Plate Tectonics
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Week - 05
Lecture – 23
Conservative Plate Margin-III, Transform Continental Margins

Okay friends, welcome to this class of Plate Tectonics. And we will continue our discussion in conservative plate margin and particularly the transformed continental margin. So, if you remember our earlier class, we are talking about these transformed faults their origin, their distribution in the continental lithosphere as well as oceanic lithosphere. And we found these transformed faults of continental lithosphere and oceanic lithosphere are completely different. And they are developed due to unequal stress distribution during the continental deformation and particularly the rigid and this thick continental plates, they produce transformed faults that are of very narrow and it is deep-seated. However, transformed faults in the oceanic lithosphere, they divide the mid-oceanic ridge into different segments and in the continental lithosphere when there is the lithosphere is young and it is not very thick and rigid, the deformation it is divided or it is spread over an area rather confined in a zone.

So, that's why this nature of these transformed faults in different continental margins as well as in oceanic lithosphere, they are of a different. So, today we will talk about these transformed continental margins. What is a transformed continental margin? If a transformed fault develops during the continental rifting, the continental margin is defined by transformed fault and is termed as transformed continental margin. So, now the question arises, the transformed fault that developed during continental rifting.

So, before introducing a transformed fault into continental system in a rifting system, Let's talk about this continental rifting, how they takes place. So, if you see this image, we have a continental rift. So, earlier if you remove the rift part, so, there was only one continent which was existing like this, this is the continental rift without rifting. Now we introduce the rifting. So, that means, we introduced a magmatic body here and due to this magmatic effect.

So, this system is now it is swelling up like laccolith or so and finally we develop this normal fault here and along this normal fault this continent is rifting and finally, it is in this form. So, what is happening here? Before the rift of this continent, this continental lithosphere it was of this much thick. However, once we introduce the rift system, this continent it is stretched in both direction and finally, you see this continental lithosphere getting thin towards the rift axis. So, that means, earlier we have a thick crust and then we make it thin and with further stretching, these two continental blocks they are completely separated and finally, a oceanic lithosphere is introduced in between and finally, a full-fledged ocean basin is developed and this is the oceanic lithosphere which is accompanying at the side of this lithosphere of continental origin and these margins they are called passive margin. So, now with this let us introduce one transform fault here that means while stretching the system so, there was a ridge here, ridge was existing and through ridge there are the transform fault that developed.

That means, that transform fault which divided the ridge into two different segments. Now, here this image is seen that one of this continental plate with earlier existing and this is the stretching direction and due to the stretching here we thin the crust, this is the symbol which is talking about thin continental crust. So, that means, this part it is here, this is the thin continental crust and with time this ocean basin is developed and this is a mid-oceanic ridge developed here. So, this is the mid-oceanic ridge and this is the ocean basin, this is the oceanic lithosphere. Now during this we developed one transform fault and with further stretching and further widening of this ocean basin this transform fault that introduced at this stage now it is growing and that's why along this transform fault this continental segment and this continental segments they are separated and due to this separation this oceanic segment of this edge and this edge they are getting close to each other.

So, that means, I want to say we introduced a transform fault during our stretching system and stretching mechanism and finally, we divided this continental lithosphere or this continental margin into different segment through this transform fault. So, this transform fault is now that is this part this yellowish part if you see it is passive transform fault that means, these are not active now. However, the red part which is in between that is active part and this is inner corner and this is outer corner. So, this way we introduced a transform fault in the continental margin and its initial contact with the continental counterpart on the adjacent plate and subsequently changed to contact with oceanic lithosphere and the oceanic ridge and finally, it is separation proceeds. So, that means, from here to here developing a rift as well as a transform fault and finally, we are separating two continents away from each other with hundreds of thousands of kilometer apart.

However, the transform fault which are introduced at this stage this remain active and it is now it is coming to this oceanic system, but still part of this continental system they are affected by this transform system or transform fault. So, these transfer margins they are definitely different from this other type of continental margin that is for example, it is the passive continental margin. So, in the passive continental margin suppose there is no transform fault at all. So, how this margin looks like if you see here we have a rift basin and if you see suppose for example, this area I am looking I am showing it here. So, this is the continental lithosphere or continental crust and this is the oceanic crust and if you see this is the continental shelf it is a wide zone and this wide zone it is of thin and it is very shallow dipping or shallow sloping and this is the continental slope it is also not very deep.

However, this wide continental shelf is separating this continental slope with a relatively you can say it is a broad zone. However, if I am introducing a transform fault here had it been a transform margin. So, its cross-section would have been different for example, here there are 22 transform margins have been studied and their cross-section has been shown here. If you see here this is the continental shelf and this is the shelf break and this is the continental slope and the slope break. What is the difference between this and this you can see we have a narrow continental shelf.

