Plate Tectonics
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Destructive Plate Margins-IV, The Back Arc Basin and Accretionary Prism

Okay friends, welcome to this class of plate tectonics. And we are talking about this destructive plate margin and within the destructive plate margin we are talking about this island arc system. And in island arc there are few elements that we have discussed many of those and today we will talk about this back arc basin and this accretionary prism. So what is the back arc basin and what is an accretionary prism? For example, if you see the back arc basin like the forearc basin this term is also self-explanatory. We have an arc system that is magmatic arc this magma is there erupting and we have volcanoes. So in front of this region that is called forearc region and this side is called back-arc region. So anything which is happening at the back side of this arc that is called back-arc region or the back-arc activities.

So in this backarc region we are creating a basin which is called the backarc basin. And now if you see this overall subduction zone it is in a compressional system because two plates they are moving to opposite direction. However, once the plate is subducting down and it is partial melting taking place in the mantle system this magma is erupting here. So due to this, there is an extension there is a stretching, and due to stretching this extension is occurring here. And due to this extension a basin a sedimentary basin is created here that is called back-arc basin.

So they develop in response to extensional tectonics in the existing island arc system. So here if you see the back-arc basin how it is developing and this development of the back-arc basin how it is affecting the angle of subduction how it is affecting the strength retreat or this hinge retreat that is explained here. Suppose for example, it is time one that is T1 and with time how the system is changing. So we have a plate which is subducting down and it is melting take place. So once it is subducting down here what is happening before subduction this convection current was moving here. Similarly this side this convection current was moving here. Now we put a plate here. So once we are putting a plate so this convection current which was earlier it was moving like this we are restricting this convection current here. So it will hit this region and will come back and it will try to move up.

So once it is moving up so that means again this crustal bulging it is taking place the crust will bulge like this and due to bulging we will have this normal faulting and finally, we are creating horst and grabens and we are creating a basin and with time we are finally creating a back-arc basin. Now once we are creating a back-arc basin a full-fledged mid-oceanic ridge system is developed here. Now this plate will move in this way and this plate will move this way. So once this plate is moving in this direction and with more and more push from the ridge so this part of this plate will move in this direction. Once it is moving in this direction finally, it is putting more and more stress on this down going slab.

So due to this more stress accumulation so this part this will move in this opposite direction because pushing from this direction is tremendous. So that is why this bending was occurring earlier here the bulge was here now due to extension of this basin this plate is moving this way finally, due to pushing so this bending or this bulge is shifting further towards east or you can say the trench which was earlier here the trench is shifting its position.

The subduction zone is shifting its position. Similarly, further extension of this back-arc basin further shifting or retreat of this trench is occurring towards this direction. So that means, here the back-arc basin is forming and it is spreading it is acquiring its size with time and that result the trench retreat. So the trench is retreating back. So retreating of trench of subduction zone with time it is depicted here.

Now this back arc basin that is of two kinds one is the extensional back-arc basin that means, we have extension because this magma or this mantle material or the mantle convection which has restricted here and will creating a convection current here. So that is why it is creating an extensional basin here and provided that here you see the angle of subduction it is high, but if the angle of subduction is low for example, this case. So, what is happening here the angle of subduction is low and due to this low angle of subduction the interaction between these two plates. So, this is the overriding plate and the underthrusting plate the interaction of these two plate it is more. So, here if this angle of subduction is low due to high degree of compression or interaction this plate it is exerting a compressional force that means, compression from this plate is directly transferred to the overriding plate.

So, as the compression is directly transferred in a compressional environment we will create the thrusts. Finally, instead of normal fault like in this case we are creating some thrust. So, these are the sedimentary basins will be created within the thrust sheet. So, these are the compressional system or compressional sedimentary basins may form and more it like it is a piggyback basins or so. So, due to this high degree of interaction so, more stress is accumulated here.

So, that's why the earthquake which is generating at B that is B region if you remember our earlier class when we were talking about this subduction zone tectonics this was the zone A which was the flexural bending then this is the zone B which is due to thrusting this is the zone C where double Benioff zone is getting due to dehydration and here this is the zone D due to the phase changes. So, now as the interaction is very high between this overriding and underthrusting plate here the earthquake which is happening due to this thrusting it is very high magnitude and high amount of energy is released here. So, that is why subduction zone with a shallow dip have a stronger coupling with the overriding plate and giving rise to large magnitude earthquakes in the region B and it give rise to backarc compression rather than extension. So, we are getting a compressional system rather an extensional system. Shallow dip also restrict the flow of asthenosphere in the mantle wedge above the subduction zone.

