lines these are representing the mobile belt.

Mobile belt that means it is tectonically active regions and here we have mobile belt in the past we have or we had this eastern ghat granulite belt or eastern ghat mobile belt. So now, this red colour this representing the shield area that means where these pre-cambrian rocks high-grade metamorphic rocks they are exposed to the surface. So, these are the shield area we have Indian shield, we have Canadian shield, we have Australian shield, African shield like that there are number of shields and this area throughout this world it is exposed. Now, we know the crust it is maintaining a compositional stratigraphy from the beginning that means from the beginning of the earth the lighter rocks or the lighter materials lighter elements and lighter minerals they are covering at the outer shell of this earth that is forming the crust. Gradually once we are going down from crust to core the mafic content increases and the heavier part that is remaining at the inner core mostly it is the nickel and iron core is there.

So, that means the crust it maintains a compositional stratigraphy. So, now if you see here this composition of this continental crust it is mostly it is composed of oxygen and here if you see very important is the radioactive elements. So, different models are there which is proposed for this bulk chemical composition of this continental crust, but some of them are acceptable and some of them have some difficult to accept. So, that means but exactly what this continental crust is from top to bottom it is difficult to precisely define because there are certain uncertainties in each and every model. However, there are some models which are acceptable still there are certain difficulties to accept it.

So, but the most convincing model it says this earth's composition it is mostly composed of oxygen then we have magnesium, sodium, calcium, Fe, Al like this. So, these are the most common element that does not mean the earth is composed of this much only there are certain trace elements are also, but it is the most common element it says oxygen is the forerunner of it. The crust shows abundance of heat producing element like uranium, thorium, potassium and other incompatible element with it. This is the most common possible element probably you have heard this term. During this magmatic differentiation there are certain elements they do not go into this crystal structure easily and they remain in the constituents form in the ionic form in this magma and finally, at the later stage when these later minerals or the low-temperate minerals are crystallized those they are occupying their lattice structure.

So, these are called incompatible elements. So, this crust it is composed of this lighter elements like the quartz, feldspar and some and some other elements as well as this heat producing or this uranium, thorium, potassium like minerals which are radioactive. And the degree of abundance of these elements in the crust suggest the degree of depletion in the mantle. So, that means it says the more it is abundant in the crust the more they are depleted in the mantle. Now, the composition of the upper continental crust.

So, we know the continental crust is divided into two segments vertically the upper continental crust and the lower continental crust and it is divided by a discontinuity that is called Conrad discontinuity. And conrad discontinuity for your information if you remember our earlier class it is not present throughout the globe that means here some places this conrad discontinuity is there, but some places it is not there. So, it may be related to orogenesis or so. So, earlier it was believed that the upper crust is of granitic composition because granite is the most common rock in the upper continental crust.

So, that was believed that probably the granite composition is fit for the upper continental crusts composition, but later on it was discarded.

Why discarded? If you see this graph it is the gravity anomaly map. Gravity it says the vertical and lateral density contrast. So now, if you see here we have a granitic intrusion that is a granitic pluton and we carried out this gravity survey that means we are taking the gravimeter from here and we are going this way. So, once we are approaching the granite body if you see this gravity value gradually going down and once we are going away from this again it is approaching to the normal. So, had it been of granitic composition why there is a lower of this gravity value from this normal? So, that means that's why it is discarded that yes, this upper continental crust is of granitic composition because it does not fit with the density.

These anomalies demonstrate that the density of the plutons it is about 0.1 to 0.15 mg per meter cube less or lower than the average value of the upper crust. So, that means you see if this upper crust graph is here once it is reaching to the granite it is coming down it is coming down from this value. That's why this granitic concept of the upper continental crusts composition it was discarded.

