Plate Tectonics
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Week - 06
Lecture – 27
Destructive Plate Margins-III, The Island Arc System

Okay friends, good morning and welcome to this class of plate tectonics. So, if you remember our last class, we were talking about the destructive plate margin and where the lithosphere is subducted, it is destroyed. So, that is why it is called destructive plate margin. And in the destructive plate margin, there are number of elements. So, we were talking about the trench system where the oceanic lithosphere subduct down into the mantle or the asthenosphere and associated with this subduction zone, there are number of geological features and we will talk about these features one by one. And today's topic is the island arc system. So, what does it mean to you? This island arc, this term is itself explanatory.

For example, if you see here, this term island is used and arc is used. So island, so that means you can see here, this is the ocean basin and these are the islands are there and this is the island which is forming here due to volcanic, that is volcanic island and arc, the other term arc means it is a curved one. So, that means the arrangement of volcanoes, if you see this is in a curved fashion. So, you can draw a curve like this.

So, that is why it is called arc and island that means within that ocean body and arc that means the fashion of arrangement it is in a curved manner. So, that is why it is called island arc. So, this island arc, they are formed when the oceanic lithosphere is subducting under another oceanic lithosphere. For example, here if you see, we have one oceanic lithosphere which is going down and once it is reaching at the asthenosphere due to sufficient temperature, pressure, there will be devolatilization. So, this partial melting taking place here and whatever this magma is generating that magma is erupting and creating volcanoes and these volcanoes are rising above this ocean floor and is creating an island.

So, here one oceanic lithosphere it is subducting under another oceanic lithosphere, this side is oceanic lithosphere, this side is also oceanic lithosphere and they are the principal way by which the continental growth is achieved. So, how this continental growth is achieved by this island arc system or this lithospheric subduction let us talk about. So, now imagine we have one oceanic lithosphere here and this side there is continent for example and here we are putting this oceanic lithosphere below and finally, there is these volcanoes with time we will have the back arc basin that will generate this side and this back arc basin there is an extensional basin. So, this part will move in this way. So, once this part is moving in this way, this volcanic system and whatever the other volcanic system that will regenerate here that will amalgam here with this system.

So, finally, there is a zone where this amalgam volcanic system they are associated with the other lithospheric system and that is why this continental growth can achieve. And detail about this continental growth and this amalgamation of the different elements of this subduction zone, we will talk in the topic of orogeny and epi-orogeny. How the orogenic system develops in a subduction zone that will be detailed discussed in that class. So, here if you see this distribution of the island arc system in the global tectonic map, here you see they are typical of the margins of shrinking oceans. That means those ocean basins which are subducting down these island arcs are forming there.

For example, if you see this Pacific, we know this Pacific is subducting here and also the Pacific is subducting here. So, that is why most of these island arcs they are in the Pacific So, majority of these island arcs are located here, particularly in the western Pacific. Apart from that, we have the western Atlantic here there are few island arcs are also associated. So, most of these island arcs they are just around the Pacific and few of them are here and there are other island arcs also present where this oceanic lithosphere is subducting under another oceanic lithosphere system. And if the oceanic lithosphere is subducting under a continental system, for example, here this is the Peru-Chile trench and this Andes mountain is here.

Here the oceanic lithosphere that is the Nazca Plate it is subducting on the South American Plate. Here we have these volcanoes, they are associated, but these volcanoes they are not in the ocean, they are in the continent. So that is why they are called volcanic arc. Again the arc term is used because this arrangement of these volcanoes they are in this continent, but it is in curved form. So that is why this arc term is used.

So we will say it volcanic arc and once these volcanoes they are erupting on the ocean, we say it is island arc because they are creating islands. All these components of the island arc systems that are usually convex to the underthrusting oceanic lithosphere. For example, if you see this is the Japan arc and this is the Pacific which is subducting down and you see this curvature. So they are convex towards the under thrusting ocean. This is the Pacific which is under thrusting under the Philippines Plate and this under thrusting ocean for example, here if you see the Google Earth image, here this is the

Mariana Trench and this Mariana Trench is somewhere here and this is the arc and this is the Pacific Plate which is going and it is subducting down here this one, the subducting down under the Philippines Plate and that is why it is the arc shape and the convexity is towards the under thrusting plate which is undergoing.

