Plate Tectonics

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Week - 02
Lecture - 08
Oceanic Crust- II

Ok friends, in the last class we were talking about the oceanic crust, its composition from layer 1 it is sediment, layer 2 it is the pillow basalt, layer 3 it is sheeted dykes and layer 4 it is gabbro and peridotite So, this class we are going to discuss about ophiolite which is close resembling to this oceanic lithosphere that we have discussed. Now we are making all those layers into a package and this whole package we are thrusting it or we are exposing it at the continental-continental collision system or at the subduction zone where at the surface this layers are exposed to us. ophiolite if you see this term ophiolite it is from this Greek term that is ophio means snake and lite means stone or in the other word you can say this term was introduced because the rocks were looking like snake skin. So, here for your information these are the field photographs and some ophiolite and here some of the snake skins. Now if you can see these color and texture wise they are closely resembling to each other. So, this total package of this oceanic lithosphere that is the sediment, pillow basalt, sheeted dykes then the gabbros and peridotites this all they abducted that means, it is up thrusted during the continent-continent collision or during this ocean-continent interaction and this abducted part it is called the ophiolite sequence and it is exposed above the sea level and often embraced at the continental rocks.

So, nowadays if you are going most of these continental-continental collision zone particularly if you go to this Indian context go to the northern Indian plate boundary that is the Indus–Tsangpo suture zone around this you will find number of places this ophiolite sequence are exposed. So, let us discuss in detail what exactly the ophiolite is and when it is emplaced, when it is up thrusted, what is its link or what is its compositional variation and how it resembles to the present day ocean basin or the oceanic lithospheric system. So, before going to that here some of this worldwide studies ophiolite sequence are listed that is starting from this Bay of Islands to Corsica here if you see this is the ophiolite sequence and you see this is the diagrammatic representation based on all these studies. So, this ophiolite sequence it is representing a complete sequence from top to bottom, this top one it is represent the pelagic sediment, abyssal, deep water fan, terrigenous and arc-type deposit.

So, this is representing layer 1 of this oceanic lithosphere if you remember the last class. Then the second one it is pillowed and massive lava. Pillow lava we have discussed in the oceanic lithospheric composition. Then this pillow lava has a transitional contact with the sheeted dykes. These are the sheeted dyke that we have already discussed the sheeted dykes are nothing these are the conduits the fracture zones through which magma is supplied to form this pillow at the surface.

So, then after the sheeted dyke it is again a transition zone this transition is to non-cumulate plutonic rock and diorite and plagiogranite that is the plagiogranite if you remember. So, this is the last one which being felsic which is intruded into the system that is the plagiogranite. Then we have mafic cumulates, ultramafic cumulates, ultramafic tectonites, metamorphic complex So, all these layers if you compare with the oceanic layers or oceanic lithospheric layers they are closely correlated. So, that means, that's why it is believed that the ophiolite sequence which are now abducted at this continent at the subduction zone or the continental collision zone they are nothing these are the remnant of this oceanic lithosphere and they are abducted during the ocean and continent interaction or the continent-continent interaction. So, here this ideal ophiolite includes from bottom to top as follows the ultramafic tectonites that is harzburgites, harzburgites is nothing it is one of this ultramafic rock which is composed of olivine and calcium poor pyroxene like the enstatite.

So, these two components they are the chief mineral constituents with the olivine and this enstatite they are the chief mineral component of harzburgites and mostly it occur as layers. If you remember this layered gabbro, so it is mostly occurred as layers and sometimes it is cumulates also. Now second is the layered cumulate gabbros and ultramafic rocks that is layered cumulate gabbro that the layered gabbro and cumulating gabbro or the isotropic gabbros. Then non-cumulate gabbros and diorite and plagiogranites. Then sheeted dyke or sheeted dyke, then pillow basalt, then oceanic sediment that is mostly pelagic and volcanoclastic.