Then what is the method? What is the correct method of studying this upper continental crusts composition? So, that is coming from the large scale sampling from sedimentary rocks. So, sedimentary rocks we know there are basins sediment rocks are deposited starting from this beginning up to now. Now the question arises where these sediments come? The sediments they are product of the weathering and erosion of the upper exposed surface that is the upper continental crust. So, that means a concept was there if we can sample the sedimentary rocks worldwide and we calculate its chemical composition then probably it will yield the correct composition of the upper continental crust and it is true. So, that's why worldwide sedimentary rocks that were sampled and it is composition was analyzed and that's why this composition yields this upper continental crust is of granodioritic and dioritic composition.

So, not of granitic composition, granodioritic to dioritic composition that means some mafic part is there not only the felsic part granite means it is quartz and feldspar but granodioritic and diorite that means we are increasing the mafic content. So, that means not only this felsic content it is occupying the upper continental crust along with felsic there are certain mafic content that is also present in the upper continental crust. However, it must be cautiously used because it is necessary to evaluate loss and gain of element during weathering, erosion, deposition and diagenesis. So, it is not simple thing that this minerals they are getting weathered from this upper continental crust and depositing. So, during weathering there is certain loss of element, during erosion there are certain loss of element and during diagenesis some loss of element and some gain of element.

So, that means this gain and loss it must be compensated while we are representing the upper continental crust is from the sedimentary rocks. So, here in a photograph wise it is described we have granite to granodioritic composition if you see this two rocks here the mafic content gradually increasing from granodiorite to diorite. However, the granitic it is of mostly of felsic nature. Now, it was the story for this upper continental crust. Now, coming to the middle and lower continental crust.

The middle crust around 11 kilometer thick that is starting from 12 kilometer to 23 kilometer and the lower crust it is 17 kilometer thick that is from 23 kilometer to 40 kilometer. Now, in tectonically active rifts and rift margins the middle and lower crust are generally thin or it is very negligible. Why? if you see here we have rift basins we are developed the rift system. So, that means rift system that means it is extensional tectonics we are stretching the system and once we are stretching the system the upper continent upper continental crust it is rigid and once we are stretching a rigid system there will be fractures. So, that means we are creating normal faults.

However, once we are going down the ductility increases. So, that means a ductile material or partially ductile material we are stretching. So, that means gradually its thickness is decreasing. So, that's why in the rift basins the middle and the lower continental crusts they are relatively thin and that's why here in the orogenic belts the crust must be thicker than the normal. So, now here you see we have a collisional zone like the Himalayas.

Here the Indian plate and the Eurasian plate they are colliding. So, once it is collisional zone so that means it is talking about the compressional tectonics. So, that means a thin body or a crustal thickness of this much we are compressing, so gradually its thickness is increasing. So, that's why at the collisional zone at the active mountain building zone the crustal thickness is much much more than the normal. However, at the rift basins the lower and the middle continental crust which is thin as compared to the normal continental crust thickness.

So, if you see here this is the full face rift basin. Now you see the normal faults they are arranged in arrays and this is occupied by the sediments. So now you see the crustal thickness gradually increasing away from this rift system. So that means at the rift due to extension the crustal thickness is less and at the collisional zone due to compression the crustal thickness is more. Now the middle crust in general may contain more evolved and less mafic composition compared to the lower crust.

Because we know once we are going from top to bottom the mafic content increases, the ductility increases and towards the upper the felsic content increases. So, that's why the middle crust is evolved and less mafic composition as compared to the lower crust. And the degree of metamorphism, density and the mafic content increase and this concentration of heat producing element decreases with depth. Because few minutes back we are talking about this compatibility, incompatibility. So gradually once we are moving towards the more felsic content, so we are increasing the heat producing elements like this uranium, thorium, potassium whatever the radioactive minerals are there.

So gradually once we are going down their content is decreasing. And the seismic velocity range of the lower crust it varies from 6.8 to 7.7 kilometer per second which may suggest more mafic chemical composition or the presence of dense and high pressure phases. So this seismic velocity it is representing a mixture that means the incorporation of more mafic content in the lower continental crust and that also increases the presence of high dense phase, high pressure phases are there.