And the convexity may be a consequence of spherical geometry of earth. For example, if you see here we have divided the earth into different spherical cells. If you remember our earlier class when talking about this lithospheric plate, they are like curved caps. So now imagine one curved cap is here and it is undergoing another curved cap. So you are looking from the top.

So this intersection it is the curved one and this convexity is towards the underthrusting plate. So that is why the convexity may be consequence of spherical geometry of this earth or spherical geometry of these plates which are undergoing and which are also over thrusted. So this can be explained here how this radius of curvature that varies with different island arc system and that can be explained here by this ping pong ball theory. For example, suppose there is a flexible spherical cell is indented at an angle theta. This is the angle theta.

So one plate is going here and it is subducting down. So this angle is the theta. So that means the angle of subduction. Suppose imagine this is the cross section of this earth and one lithospheric plate, this is the blue one, it is going down and it is subducting here. This is the angle theta or that is the angle alpha here.

So here suppose it is subducting at an angle alpha, the indentation is a spherical surface with a same radius of this curvature of the shell R. So that means here this indentation is there and if you see this angle of subduction here if you take this one, so this will be the radius of curvature R which is similar to that. And the edge of this indentation is a circle whose radius R is given by half R alpha where alpha is in radian. So this curvature, what will be the curvature of this system? This curvature is the R where this R is half R alpha. And if this theorem is applied to the plate of earth surface, the alpha represents the angle of underthrusting and the oceanic lithosphere which average angle is around 45 degree.

If this is so, then what is happening? That means we are getting a radius of curvature around 2500 kilometer if the angle is 45 degree and the radius of earth is this is kilometer. So if you are taking this value, then a plate which is subducting at 45 degree angle that can create a radius of curvature that is of the arc that is 2500 kilometer. So the radius of curvature of the trench and the island arc on the earth surface depend upon the angle of subduction. So if the angle of subduction varies, then this radius of curvature is varies. And in the global scenario, if you see this angle of subduction of different plates, so it is varying from 10 degree to around 90 degree.

So that means according to this formula, so this radius of curvature should have a variation around a wide range depending upon the angle of subduction. But this formula, though it is used for this average angle of subduction and is based on this observation, but many case it is mismatching. So that means there is some other factors that are also responsible for influencing this radius of curvature and the angle of subduction. So that is why this value is in agreement with some but not all island arc system. So that means this formula whatever we are using, this radius of curvature should be this is for example, it is proportionate to this angle alpha, this is the angle of subduction, but with some it is agreeing, but with many it is not agreeing.

So that is why there is some other reason which is also influencing the angle of subduction. For example, this angle of subduction of under thrusting of the mariana arc is around 90 degree, but it has one of the smallest radius of curvature. So that is why this formula is not applied everywhere. So island arcs can either be active or inactive that based on the seismicity and volcanoes. So it may possible that this island arc is inactive or active.

So if frequent seismic activities is going on here, the volcanoes are active, then we can say yes this is an active island arc system. But there are many island arc system that was representing the past subduction zone there nowadays it is extinct. So those are the island arc system but not in active form. So active island arc processes a distinct curve form of a set of features. So these features one is the flexural bulge, another the recently extinct volcanoes, third is the deep sea range, fourth is the accretionary prism or accreted prism.

So these are the element of an island arc system. So island arc system it is a set of system, a set of elements they are placed one after another and those systems they are combinedly forming this island arc. So island arc system is a combination of many features. So these are the different elements one is the flexural bulge would be there, then volcanoes should be there either active or recently extinct, then deep sea trenches should be there, then accretionary prism should be there. Out of these four elements we have already discussed about the deep sea trenches in the last class.

The remaining these flexural bulge the recently extinct or the volcanoes and the accretionary prism we will discuss in this active island arc systems. So first is the flexural bulge. What is the flexural bulge? Why this flexural term is used and why it is bulge? Bulge means just it is in elevated part, so it is bulging out and this flexural means there is a flexural slip, flexural slip has been noticed there. So how it is happening? For example, suppose you see this is a plate of the lithosphere which is subducting here under another lithosphere. So this subduction is not a very smooth one.

So one way this plate is moving in this other direction and this one is moving towards the opposite direction. So this lithospheric plate of huge thickness they are colliding each other, they are approaching towards each other, so that means it is a tremendous force is associated, tremendous stress is associated with that. So that is why there will be bulging on the under-thrusted plate because due to this loading of this plate, this plate you see if you see this dotted line which is the normal level of this lithosphere and this part it is slightly moving up, similarly this part is slightly moving up. So, this means these are the bulges, different lithospheric bulges are there in front of this subduction zone, in front of this island arc system.