So, that means if you see this layers and its composition it is very very very close to this oceanic system or the oceanic lithospheric system. Now this lower part of the most ophiolite is represented by the sheared and serpentinized ultramafic that is the harzburgite. Harzburgite if you remember it is nothing if the two cumulates that is olivine and this calcium poor pyroxene and which is sheared and serpentinized. Why sheared and why serpentinized? Serpentinized because of this percolation of water through fractures through pillow basalt So, it is serpentinized and sheared it is sheared because at the lower part of this lithosphere the system is moving with the asthenosphere. So, that means due to this movement that means lithospheric system at the base of the lithosphere the system is moving with asthenosphere.

Asthenosphere and lithosphere there is a shearing movement here. So, that's why this part is sheared and with the pronounced foliation. This foliation it is the layer-like appearance. So, this layer like appearance generally it is the compositional bending. If you remember we are talking about this layered gabbros.

So, this is nothing the compositional bending and lens of dunite and chromite occur within that harzburgite. So, lenses of dunite, dunite it is a monomineralic rock mostly it is composed of olivine. Then chromite as it is forming at high temperature this chrome spindle is there. So, that's why chromite is sometimes associated with that. So, that means at the lower part of this ophiolite sequence we are getting such information and it very important thing that it is sheared and it is serpentinized.

These tectonites are overlain by cumulate, ultramafic and gabbroic rock that have formed fractional crystallization. So, fractional crystallization within a magma chamber once it is crystallization starts olivines are percolated down then pyroxenes. So, that means collectively that form cumulate ultramafics and gabbroic rocks. Some ophiolite contain non-cumulate gabbros diorite and plagiogranite and the upper part of this non-cumulate zone. So, there are certain exceptions are also there.

So, may not be some everywhere there will be some cumulation there may be non-cumulate gabbros diorite and plagiogranites. The sheeted dyke complex it is lies above the non-cumulate gabbroic zone. So, although dominantly it is diabases dykes are there it range in composition from diorite diorite to pyroxenite. And in this composition it is a dyke thickness also varies from 1 to 3 meter. So, now, if you see here these are the dyke though this photographs can be tilted like this or rotated clockwise.

So, that you will find this is a dyke and we have chilled margin these are the chilled margin. So, chilled margin they are formed when a new dyke intruded into the old dyke. So, it is a cumulate environment where water is percolated down a new magmatic system is intruding to a relatively cool system and it is suddenly getting cooled due to this percolation of water. So, that's why this margin is chilled. So, it same happens in the pillow basalt also.

In the pillow basalt when it erupts it within the system the margin is chilled due to this water presence of water. So, that's why you will get a chilled margin a balloon-like margin at the periphery of this pillow basalt. Similarly, this chilled margin it is found in the sheeted dykes. So, one way chilled margin are common in sheeted dykes. So, a feature generally interpreted to reflect vertical intrusion in an oceanic axial rift zone where one dyke is intruded in the center of another as a lithosphere spreading.

So, that means one side it is chilled another side it is chilled. So, that means we are getting the chilled margin which is representing the subsequent dyke intrusion into the new dyke system. The uppermost unit of ophiolite is the ocean-ridge basalt occurring at the pillow and flows in a hyaloclastic breccia. So, this uppermost unit of the ophiolite is the ocean-ridge basalt and occurring as a pillowed structure. So, that we have pillow structures we know and we have hyaloclastic breccia that means broken into different pieces that is hyaloclastic breccia.

In the thickness of this unit varies from few meter to 2 kilometer and the pillows from honeycomb network of individual pillows arranging up to 1 meter across and a few dyke caught into pillow basaltic system. So, here some of these field photographs of the pillow now you see the arrangement of this pillow in such a way that it is forming a honeycomb structure and through this honeycomb structure somewhere the dykes are intruded to the system. Many ophiolites are overlain by sediments of a pelagic and abyssal or arc deposition environment. Pelagic sediments include radiolarian cherts, red fossiliferous limestone and metalliferous sediments and abyssal sediments. So, this all these sediments are nothing this is representing the layer 1 of this oceanic crust.