However, here is a broad continental shelf and this break is very sharp and it is high deep however, this break is not sharp and this slope is somehow less. So, here these margins differ from the rifted or the passive margin by a narrow that is less than 30 kilometer continental shelf and a steep ocean continent transition zone So if you zoom this area and it is shown here that is the continent-ocean boundary here the continent and ocean boundary you see this is the deep. So, this is how this slope is varying. However, if you zoom this part and it is shown here you see this is more steep as compared to this so, that's why this is definitely different from this that is this passive margin or the passive continental margin which was introduced or which was formed without having a transform fault. Now, among this transform margins or the transform continental margin the best studied transform margin is the Ivory Coast-Ghana margin here is the African continent and this is the Ivory Coast-Ghana margin is there and it is found that this margin formed during early Cretaceous opening of the South Atlantic which was accompanied by a transform motion with what is now it is the Romanche fracture zone.

This zone is called Romanche fracture zone. So, Romanche fracture zone is not only a single transform fault there is a group of transform fault which is separating this Ghana Ivory Coast continental margin from the rest part of the part in the South Atlantic Ocean. The same thing here if you see we have a continent and we have a transform fault and finally this continental lithosphere get thin here and we introduced a mid-oceanic ridge system and further with time this mid-oceanic system spreading continues this ocean become wider and wider and this transform fault become confined here along the different segment of this oceanic ridge and this part become inactive this part become inactive. However, if you see this triangle which is of orange color that is given a marginal ridge where this marginal ridge comes out so, before talking about this marginal ridge imagine we have a continent earlier which was without any fracture without any stretching. Once we are stretching that means we introduced a magmatic system below and we make it like this we make it like this and finally we introduced some normal faults here so, that means along with we are separating this two so, finally, we made it like this and another case we made it like this so, this become one continental side and this become another continental side so, what is this? This is a ridge this is a ridge you are looking the cross-section so, that means this marginal ridge which was earlier formed during the stretching that remained and its topography remains as a positive one so, that is representing the marginal ridge system.

So, the Ivory Coast Ghana margin displays a triangular shaped continental shelf a steep about 15 degree continental slope and a narrow 6 to 11 kilometer ocean-continent transition zone if you see this Ivory Coast system as I have told you this is a group of transform faults are here so, this is looking a triangulated part why it is triangulated part because this part it is affected by this transform fault so, that's why this is a sudden break here. So, that's why it is showing a triangulated part and this steep slope around 15 degree and the continental slope and a narrow 6 to 11 kilometer continental-ocean transition zone is there and that can be seen here through this topographic color that is the color coding and this is the age of this oceanic lithosphere. So, this color coding is there and along this transform fault as we have already known that this age of different continental lithosphere they come juxtaposed to each other so, now, if I am introducing one transform fault here and it is the directional transform fault so, that this motion is like this. So, imagine so this is a block and I am introducing one transform fault is like this. So, that means I am pushing this part in this way and I am pushing this part in this way so, once I am pushing this part so that means I am creating some folds like this so, this fold axis that will be parallel to this direction of movement and this axial plane is also parallel to this movement direction so, that's why folding and faulting associated with a dextral motion with a 10 to 20 kilometer wide zone is reported.

So, that means those area which is affected by this motion of this transform fault that is deformed in a wide zone that is 10 to 20 kilometer wide zone. If you remember earlier class when we are talking about this continental transform fault and this transform fault is started with a point with a line and finally, it is becomes wide towards the outer side towards the newer side. So, similarly once it was introduced here it was initiated here and it is moving in this direction and finally, it is creating a wide zone of deformation where the folds display northeast trending axis that are compatible with the dextral motion that I have already explained to you if I am using this part in this way So, I am creating some folds which are parallel to this motion and the faults record both strike-slip and dip-slip reflecting at least two episodes of strike-slip deformation so, this motion is not a continuous process. The motion that is recorded at this Ivory Coast Ghanam origin at least two episodes of deformation so, what is these two episodes? How these two episodes are distinguished? What is this time difference between these two episodes? Let's discuss. The first episode that involved a combination of strike-slip motion and extension of northeast trending faults leading to the formation of a pull-apart basins.