Now, here imagine earlier this mantle convection was moving like this. Now we are putting here and it is a shallow depth. So, the part of this mantle or the part of this convected material which was restricted here it is not able to move. So, that means due to this restriction of this low angle this you cannot create a full fledged convection system in the mantle. So, that is why it restricts the flow of asthenosphere in the mantle wedge which is above the subduction zone.

Now, if this is so a plate is subducting down here different zones of earthquake has been decided. So, these earthquakes they are arranged in a particular fashion, particular plane and that arrangement is called the Benioff zone or the Wadati Benioff zone in the name of its discoverer. So, now you see it is a plane that dips under the overriding plate where the intense volcanic activity occurs which is defined by the location of hypocenters below the arc. Earthquakes occur from near surface to about 660 kilometer depth and this dip of the Benioff zone arranges to a near vertical. For example, if you see this plate is subducting down and the earthquake it is near surface to around 660 kilometer depth.

Why 660 kilometer depth? Because up to now there is no earthquake deeper than 660 kilometer has been recorded. So, that is why we believe the plate which contains it's rigidity up to 660 kilometer. So, that is why this Benioff zone is here. In this figure if you see the earthquakes they are occurring here and there no special arrangement of any plane. So, that's why we can not say this Benioff zone exist here.

So, Benioff zone only and only exist when these earthquakes, hypocenters they are falling in a plane and the deep of the plane may be any, may be 45 degree, may be 30 degree, may be 10 degree, may be 90 degree, may be 80 degree anything. So, not necessarily it has to dip around 45 degree or so. So, any angle of dip it is ok, but must be the earthquake hypocenters they fall in a plane. So, that is why we can say it is a Benioff zone exist. Young oceanic lithosphere is relatively thin and hot consequently it is more buoyant than the older oceanic lithosphere.

For example, here if you see about this Nazca plate which is going down under the South American plate. So, here the angle of subduction is very less and why it is less? Because if you remember our earlier class when we were talking about this divergent plate margin system at the mid-oceanic ridge which is at the Pacific and this South American plate which is very close to each other. So, a plate which is generating here it is just moving this much distance and it is subducting down. So, that's why the distance is very less and it is close to the heat source. So, that's why it is young as well as hot because it is not cooled.

However, the opposite side we have Japan, we have Mariana. So, this plate which is created here at the mid-oceanic ridge it is to travel this much distance to subduct under this Japan arc. So, that means, up to here once this plate is moving this much distance it is cool, rigid and compact in intact. However, compared to this it is young and it is cool and it is not rigid. So, that is why these plates which are young and not too cool.

So, they are subducting at a less angle and due to this more buoyant nature. So, that is why they are giving rise the subduction zone which are of shallow depth. And young subducting lithosphere underthrusting at a higher rate and thus give rising shallowest dip and in case of Peru-Chile trench. So, due to it is young and it is hot, so they are underthrusting at a higher rate. So, once they are under thrusting at a higher rate, so that means, frequent slip is there high slip rate is associated.

And once we have high slip rate that means, there is less chance of stress accumulation and expecting larger magnitude earthquake is not here. So, that is why high slip rate indicating this frequent release of strain. So, that is why no question of occurring high magnitude earthquake here. But if the reverse is true that means, low slip rate that means, more intact is there more stress is accumulated. So, once it is there that means, we can expect high magnitude earthquake is there when there is any slip.

So, it seems probable that absolute motion of this overriding plate is also contributing factor to determining the dip of the banyeop zone. How it is happening? If you see the absolute motion of this plate, suppose for example, this plate is moving 5 centimeter per year for example, so that means, 5 centimeter per year this plate is once it is moving here it is putting pressure according to that, but suppose it is moving for example, 10 centimeter per year. So, that means, it is putting more pressure with less time here less pressure with time, but here it is more pressure with time. So, once more pressure with time that means, more bending of this plate. So, that is why the absolute motion of the overriding plate is also a contributing factor determining dip of the Benioff zone that means, more accumulation of material more stress is there.