So the bulging if you see, gradually it is increasing towards the trench and decreasing away from the trench So here from the normal lithospheric level, this height is just few meters or few kilometers that is 4.5 meter and here if you see this bulging is around some kilometer of some meter that means I want to say gradually once you are moving away from the trench, the effect of bulge is decreasing and as you are here at the bulge, so that means here this is the zone of extension that is why if you can say these arrows are in the opposite direction that means we are folding the system. So we are bending the system, we are folding the system, once we are folding the system, so that means here you have the extensional system, extensional tectonics, extension. So overall it is a compressional zone because two plates are approaching towards each other. However, locally at this bulge, we are experiencing extensional tectonics, there will be extension because it is a fold, it is just stretched. So due to folding some normal faults will be developed and some horst-graben structure of few meters elevation you can find here.

So the flexural bulge, it is about 500 meter high, occurs between 100 to 200 kilometer from the trench. So this distance is around 100 to 200 kilometer within that it is occurring and around 500 meter high from the trench. So this geometry of this bulge, how high it will be either it is smooth or it is a very huge one that depends upon the interaction between these two plates. For example, if you see these two cases have been described here, the first case is the high angle of thrust moment. You see here, this is the plate which is overloading on this.

So once they are overloading and the angle of overloading is high, the angle of thrust moment is high. So what is happening here? Resulting the shortening of the underlying crust. So here this is the underlying crust, this blue one and we are loading at this end and at a high angle. So that means we are increasing the load here. Once we are increasing the load here, finally we are creating a bend, but a distinct bend is there that is the folding.

So we are folding the system here and if the reverse is true, for example, suppose here this is the angle of subduction or this low angle thrusting are there, two plates they are interacting at a low angle. So here the large slip rate resulting in the, flexural bending of the underlying crust here, that means low angle of underthrusting is there. So that is why there will be easy moment for this plate towards down and this plate towards up. So that is why this is the flexural bulge which is not so much distinct as compared to here. So that is why here the flexural bulge is due to this gravity where gravity is playing major role to bend this plate here and here this loading of this overlying plate is playing major role in bending of this plate.

So this flexural bulge is just in front of the trench around 100 to 200 kilometer and depending upon this mechanism of the underthrusting, the angle of underthrusting, its geometry is varying, its height is varying. So this classical example of this overthrusting and the flexural bulge is Indian plate at the periphery of this Indo-Gangetic foreland basin. You see here this is the Himalayan system which is loading as a thrust and it is replicated here. Now see this Himalayan system the thrust sheets they are migrating towards the south and it is loading on the Indian lithosphere. So that is when you see there is a bending here and this bending is nothing it is the flexural bulge and this flexural bulge if you can draw this axis of the system you are representing the Delhi-Sargodha ridge.

So the Delhi-Sargodga ridge, it is moving parallel to this Indo-Gangetic plane and at the southern edge of the Indo-Gangetic plane. So this is representing around 500 meter high and this high is like this it is a folded like this, this is folding and if I join this fold axis, so we are representing this Delhi-Sargodha Ridge. So this bending that means we are stretching the system here and this stretching we are creating some normal faults. So we will find parallel normal faults at the southern end of this Indo-Gangetic plane which is representing the Delhi-Sargodha Ridge flexural bulge.

So another system it is the volcano another element of this island arc system it is the volcano. So now you see this volcano which is erupting here at the initial case what is happening this volcano will generate some material and it will remain within that ocean basin. So with time more and more addition of this material this volcano is growing so with time this material is so much accumulated here the volcanic material ejecta they are accumulated here finally this growth is above the sea level. So once it is emerging above the sea level it is creating an island so that is the island arc and this can be represented here with increasing time. So at the initial moment if you see this is the plate which is underthrusting and at the asthenosphere it is melting here this mantle melting is taking place this material is rising at the volcano here you see from the sea level it is just rising few meters or so.