So, this pull-apart basin that we know how this is if the fault plane is not straight. So, suppose for like this and we this part is moving this way and this part is moving this way so, that means, we are creating a pull-apart basin here so, that means, the first motion that is involved a combination of strike-slip motion and extension here due to strike-slip motion if you see this is moving this way and this is moving this way this strike due to the strike-slip motion this is forming a pull-apart basin here. And the second phase it involved strike-slip motion and folding possibly as a result of change in the direction of motion in the transform fault. Suppose for example, we created a basin here pull-apart basin and again we reverse the movement direction suppose we are changing the motion, this part is moving this way and this part is moving this way so, that means instead of a pull-apart basin whatever this area which was here representing the pull-apart basin that will be folded because this zone becomes a compressional zone. So, this to compression this will again folded and faulted and thrusted.

So, what is the folding effect and what is the faulting and thrusting effect like positive flower structure and negative flower structure we will talk in the next class, but at this stage you should remember when they are moving towards each other and this fault plane is curved so, this area will remain as a compressive one. So, that is why whatever the sediments were deposited in the pull apart basin that will be folded, faulted and thrusted. So, these two different episodes of motion along the strike-slip fault is representing two different direction of motion. So, that's why once upon a time which has believed to be a pull-apart basin. So, now, this pull-apart basin sediments or other surrounding rocks they are compressed due to the reversal motion so, four main phases of evolution of transform boundary has been established, what are the four main phases of evolution that is phase 1.

Phase 1 it says this is the thick continental crust and this is the divergence and this point is the observation point so, now, imagine we are stretching the system two different direction so, that means, we are making the continental crust thin so, once we are making the continental crust thin so, we are developing a thin crust here so, phase 1 is there is contact between two continents so, now, you see this is contact between two continents and we are stretching that means, we are developing a zone which is which will represent a weak zone in future and through this weak zone the failure will occur or deformation start from this weak zone. So, in this first phase the strike-slip motion results in the brittle deformation of the upper crust and ductile deformation at the depth giving rise to pull-apart basin and rotated crustal block so, now, if you remember our earlier class when we were talking about the crustal system, the crust is brittle up to few kilometer and gradually due to this increase of temperature and pressure the lower part of this crust it is behaving as a ductile matter so, now, imagine we have a column of lithosphere and the upper part is brittle nature and the lower part is ductile nature and we are stretching it so, once we are stretching the upper part of this continental system that will deform in brittle format however, the lower part that will deform in the ductile format so, that's why the strike-slip motion results in brittle deformation of the upper crust and the ductile deformation at the depth. So, result is giving rise to pull-apart basin and rotated crustal blocks pull-apart basin few minutes back we were talking if it is a curved fault like this and we are moving in this way so, this region is getting separated from this region. So, finally, this normal faults will develop this side the normal faults will develop and this becomes a pull-apart basin so, what is this second phase? The second phase once we are stretching and the stretching is continuous the second phase is that this crust becomes thin so, this marginal part and earlier which we have introduced as a weak zone and from this weak zone this crust becomes thin this part becomes thin so, in phase 2 as the rifting and the crustal thinning accompanying the deformation of divergent margin continues the contact in between the normal thickness continental lithosphere and the thinner stretched continental lithosphere occurs. So, that means, we have this divergent margin finally, we are developing but at this stage what we have introduced that this part of this crust become thin and this part becomes thin and this part become that ridge which was earlier explained that how the ridge came into existence or came into the picture.

That means, while we are stretching we have a magmatic system earlier we introduced so, that means, we stretched we make a bubble like this and now we are separating one part in this way another part in this way. So, this is the marginal part and this is the wedge earlier which was existing. So, that means, at the second phase as rifting and the crustal thinning accompany the formation of a divergent margin continues the contact is between the normal thickness continental lithosphere and the thinner one stretched continental lithosphere occurs so, now, we have stretched the lithosphere in the second phase and this newly created rift basin experiences rapid sedimentation from this adjacent continent and subsidence associated with the crustal thinning. This is very important here to understand so, we stretch the system and due to stretching we introduced certain normal faults in this zone. And if you remember our earlier class we were talking about there are two types of area existing one is mobile belt another is your shield area.

See mobile belts they are the belts or they are the zones of deformation where faults are active folding is going on anyway there is a topographic change. And once the faults are frequent this area or the continental lithosphere is undergoing many phases of segmentation so, that means, its sediment production capacity increases. So, once the sedimentation sediment production capacity increases so, whatever the sediment produced due to faulting due to erosion like that that sediments are now deposited in that area so, that means, this area is representing a rapid rate of sedimentation. Now, imagine a rapid rate of sedimentation that means, we are eroding this surrounding system and that sediment is being deposited here but at the same time we have some weak zones there are the faults, some fractures which are in between and the crust is thin and once we are loading the sediments on the thin crust having some fractures in between there are more chances that this area becomes failure. This region with evidence the failures because it is overloading and thin crust having some weak planes so, that's why the subsidence occur.