So, more bending is there more loading is there more bending is there. So, if this high rate of movement is there in the overriding plate that means, within a very less time we are overloading this Benioff zone or overloading this bending. So, that's why this plate can bend, and finally, the dip of this subduction zone will vary. Now, the next element or the last element of this subduction zone or this arc island arc system that is the accretionary prism. Accretionary prism this word is also self-explanatory.

So, what is accretion means addition. So, a prism is developed or a prism-shaped body is developed sedimentary body is developed due to accretion due to addition where it will be added will be added at the front and will be added at the base. So, how it is happening? So, this accretionary prism developed where the trench-fill turbidites on flysch sediment and its more pelagic sediment are scrapped off with the descending oceanic lithosphere and leading edge of the overriding plate by which it is accreted. For example, if you see we have an plate which is subducting down and we know this is the basaltic system and these are the faults. So, that means, this interface is very rough and this is pillow basalt again this interface is very rough and we have sediment and if the sediment is sufficient enough the sediment which is scrapped off here and it is forming a prism that is called accretionary prism. And this accretionary prism which is equivalent to the foreland basin that is in the foreland system in the continental system.

And if you see this animated image here this material is going down and finally, it is added at the lower side of this prism. This is the accretionary prism which is developed and this material which is subducting it is scrapped off from this upper part of the plate and is welded below the lower side of this material. So, once it is added at the lower side of this material that means, gradually the thickness of this accretionary prism it is increasing from the lower side. So, that is why this is called the accretionary prism because it is accreted added sediment from the front as well from the base. And equivalent to that accretionary prism we have the foreland basin for example, we have the Himalayas which is rising here and we have the Ganga foreland basin and this is the sediment.

So, this sediment it is here a wedge shaped material or is a prism-shaped material that is the foreland sediments. So, now beneath the prism the plate boundary is defined by a 20 to 30 meter thick gently dipping fault or shear zone that is called the subduction channel. For example, if you see we have this basaltic system here and we have continental plate or another plate which is here that is the overriding plate. Now we are scrapping of sediment here and the sediment is going down this plate is going down and this zone which is the interface between these two plate it is a highly compressed zone. It is not very easy that this plate is going down.

So, it is high stress environment is there. So, this material which is crushed here and that's why this zone it is a zone of crushing, zone of shearing, zone of faulting. So, this zone of crushing and faulting it creates a zone about 20 to 30 meter which separates the overlying accretionary prism or the sedimentary body which is highly deformed, thrusted, faulted, folded because it is a compressional zone. And the low lying this is the lower area which is representing the oceanic lithosphere it is a basaltic origin or basaltic crust along with some part of the sediment which is totally welded and consolidated there. So, that means, this part it is the oceanic lithosphere is taking this oceanic that means the basaltic system as well as some part of the sediment down and some part of the sediment which is scrapped off here and forming the accretionary prism.

And this is called the subduction channel. So, that zone that is the 20 to 30 meter zone or around 50 meter zone which is highly crushed sheared material which is separating the relatively undeformed oceanic system to relatively highly deformed this accretionary system this zone is called the subduction channel. And why it is called channel? Because in the channel flow takes place. Similarly within that channel the sediments flow takes place because once this sediment is going under highly compressed environment gradually the compression increases because you see here the thickness is this much. So, that means, the compression will be relatively less. Here the thickness is this much it will be more here thickness is this much will be relatively more and here it is little more and further it is more.

So, gradually once we are going down in the channel the degree of a compression the degree of a shearing degree of crushing increases. So, as a result what is happening the sediment which is going down it is not going down very easily. So, part of it is welded to the lower part of the secretionary prism and part is going down into this asthenospheric system. And this addition of this material at the lower part of this system that is called underplating or duplexing. So, that means, the sediment which is passing through this channel with highly compressive environment highly sheared material once they are getting chance to release their stress they are just underplating they are added to the lower part of this material. So, this flowing to this upward of this accretionary prism and partly they are moving downward to the asthenosphere. So, the subduction channel that is why it is called channel through which the sedimentary movement takes place. So, this subduction channel it is consisting of highly sheared and poorly consolidated sediment with variable thickness ranging from several hundred meters to several kilometers. Within that subduction channel material it detached from the lower part and to the upper part it is mixed together and flow upward and downward along this interface between these two converging plate and forming the channel flow that we have discussed why it is called channel flow.

