Plate Tectonics

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Week - 05
Lecture – 25
Destructive Plate Margins- I

So, friends good morning and welcome to this class of plate tectonics. So, if you remember up to the last class, we have covered the constructive plate margin as well as the conservative plate margin. And in today, we are going to discuss about the destructive plate margin. Before going to destructive plate margin, we must recall when we were talking about the assumption about the plate tectonics, it says the Earth's total area remain constant. And once it says the Earth's total area remains constant, so that means in this constructive plate margin, we have created certain part of this plate or mostly the oceanic part so, once we have created to maintain this total area constant, so we have to destroy it that so that much proportionate way we have to destroy it. So, that's why the destructive plate margin will give us insight how this area is destroyed and how this total area of this Earth remain constant.

So, in that case, if you see these three diagrams, so here one plate is undergoing an another plate. Similarly, here see one plate is undergoing another plate. However, in the third one, here neither of these two plates they are undergoing rather they are colliding here as a result, you are showing that this area it is compressed and there are mountains being developed. So, this is the mountain building activity is going on here.

So, what does it mean? So, destructive plate boundary, it happens when the two plates they move towards each other and interact. For example, here if you see this is one plate and this is plate number 2 and these two plates they are moving and this movement mostly it is governed by and it is propelled by this convection current. Here below this plate, this mantle convection will be here and this plate the mantle convection will be here. However, this convection current will be of two different directions. For example, this plate which is moving in this direction, this convection current will be like this anticlockwise, but here this plate which is moving in this direction the convection current will be clockwise.

As a result, two plates they come close to each other and start interacting but either of these two plates which one is heavy that will move down. So, here this side or this plate number 2 is heavy that's why it is going down. So, now if I extend this down going plate to in this direction so that means somewhere I have a mid-oceanic ridge here which was created from this place and it is going down and it is subducting. So, that means this much area which was added to the earth's surface it is now consumed by down going slabs and here whatever this area was there suppose this is the continental crust and this is another continental crust and this side there will be if I extend this plate in this way there will be oceanic system here and there will be oceanic system here. So, here will be a mid-oceanic ridge, this side will be a mid-oceanic ridge and through this mid-oceanic ridge the plates are created.

As a result, this type of this side of this continent is pushing this way and this side of this continent is pushing this way and these continents they are converging towards each other and they are colliding with each other and as this continental plates they are of low density compared to this mantle. So, neither of them they can subduct down because the mantle is here which is high-density material and this continental crust it is of low-density material. So, if I am putting this continental crust down, so there will be opposite force that is the buoyancy force that will push it opposite way. So, that neither of this continental plate will move into the mantle as a result they remain at the top surface and they collide with each other and due to collision there is mountain building activities is going on here. So, that means, I want to say either it is continental plate or it is oceanic plate.

So, once they are moving towards each other they started interacting as a result of interaction there is a destructive plate boundary that is developed. So, the term destructive plate boundary itself it is self-explanatory that means it says one plate is being destroyed or either of these two plate one destroyed first and the rest one will be destroyed second. So that means the net destruction takes place in the area. So, that's why it is called destructive plate boundary. So, destructive plate boundary or the other way it is called convergent plate margin that means two plates are converging towards each other that develops when two plates move towards each other and interact.

So, this is the zone where the old, cold lithospheric plate descends or it subducted into the earth's mantle. Here this is the cold and old lithospheric plate because once I am creating a mid-oceanic ridge here from this mid-oceanic ridge this plate is moving in this way and this plate is moving this way and this is the new part or that the mid-oceanic ridge the newest version of the plate is generated. So, once you are moving away from the mid-oceanic ridge. So, suppose for example, here is the subduction this plate is subducting. So, this part is the oldest segment of this plate.

So, that's why it is called the old and cold oceanic lithosphere because at here with the mid-oceanic ridge this is the magma source there is the heat source is here so, once we are moving away from the mid-oceanic ridge we are moving away from the heat source that's why this plate getting more cooler and cooler once it moving away from the mid-ocean ridge system. So, that's why here once this plate is reaching at the subduction zone it is the oldest segment of that plate and is the coldest segment of that plate. So, that's why it is the old and cold lithospheric plate which is descending or it is subducting down into the earth's mantle. So, once it is moving into the earth's mantle. So, it has some changes in composition, it has some changes in its thickness, it has changes in its mineralogy.

