Plate Tectonics

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Week - 05
Lecture – 21
Conservative Plate Margin-I

Okay friends, good morning and welcome to this class of plate tectonics. So, you remember your last class, we were talking about this constructive plate margin or the divergent plate margin, where this plate or particularly the oceanic plate is created at the mid-oceanic ridge. So, today we will talk about the conservative plate margin. So, now if you see this tectonics map of the world, here these are the mid-oceanic ridges and these are the trenches and in between if you see in the mid-oceanic ridge system there are partly it is white colour and partly it is orange colour and this white colour they are representing the divergent plate margin and the orange colour if you see it is near about perpendicular to this white part and this orange colour it is the transform plate margin. And here if you see these transform plate margins, they are offsetting the divergent plate margins. So, now the question arises if there are three types of margins.

So, here the great question to be answered is where do ridges and the trenches terminate horizontally? So, there is no obvious answer to that till few years back when this Wilson 1965, he proposed that the fault terminate at the end of ridges or the trenches and that's why this fault is called the transform fault which are normally at right angle to this convergent as well as divergent plate margins. So, now if you see here there are three types of figures one type it is says there is a divergent plate margin that is the mid-oceanic ridge system and this is another segment of this mid-oceanic ridge system and it is offset horizontally to certain kilometre and that is the transform fault. And here if you see we have a divergent plate margin or it is the mid-oceanic ridge and here this is the subduction zone and the subduction zone here this is the abducted plate or the overriding plate and here it is the subducted plate or this undergoing plate. So, in the cross-section it would look like this, this is the abducted part and this is the subducted part and this segment which is separating these two that is the transform fault.

Similarly, in this case this is the transform fault which is separating two convergent plate margins and here it is the abducted plate this is subducting down and this side it is the abducted plate and this it is subducting down. So, that means, I want to say we have transform faults they are at right angle to the plate margins and rather offsetting them and that's why it is called transform fault and this is because the lateral displacement across this fault is taken up by transforming it into either the formation of a new lithosphere at the terminated ocean reach segment or the lithosphere subduction at a trench. So, here the same case has been explained either it is new oceanic lithosphere is creating or it is destroying here by subduction. So, anyway it is transforming that's why this term transform fault is used. So, this conservative plate boundary if you see this animated diagram here, this plate is moving in this way and this plate is moving in this way and without any loss or gain at the boundary condition.

So, that's why this conservative plate margin it is a plate margin where none of this plate this loss their area and provided that this orientation is straight and if this orientation is somehow curved or somehow different geometry probably there will be some other type of structure that will be developed. So, it will not as simple as it is shown here and that will be discussed in the next class. So, this conservative plate boundaries occur where the lithospheric plate side past each other horizontally and where the crust is neither destroyed and nor it is formed. So, that is the transform plate boundary and these plate boundaries are commonly associated with and evolved as a consequence of accommodation of the displacement across this spreading ridge So, now we have this mid-oceanic ridge system and this segment it is called the transform fault. So, this boundaries these are neither created nor destroyed and the lithosphere that is not created here not destroyed here and the motion is mostly of strike-slip nature.

So, this interpreting these fracture zones as a large strike-slip fault has a problem. This problem is that there is no obvious way in which the transform fault terminate. So, now if I say this is the transform fault now the question addressed where this fault to terminate. So, there should be some termination. So, that means beyond this if I am moving.

So, this fault's extension is traceable however this part will not active and this part will not active. So, only it is active between these two ridge segments and that's why this part only it is called transform fault and beyond that so that is called fracture zone this is called also fracture zone. So, this transform fault the terminology only and only restricted to those segment which are separating two major plate boundaries only. So, here this transform fault is only active between the offset ridge crest this one this can only be say it is transform fault. So, here it is dextral and it is sinistral is also possible.

However if you see this case this is the fault which is originating here or beyond that and it is terminating here or it is beyond moving this. So, in that case it is called transcurrent fault. So, it is transcurrent fault or a strike-slip fault cause along this vertical plane which must stretch to infinity beyond the ridge crest. So, this only from the ridge crest to ridge crest this segment it is called transform fault. However if it is moving beyond that so that is transcurrent fault and this side it is called fracture zone this side is also called it is fracture zone.

So, by this combination there are six possible type of dextral transform fault. Similarly there is other six types of sinusoidal transform fault is also possible. What is that? The first one is ridge to ridge. For example here this is one mid-oceanic ridge another segment of mid-oceanic ridge. So, this transform fault it is separating two ridges or it is joining two ridges.