With time more and more eruption more and more volcanic system are added to the system gradually its height is increasing and you see it is increasing somehow more height from this sea level. And further with increasing time this volcanoes are generated new and the old volcanoes are here so finally it is creating a full-fledged crustal system and it is making a cut-off to this sea from here to here. So this way the island arc system and the volcanoes at the islands arc system they are increasing with time. So over millions of years the erupted lava over volcanic debris pile up on the ocean floor and finally a volcano rise above the sea level to form an island volcano. So such volcanoes are typically strung out to the chain it is called island arc.

So that means you are looking a cross section the volcanoes are here but if you see this plan view you will see this is convex towards the underthrusting system this is the underthrusting slab and you will find this arrangement of the volcanoes are like this that is forming this arc. So elements of this island arc system the trench then we have discussed which one then we have the forearcs. Forearc means this front of this arc. So for example here this is the arc system that is the volcanic arc the volcanoes in front of this arc this side it is called the forearc region and this side is called the backarc region. So any material which is here this is the part of this forearc system and this side it is the back arc system particularly back arc basin is developed here but number of elements are here at the forearc system.

Then in the backarc which is the back side of this arc then Wadati- Benioff zone this is the benioff zone benioff zone that means if we are plotting this earthquake hypocenters. So the hypocenters they are arranged in a particular fashion so that particular fashion they are representing the slabs rigidity that means a rigid slab which is there and that is the that is called the Wadati-benioff zone. So if the volcanoes they are haphazardly distributed with depth so that means there is no bennioff zone exist. So these are the different elements of the island arc system. Forearc region if you see here the forearc region it is comprised its trench so this is the arc and this side is the four arc region here we have the trench and with the trench at side we have the accretionary prism it is another element of this island arc system.

Then we have the forearc basin here we have a sedimentary basin it is forearc basins. So these are the prominent elements which are at the forearc region one is the trench another is the accretionary prism and third is the forearc basin. In the accretionary prism it is constructed by the thrust slices of the trench filled flysch sediment and possibly the ocean cross sediment that have been scrapped off down during this slab is going inside. For example suppose imagine we have a sedimentary basin or we have an ocean floor for example and if you remember our earlier class we are talking about this is the layer one which is sediment then layer two we have pillow basalt then we have sheeted-dikes then we have gabbro of different layered gabbro and cumulative gabbro then isotopic gabbro then we have peridotite. So this is the total ophiolite sequence or you can say it is the sequence which is of oceanic lithosphere.

Now this oceanic lithosphere one it is subducting down so that means those sediment which are intact and consolidated and it is now it is welded you can say with the oceanic lithosphere with the basaltic system they will remain intact with that. But those who are unconsolidated and semi-consolidated they are loose sediment so those sediments they will scraped up here and due to scraping up we have sediment accumulation here and this accumulated sediment it is giving rise to accretionary prism. Accretion means addition so more and more sediment is added here it is called accretionary prism. So, with this accretionary prism developed here in a compressional basin because this plate it is moving in this way and this plate is moving this way. So, here whatever these sediments are accumulated they are compressed and in a compressional tectonic regime we know there is folding there will be thrusting so that is why we will have folds we have thrust slices that are developed on this system.

So, this folds and thrust slices are the representative of this accretionary prism that will take another class to distinguish the accretionary prism it is anatomy or something like that. So, here at this stage you should just remember this accretionary prism is nothing this is the accumulation of the sediments which are scraped off during the subduction system and mostly the flysch sediment. Flysch sediment there are two types of sedimentation in the tectonic environment one is called flysch sediment and another is molasse sediment. Flysch during this subduction during this underthrusting of one plate whatever this fine grain sediments accumulated there fine grain sediments they are called flysch sediment. And after this mountain building whatever the coarse material which is eroding from this mountain system and depositing at the basin that is called molasse sediment.

In the Ganga plain we are getting the molasse sediment which is eroding from the himalayan system. The island arc system is made up of an outer sedimentary arc and the inner magmatic arc. For example, we have volcanoes here and this side it is the fore arc region and the forearc region what we have the forearc basin this side. So, here we have a magmatic arc these are the magmatic this is the volcanoes they are generated here and we have this magmatic arc and we have a sedimentary arc. So, outer side we are getting the sedimentary arc and here we have magmatic arc.

So, that is why we have outer sedimentary arc and the inner magmatic arc are there. And the forearc region is a region of a tranquil flat-bedded sedimentation between the accretionary prism and the island arc system. We have an accretionary prism here and this accretionary prism and this volcanic arc whatever the sedimentary basins are there these are the forearc basins. And the forearc basins they receive sediment from this side and also they receive sediment from this side. Additional to that we have volcanoes during volcanic eruption they will get the volcano plastic sediments here volcanic erupted sediments.