So, due to subsidence again the basin widens so, the sediments are folded and faulted by the transform motion and the blocks of the material are uplifted forming scraps of marginal ridges so, once we have a normal faults that we know during normal faulting the horst and the grabens are formed so, the horst they are represented as ridges and the grabens they are basins so, we have a series of basin that is horst and the grabens are there and the sediment are more thick in the grabens and thin in the horst. This tectonism is recorded in unconformities in the sedimentary sequence and other structures. For example, we are introducing some horst and some grabens for example like this. So, what is happening here this horst and grabens their sedimentation is going on and this sedimentation is going on because sedimentation will occupy in the lower part. At the same time this area there is no sediment and rather it is introducing erosion.

So, finally, once this sediment is filled with this graben this sediment will be filled with graben and this will be filled here so, what is introducing here we are facing an unconformity that is the area of erosion or non-deposition so, that's why at different blocks having different elevations. So, the unconformity will be different so, there are number of unconformity surface found at this basin boundary and particularly during the horst and graben stage or the initial phase of rifting now, it is the phase 3. Phase 3 says the new oceanic lithosphere emerges along a spreading center to establish an active ocean continental transform fault that means, we have stretched the system to certain extent or to the large extent so, that this continental lithosphere from both side now they are separated so, that's why this magma is coming out and forming a basaltic layer here and a full-fledged ocean ridge is developed here. And through this ocean ridge the basaltic system it is occupying at this oceanic lithosphere and finally, we are developing one continental lithosphere here and it is thin continental lithosphere and this is the mid-oceanic ridge system and this side you also thin continental lithosphere and this is the thick continental lithosphere so, this ocean basin we developed this is the basaltic crust and this is the thin part of this continental crust this is the thinner part of the continental crust so, in phase 3 the new oceanic lithosphere emerges along a spreading center to establish an active ocean continental transform system. Now, at this stage there is contact between faulted continental margins and the oceanic crust.

Now, you see we have the faulted continental margins and oceanic crust. So, this transform fault is now here earlier it was here it was separating or joining these two continental lithosphere then its position changed to this thin continental lithosphere to thin continental lithosphere now, this transform fault is separate or it is joining or it is here it is the thin continental lithosphere and the oceanic lithosphere. So, in this zone now this position of this transform fault is there. So, gradually the transform fault its position is shifting from continental lithosphere to full-fledged oceanic lithosphere so, the faulted margin passes adjacent to the hot oceanic crust of this spreading center and this thermal exchange is experienced results in the heating and differential upliftment within the faulted margin especially near the continent-ocean boundary. So, here it can be explained here that we have this continental lithosphere this side and the oceanic lithosphere this side so, we have this transform fault here and whatever this magma is introduced at the mid-oceanic ridge system.

This magma is not only it is moving here and it is spreading like this. This also affected by this transform fault system. For example, due to magmatic under plating in the deep portion of this continental crust the magmatic features align the transform faults also. For example, if you see from gradual change of this magmatic system we have a stretching system that is the rift basins and finally, we introduce the magma and due to this transform moment this magmatic body now you see how they are separated and they are aligned themselves. So, that means, I want to say this transform fault not only affecting this lithospheric system only it is also affecting the magmatic emplacement which is at the mid-oceanic ridge system so, now, the last phase or the phase 4 this transform is only active between the blocks of the oceanic crust and this appears as a fracture zone so, now, see in the phase 4 what is happening this is the position of this transform fault and this is the position of this transform fault now, it is separating this oceanic lithosphere to oceanic lithosphere and part of this continental lithosphere here and here now this becomes inactive so, gradually we started our transform fault here if you see this point so, we started this failure here and gradually it is coming to this stretched part of the or the weak part or the thin part of this continental lithosphere and finally, it is the joining this thinned part as well as the ocean basin now, this point is here that is within the ocean basin so, gradually a continental lithosphere which first introduced this transform fault it become inactive and this active part is remained within this oceanic lithosphere only and about this oceanic transform fault we have studied in earlier classes so, the faulted margin is then in contact with the cooling oceanic lithosphere and its subsidence evolved a manner similar to these other rifted passive margins so, here already passive margin is developed and this transform movement is just jumped to this oceanic lithospheric system.