So, it is changes in its rigidity and there are number of changes is occurring. So, that changes that will define what type of magmatism will be there what type of metamorphism will be there and what type of mineralization will be there. So, all that is governed by this interaction between this mantle and the down going plate and the pressure-temperature regime this angle of subduction. For example, here this plate if you see this subducting this plate it is subducting at a lower angle relative to this here around it is 45 degree or so, here about 20 to 25 degree or so. So, this angle of subduction also it defines what type of magmatic activity will be there, what type of metamorphic activity is there, what type of seismicity will be there, what type of deformation will be there.

So, that means I want to see all these geology, geophysics, geochemistry, geomorphology and everything at this subduction zone that is depending upon this temperature-pressure regime this is the angle of subduction and what type of plate is undergoing. So, now if you see this global tectonic map, you see this plate boundary they are defined either it is by these arrows which are moving away from each other for example, here so, these are called the divergent plate margin or the mid-oceanic ridge system that already we have covered. And here this is if you can say these two arrows they are moving slight past each other these are the conservative plate margin that part we have covered. But here you see these two arrows are facing towards each other opposite to each other that means this is the convergent plate margin this is the convergent plate margin so now, if you see all around this pacific ocean if you are moving most of these convergent plate margins they are distributed throughout. Apart from that there are convergent margin which is occurring here and in this India and Eurasian system and number of other systems are there.

So, there are three types of convergence based on this depending upon this which type of plate is converging down. One is the oceanic is the oceanic convergence that means, one oceanic plate it is converging under another oceanic plate for example if you see it is here one oceanic plate here another oceanic plate is here and here one oceanic plate another oceanic plate so, this is oceanic-oceanic convergence for example, here you see one oceanic lithosphere it is undergoing for another oceanic lithosphere this is also oceanic this is also oceanic another type of convergence it is called oceanic continental convergence. Oceanic one plate is oceanic and another part is continental. So, this oceanic plate being it is heavy so, it is subducting down under the continental lithosphere. Because, we know this there is a density difference between basalt and granite to granodioritic and this continental plate mostly it is composed of granitic to granodioritic composition and the oceanic plate it is mostly it is basaltic.

So, that's why being it is heavy so, it is going down under this continental lithosphere. So, this is oceanic and continental convergence. Another is continental-continental convergence that means, two plates are continental. So, neither of this plate will move down. So, that's why this plate and this plate they will collide with each other and finally, we will get this collisional mountain system like the Himalayas.

So, India plate and Eurasian plate they are colliding here and giving rise the Might-Himalaya mountain system. So, that's why these first two that is the oceanic-oceanic convergence and oceanic-continental convergence this first two give rise the occurrence of subduction zone. Subduction zone; however, this continental-continental convergence it will give rise collisional zone. So, there are difference one is subduction zone another is collision zone. So, collision means simply just hitting each other none of them are going down but subduction means one is going down and mostly which one will go down? the oceanic one if it is the oceanic-continental is converging that oceanic will go down the oceanic plate that will move down that's why this is called subduction zone.

And in two oceanic system which one is older and thicker compared to this two oceanic system which one will be older and thicker that oceanic plate will first move down then the rest one. So, that's why the oceanic plate once it is involved in the system that means subduction zone occurs. So, this continental plate if these two plates are continental origin then collisional zone occurs So, subduction means to be pulled under. So, pulling under occurs when one is heavy. So, the heavier one that is pulled down.

So, that's why the subduction zone occurs. So, let us see what is the example or the global example of the oceanic convergence. The best example is the Philippine plate it is converging under the Pacific plate. For example, here we have Pacific plate here and we have Philippine plate here. So, this is Pacific plate is going down under the Philippine plate.