So gradually once we are moving down the pressure increases. It is obvious that once we are going down high pressure phases will be more dominant as compared to the low pressure phases. However, in the oceanic crust and this orogenic belt that may be certain deviation when we will talk in detail about that we will talk elaborately. Now in the over thickened roots of the orogens part of the lower crust may be eroded and the transition to the eclogite facies where plagioclase is unstable and mafic rock transform into very dense garnet-pyroxene bearing assemblages. So that means once we are at a collisional zone like the Himalayas, so what is happening here the crust may be recorded transition from eclogite facies because if you see this is the eclogite facies and this characteristics of eclogite facies is it is a high-pressure facies.

Once there is a collision zone two plates they are colliding so that means it is a high pressure environment. So that means here it is obvious is that, this mineral which are of characteristics of high pressure that will be more dense minerals will be available as compared to the high-temperature minerals. So that's why it is the root of this mountain where it is over thickened due to this lithostatic pressure due to this directed pressure this lower crust may record at a transition to eclogite facies where plagioclase is unstable. Why is plagioclase is unstable? Because if you remember the Bowen's reaction series plagioclase it is forming at higher temperature equivalent to olivine and pyroxene. So that's why once we are increasing the pressure and it is low temperature so plagioclase is not present at that temperature and pressure regime.

That's why plagioclase is convert to more mafic content it will transform to high dense phases that is garnet-pyroxene bearing assemblages. There are five different mechanisms that suggest how the deep crustal section can be studied. What are their five different mechanism? First is the large thrust sheet formed during the continent-continent collision. We know this continent-continent collision that will be studied in future classes but here just for your information once two continents they are colliding like India and Eurasian system. So here these two continents are colliding so large thrust sheets like this MFT, MBT, MCT all those thrust sheets they are coming from higher depth rocks to the surface or near surface.

So that's why you are seeing the higher crystalline rocks that is once upon a time that was formed at higher depth they're now to the surface exposed. So that means due to thrust migration this rocks once upon a time which was formed at higher depth higher pressure and temperature regime they are coming close to the surface or on the surface. Second method is the transpression faulting. Transpression faulting it is another mechanism which when we will talk about transform fault that we will deal with. So generally this transpression the name itself says it is pressure -compression that means there is a pressure regime.

So that means there will be one type of collision of two blocks. So due to high pressure these rocks from this lower regime they are coming near to the surface. So that is another method to study this deep crustal rocks. Third is the broad tilting of large segment of this crust. Tilting, tilting it is very common phenomena in tectonically active regions.

So here suppose one fault block is there it is bounded by two fault one block and at the one end we are overloading by thrust. So that means once we are overloading there will be tilt. So due to tilting the rocks of lower formation they're exposed near to the surface. So due to tilting if you see here these rocks are tilted and once it was formed in the lower stratigraphic horizon here they are exposed if I project it here there will be somewhere they will be exposed to the surface.

And fourth is asteroid impact. So if you see here we have asteroid impact craters like lunar crater, like Ramgarh crater, like in Dhala. So there are asteroid craters. Asteroid craters so here we're getting a cross-section where the lower crust rocks they are exposed near to the surface or at the surface. And the fifth one is the Xenolith. Xenolith if you see here this is xenolith these are the lower crustal rocks once upon a time that was formed at the lower crust during subsequent magmatic intrusion magmatic emplacement parts or the fragments of the lower crustal rocks they are exposed.

And they are exposed to the surface they are very good to study the lower crustal composition and mostly in the magmatic emplacement areas where this magma is getting emplaced these fragments of this rocks which were earlier it was in deeper stratigraphic regime they are coming to the surface. So these are the ways how this deeper crustal rocks can be studied. Additionally, we have collisional orogen, island arcs, continental rifts they are suitable places for studying the lower continental crustal composition. So here if you see there are different orogenic belts from where this deeper continental crust rocks were studied. So very common thing is that all block consists of chiefly felsic component at shallow structural level and mixed mafic intermediate and felsic components at deeper level.