And this is well explained by these 4 figures and if you see it in early cretaceous that is the Ivory Coast Ghana margin it is 125 Ma the continental rifting and transform fault initiated here this continent rifting started and this is the rift the red one this is the rift and in B if you see with this red one we have this yellow, yellow is the divergent basin thinned continental crust. So, earlier we have a continental crust which is thick continental crust and then due to stretching thin continental crust we introduced then in C if you see we introduced this ocean basin here the white portion the ocean basin is developed and here with ocean basin full-fledged ocean basin is developed now this is the transform fault so, this transform fault is now it is confined within that oceanic lithosphere only so, this is the sequence of evolution how we transform margin of continental origin it is remaining there and this transform motion is transferred from the continental system to this oceanic system and this is best seen here with the digital elevation model with all those we have explained earlier and this is that transform zone that is romanche fracture zone so, this is a zone rather a plane and in the continental system it is affecting here, but becomes inactive. So, this whatever the folds and faults and thrusts we have discussed few minutes back that were for during this continental movement or this movement of this transform fault in the continental side but now this transform fault is around this plate so, if this is so now the question arises whether this movement around this transform fault is continuous or discontinuous. So, the response is there is mixed some of this transform zone they are characterized by discontinuous motion and some of these transform zone they are represented by continuous motion how? Suppose we are talking about this San Andres fault system in San Andres fault system this is well documented continental transform fault and is well studied one so, here if you see The presence of aseismic regions such as the Great Valley and Sierra Nevada in the southwestern USA imply that part of this continental lithosphere behaves rigidly. So, here this is the Great Valley and this is the Sierra Nevada area.

So, this is showing this is aseismic in nature that means if you see this fault system they are introduced here and here here however there is a hardly any fault marked here so, these region are marked as an aseismic region. So, that means within a fault zone within a seismically active zone, but this becomes inactive part so, that's why whether the motion is accommodated by the movement of many coherent blocks separated by discrete zones of deformation or by more spatially continuous process that is a question and this question is answered due to this seismic activities and due to this GPS movement which was installed here. And depending upon that that is introduced that which part of this transform fault is moving and which one is remain idle however, in other areas such as the Wacker Lane and Eastern California shear zone this side if you see Wacker Lane in the Eastern California shear zone, seismicity reveals the presence of diffuse zones of deformation that are better approximated by a regional velocity field rather by the relative motion among the blocks and this was studied by this GPS movement how been millimeter scale movement that can be recorded. So, to distinguish between the deformation is continuous or discontinuous different models have been proposed. What are their models? The first is called the continuous velocity field model.

What is the continuous velocity field model? It says that even though the upper brittle crust is broken into faults the faults are predicted to be relatively closely spaced, have small slip rates and extend only through the elastic part of this crust. So, we know this crustal system once we are going down the ductileness increases this is the brittle part and the lower part becomes ductile part. Suppose we have a shear zone introduced here and what we believe this the brittle part it is deforming with different blocks however, this ductile part remains inactive. In this view the velocity field commonly is assumed to present in the average deformation of the whole lithosphere which consists of a thin layer that is 10 to 20 kilometer that deforms by faulting above a thick layer which is ductile in nature and it creeps in a ductile manner. So, this is the model which is called continuous velocity model.

That means, the lower part is deforming in a creep model and the upper part is deforming in the brittle manner and this model is explained by this continuous velocity field. Other is the rigid block model. What is rigid block model? This says the faults are predicted to be widely spaced which slip rapidly and extend vertically through the entire lithosphere and it is terminating at this large ductile shear zone in the upper mantle. So, here this ductile crust is here and this fault we believe that is separating this mantle or the lithospheric system separately from the asthenospheric system and in both types of model the deformation may be driven by combination of forces. So, what are the forces? These forces responsible for this deformation either of this model it says it includes this acting along the edge of the crustal block and it is the basal traction due to the flow of the lower crust and this upper mantle and this gravity.

So, these are the forces they are responsible for the deformation of the crustal system either of this model that can be explained here so, the distribution of strain with deformation continental lithosphere is strongly influenced by the horizontal variation of temperature, strength and thickness here this is the compositional model how the composition is varying with depth and this is the thermal model how the temperature is varying with depth and these two models are combined and this is giving the strength model of this lithosphere and how the strength is decreasing or increasing or it is varying with depth. So, the strength model says that the distribution of strain within the deforming continental lithosphere is strongly influenced by the horizontal variation in temperature, strength and thickness so, measures of the strength of continental transforms and large strike-slip fault provide potentially useful means of continental rheology and driving force of this continental deformation. So, that's why this transform fault deformation if it is somewhere exposed for example like this San Andres fault and this Ivory Ghana coast where this deformation around the interior of the continental lithosphere can be studied very precisely. So thank you very much, we will meet in the next class