So, ophiolite it is emplaced and in the collisional origin may be of 3 mechanisms. What are the 3 mechanisms? First mechanism is the abduction or up thrusting of the oceanic lithosphere into a passive continental margin during continental collision. So, now you see we have one continent here and we have a ocean basin and here another continent here and it is the same ocean basin it is a common in the both system now both continental system they are coming close to each other and we have a mid-oceanic ridge here earlier. As now this 2 continental system they are coming percolate. So, that means, the oceanic layer here which was earlier now due to closure this of this continental system they will create folds they will be folded and gradually they will closed again it coming close to each other finally, there is more tightly folded and then it will be up thrusted that will be thrusted.

So, this continent-continental collision zone once this 2 continent collide. So, this up thrusted oceanic system which was earlier here now they are up thrusted and lying here as a ophiolite. So, this is the one of these mechanisms. Then second mechanism that splitting of this upper part of the descending slab and abducted of this thrust sheet into the former arc. So, now you see once we have a continental system and we have an oceanic system which is subducting down.

So, this subduction is not very easy. So, here it is a high-pressure environment. So that's why once it is subducting down and we are pushing it from this mid-oceanic ridge and here this system this continental system is there and the subduction so that means, there will be thrusting because it is not an easy process it needs tremendous force. So, that's why part of the system is thrusted up and it is remained here and it forms ophiolite And the third is an addition of a slab of the oceanic crust at the accretionary prism of this arc system. So, here we have a continental system and we have oceanic system and this is the trench and finally, we are creating an accretionary prism here.

That means, the sediment which was earlier deposited on this oceanic crust these sediments are scrapping of here and forming an accretionary prism. So, now this accretionary prism is here this is continent and the same mechanism which is discussed here that means, it is at high pressure zone or high stress zone. So, the part of the system is thrusted and this thrusted system this becomes a part of this accretionary prism. So, there may be the emplacement of ophiolite. So, these are the three possible mechanisms.

So, how these ophiolites are emplaced? Ophiolites usually occur in collisional origin and their association of the deep sea sediment, basalt, gabbros and ultramafic rock suggest that they are originated in the oceanic lithosphere and subsequently thrusted upon their continental setting by the process known as abduction. So, this abduction setting it is nothing moving up. So, as we have discussed in the previous slides every three mechanism. So, it is demonstrate that it is moving up rather moving down. So, this moving up of thrusted it is called abducted.

So, here at this continental-continental collision zone this system is abducted part of the oceanic lithosphere it is abducted now abducted. So, that's why it is called abduction. Similarity of this ophiolite with the oceanic lithosphere is supposed by the chemistry this metamorphic grades the presence of similar ore minerals and the deep water sediments. So, that means, if you remember our earlier slides here we are discussing all these systems that is defining the oceanic lithospheric composition and is oceanic lithospheric system which are discussed in the earlier class. So, that's why it is believed and it is really that the abducted oceanic lithosphere at this continental-continental collision zone is giving rise the ophiolites.

Now in Indian context if you see this geological map of India you see at this northern boundary of this Indian plate mostly the Indus–Tsangpo suture zone and other suture zones where this Indian plate is ending. Here this red patches are nothing these are the exposure of the ophiolites. So, that means, here we have this Indian plate and we have this Eurasian plate and this oceanic lithosphere representing the tethys ocean it is lying here and the Himalayan sediments that is nothing the tethys ocean sediment they are crumpled, folded, thrusted, metamorphosed and now forming the higher Himalayan system. So, that's why those red patches representing the ophiolite are nothing it is the abducted part of this tethys ocean which is already consumed below the Eurasian plate and this is the same one you see this distribution starting from the Indian plate one end to other end all these ophiolites then arranged in such a manner that is defining this suture zones orientation. Now, the question arises when it formed whether it formed during this continental-continental collision or it is before that or after that.