So if you see all these orogenic belts they are placed around thousands of kilometer apart from each other. Very common thing is that the upper part if you confine yourself what is happening it is component mostly of felsic origin. However if you are going down this felsic and mafic they are intermixed. So that means it says the upper continental crust it is mostly of felsic dominated rocks and this lower and the middle continental crust it is mostly of a mixture of felsic and mafic component. Commonly lithologic and metamorphic features in uplifted blocks are persistent over lateral distance of thousands of kilometer.

So that means few minutes back we are talking about the tilting. So due to tilting in a tectonically active environment these lower regime rocks or the rocks which are formed at the lower stratigraphic level they are exposed and their aerial extent their aerial exposure it is about thousands of square kilometer or thousands of kilometer. So these are the way how the lower continental crust rock can be studied. Crustal xenoliths and fragments of the crust brought to the earth surface by volcanic eruptions. If you see here some of these xenoliths field photographs. So here these patches this represent the deep crustal rocks they are once upon a time was emplaced or formed at the deeper crustal level due to this magmatic emplacement they are coming as pieces.

If one can determine the depth from which these xenoliths come by thermobarometry that means it can estimate its relative abundance of various xenoliths population in the crust, it would be possible to reconstruct a crustal crust section. So now if you see here there is a term it is called thermobarometry. Thermobarometry means representing or determining the temperature and pressure of formation. Suppose we are getting a xenolith. So it is xenolith where when it is interacting with the surrounding magmatic system definitely, there will be change at the periphery at the rim.

Similarly there will be change in the rim there will be change in the rim part. However the middle part it remains unaffected. So that is why minerals there are certain minerals which are very characteristics to study the thermobarometry of the system. So that means we can determine at what temperature and what pressure ranges they were formed. So once we have different xenoliths in an area from that xenoliths we can calculate that this is the temperature and pressure and that this is the corresponding depth from where these were formed and from where these rock pieces are coming from this depth by magmatic intrusions.

So that's why by this way we can estimate what is the depth or what is the rock type at corresponding depth at the lower crustal regime. Xenolith bearing volcanics and kimberlites occur in many different tectonic setting thus giving a wide lateral sampling for the continents. So that means we have xenolith bearing volcanics and we have kimberlite. We know kimberlite it is a deep mantle origin. So once the kimberlite emplacing so it there are high chance that it will take the rock fragments which is coming in the way.

So that means deep crustal rock fragment that is very common in the kimberlite magmatic emplacements. So these provide direct evidence of the lower crustal composition. Lower crustal xenoliths from arc volcanics are chiefly mafic in composition and xenoliths of sediments are rarely present. So that means if you see here very peculiar thing these deep crustal xenoliths high-grade temperature metamorphic rocks high-grade pressure metamorphic rock they are very common in volcanic. However, the sedimentary rocks are uncommon because we know the sedimentary rocks they are formed at low temperature an pressure regime.

So at the high temperature once there it is placed under high temperature in magmatic system there are high chance that will be remelt. So that means that's why the sedimentary rocks are uncommon in this xenolith form but there are few but it is uncommon in xenolith form but this lower crustal xenoliths are common. In general xenoliths of mafic granulites are more abundant than felsic granulite suggesting that mafic composition of the lower crust. So that's why this mafic component this xenoliths they are more common suggesting that the lower crust is of more mafic composition than the felsic one. If we are taking the xenolith data alone it will be difficult to assign a particular composition to the lower crustal rocks.

Most of these xenoliths appear to be basaltic melt and their cumulates they were intruded into the under plated beneath the crust. So that means if you think about this lower crustal composition it is mostly of basaltic or it is mostly high-pressure and high-temperature metamorphic rock it is there. So that is there common as compared to the felsic systems or felsic rocks. So, thank you so much we will meet in the next class. Thank you.