So, the result is you see this result is the deepest trench in the world that is the marina trench. And this Mariana trench is so deep if you see here there is a comparative study between this the deepest trench of Mariana and the tallest mountain in the world is the Everest. So, if you are putting this Mount Everest under this Mariana trench still this much water depth is left. So, that means the whole mountain of the Himalayan mountain whole peak that is the Everest peak that will be submerged under this Mariana trench it is so deep. So, it is around 11 kilometer and this Mount Everest is around 8.

5 or 9 kilometer. So, that means 2 kilometer water depth still remains it is there. So, this is the Mariana Trench it is the deepest trench of the world it is a product of oceanic-oceanic convergence where the Pacific plate is undergoing the Philippines plate. When the oceanic-oceanic convergence takes place island arcs occur this island arcs means if you see here once this Pacific plate is going down so, it will reach the mantle. So, once it is reaching the mantle it is melting takes place. So, due to melting that magma is generated and that magma which is erupting in terms of volcano.

So, you will find number of volcano if you see this digital elevation model here these dots they are nothing they are the volcanoes. So, volcanic islands are there. So, this volcanic island this is called island arc. Why it is arc? that we have already told we have already been discussed that arc is nothing this is the arrangement in terms of a curve that is called arc. So, if you see here this arcs or this volcanoes they are arranged in terms of curve and this curve if you see it is convex towards the downgoing slab this slab is down going so, it is convex towards the down going slab that's why it is called island arc these are the island volcanic island and they are arranged in a arc fashion it is a curved fashion that's why it is called island arc.

Now another type of convergence that is called oceanic-continental. So, here the oceanic plate is associated that's why we are expecting one subduction zone here. So, if you see this cross-section here we have this Pacific Ocean the eastern margin here the Nazca plate it is subducting under this South American plate. So, South American plate it is a continental plate and this is the oceanic plate. So, that's why this oceanic plate is undergoing under the continental plate because it is heavy.

So, that's why we are getting this Peru-chile trench here at the eastern part of this Pacific and at the western part of the Pacific we are getting this Mariana trench and with the eastern part we are getting this Peru-chile trench. So, here the example is western coast of South America here this Andes mountain is Andes mountain chain is here and here this Nazca plate which is undergoing this South American plate once it is reaching here it is melting takes place. If you see here this due to melting these volcanoes are developed. So, we have a series of volcanoes they are arranged at the west coast of South America and that is called the volcanic arc. In here we are telling it we are giving this name it is island arc because these are the island within the ocean.

So, that's why we call it is island arc. However these volcanoes thereof continents. So that's why we use the term it is called volcanic arc. So, volcanic arc and island arc the similarity is that both are in arc form. Both are formed due to this melting of this mantle once this plate subducting down.

However, once it is in the continent we say it is volcanic arc if it is in the ocean we say it is island arc this is the basic difference. Then another type of convergence that is called continental-continental convergence that is more famous for this Himalayan system in Indian subcontinent context. So for example, this is the Himalayas. So now imagine before this onset of this Himalayas for example the age of the Himalayas it is around 55 million years. So if you remove 55 million years from the geological time scale there was no Himalayas so in the place of Himalayas there is an ocean existing that is called Tethys ocean this is the Tethys ocean if you see this Tethys ocean was existing now this Indian plate which is moving towards northeast direction and the Eurasian plate which is moving towards south.

So these two plate once they are converged towards each other so this intervening Tethys ocean it is squeezed and due to its squeezing so gradually its size decreases the width decreases and finally once the two plates they came close to each other and this system this is the Tethys ocean system this was totally vanished. So imagine when there was an ocean existing there are sediments there is shallow water facies to deep water facies. So whatever the sediments were deposited now they are folded, faulted, thrusted due to this collision and finally they are representing the Himalayas. So the Himalayan mountain system if you go to this higher Himalayan system you will get this sedimentary rocks they are limestone and dolomite whatever the sediments that were deposited there now they are having and their fossil content is very heavy. So how we can expect the fossils or the particularly the marine fossils at the mountain system so this is the result this the collision between the India and Eurasia when this oceanic system or the Tethys was vanished and finally we are having this Himalayas here so that means once the oceanic part it was earlier subducting down because this is the oceanic system so we had this oceanic lithosphere so the oceanic part it is subducted down so that due to the subduction this continental system of India and the continental portion of this Eurasia they came close to each other so that was continental collision then occurs so due to this continental collision neither of the plate can move down so that's why there is bulging occur and due to this bulging so this Himalayas is the result of this collision.