So, that to provide this exact date of a formation of your ophiolite worldwide number of ophiolite sequence that were dated and the subduction were also dated. So, it is found most of this ophiolite they are formed much before then the subduction starts before if because if you remember our Wilson cycle the Wilson cycle first it create a rift basin and with further rift it created a ocean basin and with further rift we are creating the mid-oceanic ridge system and this oceanic basaltic layer it forms started forming, but at that time started forming that means at up to that time there is no subduction. Similarly after also few million years there will be no subduction there will be only this spreading that means the new ocean basin is created the basaltic magma is coming out and it is pushing both side into opposite direction. Now, this to maintain this total area constant now somewhere this two blocks has to go down so, that's why the subduction starts. Now imagine this subduction is starting millions year after the formation of this oceanic crust.

So, now the oceanic crust is formed and there is subduction is not started. So, that means this area has to accumulate because the area have to compensate. So, there will be folding there will be thrusting so like that. So, that's why during that time the part of this oceanic lithosphere that is thrusted up, so, once they are thrusted up so now if you imagine here we have a mid-oceanic ridge here and we are filling it with basalt and we are putting it in two different directions. Now we have to subduct it here this ocean basin we are subducting it subducting it here and this is the continental system.

So, now imagine before subduction starts there will be some folding there will be some thrusting so, once it is thrusted up it is thrusted this is the thrusted block it is thrusted up. So, at the subduction zone these thrusted blocks they behave as a speed breaker. So, that once this uneven topography is created due to this thrusted up one of this oceanic lithosphere. once they reach at the subduction zone this part, this part, and this part they are separated here this is broken off they can chopped off. So, it remains there and this becomes the ophiolite this other lower part it is subducted down however the upper part is chopped off here this is called the ophiolite.

So, that means, ophiolite are forming much earlier than the subduction starts. So, that's why this dating of events indicates that the abduction of many ophiolites occurred very soon after the creation while the young and hot oceanic lithosphere is there. That means, during this oceanic lithosphere formation just after the formation ophiolite started forming because to compensate this motion to compensate the area increased area we are here however we have not created subduction so far. So, that's why to compensate that we are folding it to thrusting it like that. So, this ophiolite are much much much older than the subduction zone.

Continental collision however normally occurs a long time after the formation of a mid-oceanic ridge. So, that the age of the sea floor abducted should be considerably greater than the collisional zone orogeny. So, here some of this ophiolite sequence they are correlated also worldwide now it is correlated with the observed ocean lithosphere and you see all of this ophiolite sequence they are similar with the present day oceanic lithosphere. However the thickness may vary from place to place that we have already discussed the thickness that depends upon the rate of spreading, the magmatic supply, the sedimentary supply so like that. So, though the thickness of the ophiolites sequence varies from place to place but the layering and the order of layering it resembles to the present day oceanic layer or oceanic lithospheric layer.

Now if you see here the mid-oceanic ridge system and it is moving to oceanic plates they are moving from away from each other this is the transform fault which is separating and many of the ophiolites are altered and tectonized because of the way in which they are uplifted and emplaced in the upper crust. And in this graph if you see once this oceanic lithosphere is formed at the mid-oceanic ridge or the initiation of this mid-oceanic ridge formation the rate of magma supply is more and gradually with distance it decreases with time it decreases. Similarly the dyke intrusion is more and gradually it is decreasing. However, the half spreading rate is less and gradually it increases and it becomes constant. So, that means you see we have lava accumulation which is more however the spreading rate is less so that means there is accumulation, there will be abduction there will be folding so like that.

So, that's why before reaching to the subduction zone so this oceanic lithosphere is become thrusted, this is folded like this. So, once it reaches here this abducted part this is chopped up and remaining here as a ophiolite. So, there are more than one type of ophiolite. First one has the complete suite of units that means starting from the layer 1 to this mantle that is one suite and another is other consists solely of deep-sea sediments, pillow lavas and serpentinized peridotite. So, only the upper part remains and the lower part up to this oceanic lithosphere that is not there.