Because the material which is going down it is highly crushed while sheared and part of this material that is coming back and is added to this lower part of this accretionary prism and partly they are going down to the asthenospheric system. And this accretionary prism once you are moving from this newer side to older side gradually they are highly compressed and to corroborate this compressional environment we have some thrust here. So, the thrusting is a prominent process of deformation in the accretionary prism. So, we have folds, we have thrusts. So, above this decollement is the fold-thrust belt that is the listric thrust, listric ramps are there that means gradually they are moving in this direction and their curved thrust plates are there.

So, in a stratigraphic section they are cutting from the lower side to the upper side that means the whole stratigraphy is cross cut by this thrust system. And the seismic reflection data and the age of the deformed sediment suggests that the youngest fault is in the front part of the accretionary prism and gradually once it is moving from this deformation front this older thrusts are generated or thrust becomes older if you are moving from this side or from the front of this system to the inside of the system. So, that means thrusts are generated here and gradually this material which is coming to this direction due to compression so that means it is coming down. Now imagine a thrust which was for example, it is formed at this angle.

Now we are compressing the system. So, due to compression due to addition of the sediment the sediments are added here, we are putting the sediments here. So, gradually we are putting the sediment at the toe side. So, once we are putting this sediments with the toe side gradually this thrust which was initiated with a low angle now it will start rotating because we are adding material here more and more addition of the material at the toe the thrust which was earlier at the sliver depth they will try to rotate. So, gradually this rotated or high angle thrust they are developed to the inside of this accretionate prism and to the front of this accretionate prism we develop this relatively low angle thrusts. And due to progressive shortening the old thrust wedges gradually move upward and are rotated towards the arc by the addition of new wedges to this front of the prism.

This process is called frontal accretion. So, at the front we added more material. So, this system is called frontal accretion and due to this frontal accretion now you see we are adding this material here and we are compressing the system and we are developing the thrust. So, due to thrusting so that means, one material is moving further moving further moving. So, what is happening? Gradually the slope is increasing gradually the height of this accretionate prism is increasing. So, that means, there will be lateral movement there will be lateral movement and lateral growth of this prism.

So, due to the growth of this prism so, the compression also increases and the slope increases. So, lateral growth of this prism occurs and due to this compression and some of the thrusts which are developed from the frontal side and the some of the thrust due to compression they are occurring from below and cross-cutting all the thrust here. And these thrust which are cross-cutting all these thrust systems and are developing inside on the newly generated thrust which are generating from the inside due to compression they are called out-of-sequence thrust. Out-of-sequence because they are not in sequence with this thrust which are generated to the frontal side and getting rotated. So, these thrust this is the newest one gradually this becomes older and older like this and with time their rotation taking place.

So, this side it will be shallow dip thrust and this side there will be steep dipping thrust, but these thrust are totally new due to compression they are newly generated and due to this newly generated system they are not maintaining the same sequence as these steep thrusts. That is why these are called out-of-sequence thrusts. In addition to the frontal accretion some incoming material is carried down past in the deformation front where it is transferred or it is underplated that we have already discussed here this channels which is going down to the asthenosphere and some part it is moving to the top and this is under plated within the accretion at regime. And this underplating at the base of the decollement. So, if you imagine this side this material is moving and suppose this is underplated here.

A material which is moving from this level is underplated here. A material which is moving up to this level is underplated here. What is happening? That means a material which is here it is less metamorphosed because from less depth and less pressure this is underplated and here the material which is underplated it is relatively more metamorphosed because they are coming from a relatively deeper level. Similarly a material which is under-plated here will be further high-grade metamorphism compared to here because it is under plated from again relatively deeper level. So, that is why you are going to inside gradually the degree of metamorphism increases and once the degree of metamorphism is increasing.

So, that means gradually if you are moving from here to here as a geologist what you will see this area which will find relatively low degree of metamorphic rock and high grade of metamorphic rock further high grade of metamorphic rock because the material which is going down it is coming back which is going down it is coming back. So, now you see this arrows which are looking at a blue color. So, this arrow are indicating the movement of this mass inside this accretionary prism. Now as we are talking about there will be out-of-sequence thrusts there will be some sequence thrust. So, due to this thrust movement so finally, this height of this accretionary prism is increasing and once the height of this accretionary prism is increasing that means, the system is compressed.