So subduction zones are formed when oceanic plate is forced below another oceanic or continental plate where both plates are oceanic either one may subducted under other and sometimes depending of the local condition. Local condition means the thickness, the age, the sedimentary thickness so all that things that decide whether which plate will move down first and this basic rule is that the heavier part will move down so which one is heavier among these two that will move down so particularly either of these two oceanic system one will be older and another will be younger so it may possible that older becomes lighter due to less sedimentation and this younger becomes heavier due to high sedimentation in that case always and always the heavier one it is moving down and the polarity of subduction may reverse that means if you see here this how this polarity is reversing suppose these are two oceanic system they are moving towards each other. So this one is thicker and heavier for example and this side it is bounded by this continent this part is only oceanic system and this part is the continent. Now these two oceanic system they are coming close to each other so this is being heavy that is will move down. So now we have a subduction zone here for suppose this is plate A and this is plate B so now this plate A is moving down under plate B.

So now if this subduction is going on and this total oceanic system is consumed so now this total oceanic system once it is consumed now this oceanic system and this continental system they will come close to each other. And finally this compared to these two one is one side is continent another side is ocean see the ocean will be heavier and it will move down and under this continent so that means at the first the subduction zone was dipping towards west and this second the subduction zone is dipping towards east. So we have a subduction zone polarity change in one case it is moving in this way and another case it is moving in that way that's why the polarity of subduction may reverse. So that is the subducted plate break off and subsequently becomes the overriding plate and whilst the which was overriding begins to subduct that we have already discussed. The subduction and collision zones are the areas of active mountain building on the continent characterized by broad and almost continuous zone of deformation.

Why? If you see this collision zone or it is subduction zone here we have a subduction zone this is the Peru-chile the Nazca plate is going down and here we have the continental-continental collision this is the Eurasian system and this is the Indian system they are colliding here. So these are zones where mountain building activities they are in the continent we have mountains we have Andes mountain here in the continental system. We have Himalayan mountain system at the continental system and characterized by broad and almost continuous zones of deformation. This is a continuous zone because this plate it is a very large plate which is moving down similarly, it is the large plate which is moving down we have a subduction zone existing here we have a subduction zone existing here but this side is a collisional zone because this part this oceanic system is still existing that's why this subduction zone is here similarly this is the subduction zone here but this is the this part this oceanic system is consumed only the collision zone. So, this is the large scale at this you can say it is around 3000 or more than 3000 kilometer length.

So, this is the continuous zone of deformation and partly because continental lithosphere is weaker and more easily deformed than the oceanic lithosphere partly because it is low density and not easily removed from the subduction. So, these are the two reasons that's why this continuous deformation is going on. One is continental lithosphere is weaker another thing it is the low density so that it cannot move down that's why this is showing this continuous zone of deformation for a large distance. Now, the surface expression of a subduction zone is the deep oceanic trench on the oceanic plate and the line of volcanoes or the overriding plate may be island arc or volcanic arc that we have already discussed. So, this one plate which is going down over the oceanic plate and here this the deepest part of this ocean that is called the trench.

So, this is the surficial expression. So, in the bathymetric studies when we say this is the deepest part of the ocean so there may be a chance that is a subduction zone probably it is existing there. So, this surface expression it is representing by the deep oceanic trench and there is a line of volcanoes. For example, once plate is moving down here it is melting here partial melting taking place at the mantle system. So, due to this partial melting on the mantle it is creating the volcanoes here and these volcanoes they are arranged parallel to the subduction system. Here if this is the line of subduction so this volcano is parallel to that.

But the distance of this volcanoes from the trench that depends upon number of factors. For example, the angle of subduction and the depth of partial melting. So, like that there are number of factors we will discuss in the later classes. Remember that there is parallelism of this arrangement of the volcanoes and the subducting system or either it may be in island arc or it may be volcanic arc. That means volcanic arc which is the volcano occurring at the continent and island arc the volcanoes that are occurring at the oceanic system.