So, that is the ridge-ridge transform fault. And the second one is ridge to concave arc. So, here if you see it is the ridge and another is the concaveward concave toward the ridge so, that's why ridge to concave arc. The third is ridge to convex arc. So, it is a ridge here mid-oceanic ridge and this is convex towards the mid-oceanic ridge that's why it is ridge to convex arc.

And we know this concavity and convexity. So, this arc which is concave shape and that is called that's why it is called arc that means the term itself it is derived from its word it is a arc-shape that's why it is called the island arc. Now this fourth one it is concave arc to concave arc. Here it is concave and this side is concave it is concave arc. And similarly we have different segments.

So, here it is convex arc to convex arc and this is the concave arc to convex arc. So, there are six possible ways this transform fault has been identified and it is found throughout the globe. Now the question arises if this is so, we have six type of different transform fault. So, what is their response with time? So, now you see we have this type of images which is representing at present that means the present day configuration and the same image now it is representing after a period in terms of millions of years. So, what is happening here? So, in case i and v that will remain unchanged.

So, this one and this one. So, if you see here the present day configuration and after that this configuration. So, the length here and the length here remain same. So, the length here and the length here remain same. So, that means if this configuration is there it will not change after a period of geological time.

However, this ii and iv will grow in case. So, here it is ii now you see this ii earlier its length was of this much now it is increasing to this much. So, it is growing similarly iv, iv means if you see here this is iv and this is iv the length was this much and become this much this is growing and this third and sixth this is third and sixth that is decreasing in length. Now see this length was this much and reduced to this and this was this much and reduced to this. So, if this is so now further future time if I am projecting it.

So, this will again reduce and finally this series will be of this side and this one that is the arc it will be this side. So, that means this system will be in opposite sense. Similarly this will be in this side and this will be in this side. So, this will be opposite sense. That means with time some of these transform faults they are remaining constant and somewhere it is changing to increasing length and somewhere it is decreasing length provided that this configuration should be of this type.

So, that means we can conclude of these 6 types of these transform faults. If the extensional zone migrate towards each other the separating transform fault eventually disappears and begins growing with an opposite sense of motion. In oceans a transform fault connecting two subduction zone that is the trench-type facing each other becomes shorter and eventually disappears only to grow in the opposite direction with a reversed sense of motion. And in ocean transform fault connecting two subduction zones with the same facing does not change its length. So, these 6 images that we have discussed briefly that are summarized here and depending upon this length of facing and this length of this transform fault depending upon the direction of a facing the length of the transform fault either it is increasing, decreasing or remaining constant with the geological time.

Now describing about brief in transform fault. So, it is the ocean areas well defined by long linear bathymetric depressions. So, if you see this digital elevation models here. So, we have this bathymetric depressions here. So, mostly they are representing by deeper contours.

Similarly they are representing by deeper contours because these are the depressions. So, the transform faults in the oceans are well defined by long linear bathymetric depressions that normally follow arc of small circles. Which arc of small circle? That is the arc it is the arc of Euler's small circle. So, Euler's small circle if you remember our earlier class when we are talking about this pole Euler's pole of rotation and Euler's small circle. So, this Euler's small circles they are representing and if you remember our earlier class we are projecting this perpendicular from this Euler's small circles and we are pointing out the Euler's pole of rotation.

So, these are representing the Euler's small circles. So, direct observations of a fracture zone on this mid-Atlantic ridge shows complex swarm of fault occupying about 300 to 1000 meter width and it is a depressed zone so, that's why it is they are representing the linear depressions. And the first-spreading ridges like the east Pacific rise these multi-fault zones are wider and more frequent. And fracture zones mark both the active transform segment and it is fossilized segment. For example, here we have a transform fault here that means this segment we say it is a transform fault and these are the fracture zones.

So, this fracture zones are nothing these are the fossilized stress of the transform fault. Earlier this segment was existing here at this segment was existing here. So, these are the fossilized part and only this part is active at present. So, if you see this bathymetry contour here these are representing deeper part compared to the surrounding and it is linear and it is not a single plane there is number of planes associated with it which are parallel to each other. So, there the segments different segments are joining there.

So, this is the mid-oceanic ridge segment and these are the transform fault they are separating these two. Now, how this transform fault developed? So, their developed mechanism and the structure if we discuss it has been suggested that the fractures result from the thermal contraction in the direction of the ridge axis. If you remember our earlier class when we were talking about divergent plate margins these are the linears of elevated regions where this magmatic system is moving up and with time they are cooling down and contracting. So, due to this contraction there are fractures developed and these fractures their results from that contraction only and finally, with time they grow together. So, this internal stress that is caused by this contraction are much larger than the breaking strength of this rock and that is possible that the fracture zones develop along the resulting lines of weakness.