So, that is why these area or the sedimentary basin here they are representing flat bedded sedimentation and mostly that is derived from this volcanic arc and the accretionary prism and the volcano clastic sedimentation are there. And the sedimentary basins here they are typical allow the coralline to or the corals to develop why? Because it is very close to this temperature source we have volcanoes here and mostly you know this coralline sediments or the corals they grow in warm water rather in cold water. So, this water is warm and we have undisturbed sequence here. So, that is why we are getting the coralline sediments here. So, different coral reefs they are developed within that forearc basin and the sedimentary arc comprise that coralline sediments the volcano clastic sediment which is supplied from this volcanoes this underlying volcanic rock older than those found in the magmatic arc.

Why it is older than that found in magmatic arc? Because you see when there initial phase of subduction if you see this much is the subduction. So, there will be partial melting here and volcanoes that will form here. So now, further subduction this volcanoes will form here. So now, this volcano is formed here. So, with time this plate is bending down with its own weight and due to its further overloading the system is bending down.

Once it is bending down so that means, the volcanic front it is coming back. So, as the volcanic front is coming back so, whatever the volcanoes form here they were definitely older than these present volcanoes. So, that is why these sedimentary basins which are forming on this volcanic crust. So, this volcanoes they are older than this present one and this on this volcanic crust the sedimentary basins are developed and they are receiving sediment from this volcanic crust as well from this accretionary prism and they are representing the flat bedded sedimentation undisturbed sedimentation and allowing the coral to grow in this system. So, here this tectonic segmentation of this arc by cross faults creates discontinuities in the seamount distribution illustrating the strong tectonic control on the distribution of a volcanic in the island arc system.

For example, if you see once we have a island arc system if you remember our earlier class we were talking something this segment or this whole system this island arc for example, here suppose we are generating an island arc this is not as a whole this is segmented we have a fault here we have a fault here we have a fault here because this is a compressional zone and with this compression we will have extension opposite direction. So, we will have strike-slip faults here we have normal faults here. So, that is why this island arc it is segmented into different segments and this distribution of volcanoes this segment this segment will have different because the plate which is undergoing inside it is also segmented somewhere maybe it is high angle dip somewhere it is maybe low angle dip somewhere it is twisted. So, depending upon that this volcanic system here it is varying. So, that is why the tectonic segmentation by the cross fault create discontinuities and that discontinuities that is responsible for the uneven distribution of the seamount somewhere there is a volcanic uplift somewhere there is a fault uplift.

So, due to fault uplift which volcano which are earlier inside due to upliftment it is come to the surface or somewhere there is a subsidence. So, once upon a time this volcano which are forming the islands now they are subsided. So, that is why if you see here within that coralline sediment you know this is the fringing reef, barrier reef, atolls so like that. So, that means this fringing reef, barrier reef, atolls their distribution that is depending upon this volcanic eruption as well as the segmentation and subsequent subsidence and upliftment of this area because it is in a tectonically active zone. This volcanic substrate may represent initial sites of volcanism as the relative cold oceanic lithosphere subducts down.

And this cold plate extended further into the asthenosphere the position of igneous activity that is moved backward and to the steady state of location which is representing by the present day magmatic arc that few minutes back we were talking about. So, imagine this is the system which was subducting down. So, this was the magma erupting and creating a volcano. Now with further loading of this plate because this plate is moving this way this plate is moving this way. So, that means gradually the loading or the loading front is shifting towards west in this figure.

So, once this loading front is shifting towards west so that means it is putting more load on this band. So, that is why more bending takes place here. So, earlier the volcano that was erupted in this position now you see the volcanic position is shifting. So, further loading so that means the volcano was here now the volcanic front is shifted to this. So, gradually this side we are getting the older volcanoes and here towards this side we are getting the younger volcanoes.

So, all total that is creating this magmatic arc system. Similarly within that magmatic arc there is a series of volcano there is a series of volcano there is a series of volcano. So, within that there are sedimentary basins there are the forearc basins. So, this forearc basins that we have discussed few minutes back. So, this is all about your this is island arc system and thank you very much. We will meet in the next class.