Then accretionary prism of different size are developed at many subduction zones where other shows erosional structures. So, in the subduction zone there are two types of subtraction. One is called the accreted part that is called accretionary prism. What is that accretionary prism? At the accretionary prism it will take itself at a class, but here just for introduce you what is the accretionary prism. Remember here is a lithosphere of oceanic origin it is going down.

So, this was the oceanic lithosphere. So, at the oceanic lithosphere we know this layer 1 it is the sediment and layer 2 that is the basalt pillow basalt and then sheeted-dikes. Then we have this gabbros that is isotopic gabbro, then layer gabbro, then peridotite. This is the oceanic lithosphere opiolite sequence you can remember. So, here this layer 1 is sediment. So, sediments that means part of the sediment may be consolidated it is intact with the low-lying basalt and part of the sediment may be unconsolidated.

So, once this plate is going down so, this unconsolidated part of the sediment that is scraped off. So, due to scrapping of the sediment this scraped off sediments that accumulate here and forming a prism-shaped body with more and more sediment scraped off it is accumulated and forming a prism shaped body and that is called accretionary prism. Accretion means addition. So, this prism is formed due to addition of sediment more and more addition of sediment which was scrapped up from the downgoing oceanic lithosphere that is called accretionary prism. So, accretionary prism may be of different size that depends upon the amount of sediment Suppose, the oceanic lithosphere which is subducting down having less amount of sediment for example, the Pacific.

At the Pacific is surrounded by this trenches all side. So, hardly any continental sediment reaching at the deeper side or the open ocean body of Pacific. So, that's why in the Pacific system we have very less sediment. However, this Atlantic which is surrounded by continent in all sides. So, that's why there is high sedimentary input into this Atlantic system. So, now if the sediment amount is very less so that means, it is going down.

However, the sediment due to lack of sediment the accretionary prism which is formed it is of a smaller size. However, if the sediment amount is more here in this oceanic lithosphere. So, more sediment will be scrapped up here and finally, it will form a higher size of accretionary prism. So, that's why the accretionary prism the size that develops the different size which is developed the difference of the amount of sediment accumulated there. And if you see this global tectonic map here part of this convergent margin it is showing this triangles which are filled and part of this convergent margin it is showing the triangles are open.

So, this open triangle and this closed triangle have some significance. So, accretionary margins are indicated by solid bars which are this one and erosive margins are by open barbs. So, this area which is representing erosive margin and this area that is representing this accretionary margin. That means, if you see here this is close to continent and that's why the sedimentary input is high. So, due to this high sedimentary input whenever this plate is subducting down in the trench.

So, the sediment is scrapping up and finally, it is forming a accretionary prism. However, if you see this part. So, this plate is going down and it is far from continent and these are the trenches so, that's why there are lack of sediment here. So, once it is moving down here there is no sediment. So, once there is no sediment so that means, only a trench open trench is there without any sediment.

So, that's why if you see imagine here this is the overriding plate and this is the undergoing plate and here there is no sediment. So, there is a open trench. So, once there is open trench. So, there is a chances that there will be sliding of this part and slide it down here so, that is erosion.

So, this erosion, erosion margin it is expressed here. So, these areas which are represented by open triangle they are representing the erosion margin whereas, the solid triangles they are representing the accretionary margins. So, here this is shown how this accretionary margin and the erosion margins are formed if you see here. The sediment which is moving down it is scrapped off gradually if you see this sedimentary thickness is increasing the accumulation of sediment is increasing and finally, we are creating an accretionary plate margin or accretionary that is called accretionary triangle or accretionary prism is there. And here if you see we do not have sediment here. So, once we do not have sediment here so that means, once it is going down here that is eroding.