So, once the height is increasing finally, it will create a slope break here and due to this slope break some normal faults will be developed and due to this normal faulting that means, we will have these slides landslides the materials are removed from this area. So, that is why the tectonic underplating together with internal shortening thickens the wedge and cause the slope of this upper surface to increase. So, due to this increase of the slope there will be normal fault there will be development of basins and here this is the called the trench slope break where this normal fault is developed and the slope is reduced due to the removal of the material. So, the top of the accretionary prism is defined by relatively abrupt decrease in slope it is called the trench slope break. For example, here once this earlier this slope was like this and due to high slope there will be normal faulting and finally, this is the trench slope break is forming here and within this trench slope block break there will be small basins will be developed here that is called trench slope basins.

Between this break and this island arc the forearc basin may be developed. So, here if you see we have island arc system volcanic system here and we have a break here this is a trench slope break and this material is removed due to normal faulting and finally, we are creating a forearc basin here. And as we have discussed earlier this forearc basin it is the sedimentation takes place here is derived from this volcanic system derived from this accretionary prism. So, we will have that is calm and quiet flat bedded sedimentation along with coralline system that is coral rift will be developed and that is why this forearc basin that is very important in terms of hydrocarbon exploration because it is very close to the heat source any organic material will be here that will be in a relatively less time it will converted to petroleum hydrocarbon due to heat environment. So, seaward of the forearc basin on the trench slope small pockets of sediment also accumulate and the top of the old thrust slices.

So, these are the piggyback basins that may be developed there. So, now here this erosion of the trench slope and the other landward material that is commonly result from slump deposit as we have discussed this is landslides or slump deposit will be there that will come directly to the trench system and that's why the trench is of different kind of sedimentation is there different degree of sedimentation is there and the sedimentary nature is no defined it may be any type of that is called melange that we have discussed in the last class. So, the offscraped material first move down and it is at the base of the prism they are coming back here if you see in this figure it is going down and coming back. So, it is going down and coming back like this. So, due to this you are getting less degree of metamorphic rock here high-grade metamorphic rock here further high-grade metamorphic rock here. So, in a normal stratigraphy sequence for example, as a profile I am drawing.

So, here this normal stratigraphic level. So, if you are here at the lower side what you are getting is the high-grade metamorphic rock due to pressure and temperature and you are at this level you are getting relatively low degree of metamorphic rock and this level relatively low degree of metamorphic rock because you are stratigraphically in a normal sequence. However, if you see here in this profile if you are moving in this lower profile level you are getting low degree of metamorphic rock and at this level you are getting high degree of metamorphic rock at this level you are getting high degree of metamorphic rock. So, that means, this is totally contrast to this observation. So, that is why it is called inverse metamorphism. That means, you are getting you are going to stratigraphically upper level or topographically upper level and you are getting high-grade metamorphic rock at the top and the low-grade metamorphic rock at the bottom.

So, that is why this is called inverse metamorphism. And this sediment which is here at the trench that is the melange and the melange we have already discussed it is chaotic sedimentation no nothing is there no arrangement is there if you see this photograph field photograph of melange there are blocks and very high that means, size blocks are there and fine grain sediments are there no mixture nothing at and this melange itself indicates that some of this rock fragments they are showing blueschist facies of metamorphism and some of this rock fragment they are showing eclogite facies of metamorphism. That means, it says the at least the rock fragments had been derived from a depth of about 30 kilometers. That means, the material which is going down around 30 kilometer and once it is not further able to move it is underplated at the accretionary prism and due to this underplating its thickness is increasing and gradually they are exposed at different levels. So, this high-grade metamorphic rock they are exposed at topographically higher level the lower-grade metamorphic rock they are at the topographically further lower level and so, that is called inverse metamorphism. So, this eclogite and blueschist facies of rock which are very a plenty available at the melange that indicates that this at least up to 30 kilometer the rock is undergone and exhumed.

So, that is all about your trench' sediment, all about your accretionary prism. So, thank you very much. We will meet in the next class.