So, there is one group which is representing the whole another group which is representing only the fewer few meters or few kilometers depth. So, why it is happening? So, this is other consists solely of deep water sediment, pillow lavas and serpentinized peridotite with or without minor amount of a gabbro. If present these gabbros often occur as intrusion with the serpentinized peridotite, but in the here we have layered gabbro, we have isotropic gabbro, but here we are getting the gabbro which are of intrusive in nature. Why it is happening? Because this type of crust is thought to form when the rate of formation of this crust is very slow and is limited by gas supply rate is there. That's why we are not able to create the full-fledged and the ideal sequence of this ophiolite rather we are getting this type of second type of ophiolite where the gabbros are occurring as intrusives.

So, this type of environment is restricted to particular type of geological setting one is the vicinity of a transform fault at the low accretion rate. So, here if you see the transform fault here vicinity of this transform fault is the low accretion rate because it is consumed or it is compensated by the transform fault movement. And in the initial stage of ocean crust formation where non-volcanic passive continental margins are there. So, here also if you say at the initial stage of formation here this half spreading rate is less and gradually it is increasing.

However, the magma supply is more. So, these are this conditions where the second type of ophiolites are formed. However, the first type of ophiolite most of these oceanic ridges are characterized for. Because of this oceanic Moho is exposed in many ophiolites it is better known as continental it is better known than the continental because continental Moho it is hardly exposed somewhere because it is a depth of about 40 kilometers. And this ophiolite the oceanic layers or the oceanic Moho it is exposed there. So, that's why these Moho's characteristics compared to the oceanic system and this continental system the oceanic system Moho is much more understood as compared to this continental Moho's.

Studies of ophiolite and P wave velocity measurements are consistent with the basement and oceanic layers. Being composed largely of mafic rock metamorphosed to the greenschist and amphibolite facies. So, when it is altered or metamorphosed this says that this metamorphism occured up to greenschist facies phases or amphibolite facies. Although ophiolite contain minor amount of ultramafic rocks and felsic rocks they are much less variable in lithologic and chemical composition that says that this oceanic crust is rather uniform in composition.

So, that is the beauty of this ophiolite. So, it says about the present day oceanic lithosphere, it says about the past abduction system it is past subduction zones present. So, like that in mineralization what is happening here what is the magmatic properties which is magmatic mechanism which is going on at the lower crustal level depth or the mantle level depth. So, that can be studied from this ophiolite sequence. And now if you are coming to this ocean basin component.

So, this ocean basin it is there are different components. So, one component is the mid-oceanic ridge. This is the mid-oceanic ridge where the new oceanic lithosphere is being created. So, that means, the crust the Moho and this upper part of the mantle which are created here. And this created oceanic lithosphere it travels up to the subduction zone and where it descends down and it is contributing formation of this asthenosphere and again it recycled here so, this system it is behaving as a conveyor belt. Next is the ocean basin, the ocean basin itself it is geography, it is sediment, it is depositional environment, it is tectonic setting all this the other components of this oceanic crust.

Then the volcanic island you can say the volcanic islands are here. Once this system or this lithosphere descends down and it is partial melting takes place here and due to partial melting here the magma rises and forming the island arc magmatism apart from that within that ocean basin we have some hotspots as we know it is D-double prime layer where this magma is derived and this is also one component of the ocean basin. Then it is a trench once it is subducting down here the deepest part of this earth's crust that is the Mariana trench is there where this is also one component of this ocean basin. Then the back arc basin, the back arc basin is somewhere here if it is subducting down a new ocean basin is created and this is called the back arc basin this becomes tectonically active with later times. So, these are the components of this oceanic crust and within tectonic setting these different components they behave differently and it says its own uniqueness that how this tectonics from one region can be distinguished from other.

So, in the later class we will talk in detail about these different components what is their role in plate tectonics, what is their mineralization and what is their fault formation or this basin formation, hydrocarbon formation or other aspects too. So, thank you very much we will meet in the next class.