So, because you see this basaltic system that is highly rough system once this rough system is going down it is eroding the lower part of the overriding plate. So, once it is eroding the lower part of the overriding plate so that means this part it is subsiding. So, due to subsiding there are normal faults or there are fault system developed and due to this fault system developed this material it is moving as a landslides or so and it is reaching here at the trench. So, that's why this area is representing erosion. However, if we have much sediment here so, the sediments are scrapped up and due to scrapping of sediment here we are creating a sedimentary prism here and that sedimentary prism it is providing a support to this overriding plate.

So, this due to this providing support there is hardly any subsidence here and due to lack of subsidence so, there will be no erosion. So, here there will be erosion here there will be no erosion. So, that's why it is called accretionary margin and it is erosive margin and this is here it is shown in the animated version. So, the sediment which is the yellow part which is scrapped up here and gradually the size is increasing and that's why it is supporting not to slide the overriding plate so, that's why it is called the accretionary margin. and some facts about this subduction zone, the sites of destruction of downgoing lithospheric plate better known as subduction zone or collision zone.

So, it depends upon the type of a plate involved. Subduction zone where this oceanic plate is involved, collision zone where only the continental plate is involved. Here at least one oceanic plate is involved and it is defined by highest depth of the ocean basin at the trench that we have discussed. This trench which is the highest bathymetry in the ocean basin. So, that is the highest to depressed part is the mariana trench and the destruction of oceanic lithosphere formed at mid-oceanic ridge.

So, at the mid-oceanic ridge when we are creating some area. So, that area is consumed here at the subduction zone. Then formation of new rocks by igneous activities as we have discussed that once this plate is going down here it is melting and partial melting take place and here igneous activities and new rocks are formed in volcanoes. Sites of important mineralization and metamorphism, these subduction zones they are good for mineralization and metamorphic. So, both mineralization in terms of igneous activity and mineralization in terms of metamorphic activity and these are this area where the new sedimentary basins are also formed.

So, the sedimentary basins are more prone to generate petroleum hydrocarbon. So, that's why subduction zones are very important in terms of nation building in terms of wealth addition to this national wealth. So, formation of new sedimentary basins we have fore-arc and back-arc basins developed at the subduction zone and what is the forearc basin and back-arc basin we will take separate classes for that and it is characterized by deep focus earthquake that means high seismic zone. So, if you see this Himalayan system it is deeper seismic event is there very recently 190 kilometer seismic event just 4, 5 days back we have 190 kilometer that is the hypocenter that the depth of or the focus it is 190 kilometer or so. So, that means these are representing the highest that means a focus that mean depth earthquakes. However, if you remember our earlier class when we were talking about this divergent plate margin they are represented by shallow focus earthquake.

And in the conservative plate margin this earthquake depth may be up to 20 kilometer or so. So, that means compared to other type of plate margin this convergent margin is characterized by deep focus earthquakes. And here is in a ideal diagram of this subduction zone here one plate is subducting down and this is creating this back-arc basin here. So, this is the magmatic arc and back side of this arc whatever the sedimentary basins are formed that is called back-arc basin and it is at the front of this volcanic system volcanic arc whatever the sedimentary basins are formed this is called fore arc basin. So, we have sedimentary basin both forearc basin and back-arc basin and we have this volcanic system that is volcanic eruption mineralization.

And once this plate is going down it is going from a cool environment to a hot environment so, there will be metamorphism in the down-going slab and as well as when there is magmatic activities here there will be contact metamorphism here. So, both we have sedimentary minerals sedimentary deposits as well as metamorphic minerals we will have primary igneous minerals. So, accretionary prism is developed here and this is the trench where this sediment is accumulated to form this accretionary prism and this is changing the convection pattern of the system because if you imagine before this plate is subducted. So, this convection pattern was like this it was moving in this way and this convection was in this way.

So, this was clockwise this was anticlockwise. Now once we are putting a plate here so that means, this convection cycle which was earlier of this much size now it is forming an obstacle. So, that's why there is a restriction of this convection system there is a change in the mental convection system that occurs. So, here this is the ideal diagram of this subduction zone but not all components are present in every system. So, whatever this you are looking here so, all these components may not be present in all type of convergent plate margin some may be missing.

So, this is all about this introduction about this convergent plate margin. So, thank you very much and we will meet in the next class. Thank you.