So, ocean fracture zones must bring oceanic crust of different age into juxtapositions. That means, if you see here we have a rock segment and here we have closed cracks due to contraction and these cracks is further growing and forming this transform fault and if you see here this transform fault is the mid-oceanic ridge system and this mid-oceanic ridge system these are the transform fault we have different ages. So, at this mid-oceanic ridge the time is 0 and if once we are moving away from the mid-oceanic ridge the time increases. So, now if you see along this transform fault or across this transform fault a age of older and younger they are juxtaposed to each other. So, due to this strike-slip motion this type of juxtaposition of younger rocks to older rocks occurs in the mid-oceanic ridge segment.

And from this mid-oceanic ridge if you are moving down if you see here the age is increasing and the subsidence is also increasing. For example, here if I am taking this level 0 gradually once I am moving away from this mid-oceanic ridge the system is subsiding which is due to the contraction due to the sedimentation effect the system is subsiding down. That's why if you remember our age-depth relationship when we are talking about divergent plate margin. So, the age and depth both are increasing away from this mid-oceanic ridge. So, that's why the depth of the sea floor is dependent upon its age.

Hence the fracture zones connect from this younger to higher crust to this lower older crust here. So, the older crust they are at the lower topographic level and this younger crust they are higher topographic level. And the rate of subsidence of this ocean lithosphere it is inversely dependent upon the square root of its age. That's why the higher younger crusts subside more rapidly than the lower and this older crust. So, now here the rate of subsidence here it is more as compared to here and that's why this the higher and younger crust it is subsiding at a higher rate and compared to the older crust.

So, the transverse ridges are often found associated with major fracture zones and that provides vertical relief about 6 kilometre. This is very important here to understand. We have a mid-oceanic system here and we have one transform fault here. Sometimes it is seen that we are getting transverse ridges here and it is that ridge sometimes it may be of higher elevation compared to this mid-oceanic system. And these ridges do not originate from volcanic activities or into fracture zone or by hotspot activity.

Then now the question how this ridge system develops? So, now imagine we have a fracture zone here and imagine here this is the extension and due to the extension this mantle material which is lying below they are moving upward due to balloons because we are depressurizing the system. We are extending the system due to the extension this mantle materials they are moving up as balloons and due to this movement of this mantle material this system or this region is becomes elevated. So, it appears to result from this tectonic uplift of the blocks of the crust in the upper mantle and due to compressions. So, once we are releasing the compression from this side, so this mantle material which is lying below they are increasing. And sometimes it is possible that this spreading is oblique for example this is spreading in this way and this is spreading in this way.

So, now imagine this block is moving in this way and this block is moving this way.

So, oblique spreading, so once there is oblique spreading here there is a collision though this is a transform fault or a strike-slip motion is there, but once they are obliquely spreading, so here there will be collision and due to collision there will be positive structure there is folding type. So, that means here this occur or this topographical that means unevenness it is due to either this upliftment of this mantle material below that is the metamorphic rock and it may be due to oblique spreading there will be a collision and this collisional effect there will be upliftment. So, that's why sometimes it is possible to see that this topography here that is the oblique ridges or transverse ridges they are more in height that compared to this ridges which are representing the mid-oceanic ridges system. So, some salient features about this transform fault here, these run parallel to this fractures on one of the both side of this margin.

So, if you see here we have a mid-oceanic ridge segment, we have another mid-oceanic ridge segment and we have a transform fault here and this transform fault this is a taken cross-section from A to B and it is representing here. So, what you see, you see this topography is not uniform the one side it is going down it may one side is going up. So, that means the along with this strike-slip motion there may be some normal fault motion and it may possible that one side is moving half higher side and compared to this one. So, there may be reverse motion also. So, there will be compression as I was talking about there will be oblique spreading and there will be compression.

So, there may be thrust slicing also and maybe both side it is representing similar type of topography. So, all these type of topographical variation that is expected along this transform fault. So, they are frequently anomalous in that their evolution or that elevation may be greater than that of the crest of the spreading ridges and the age-depth relationship of this normal oceanic lithosphere does not apply here and that depth differ from the normal crust at the same age. Thus, their formation cannot be explained by normal process of lithospheric accretion. So, that means whatever the process is involved here that is definitely different from this process involved here and here.

So, this mid-oceanic ridge system that we have already discussed that is developed in a different way as compared to this topographical variation which is developing at the transform fault. Now, around this transform fault there is another term introduced that is called leaky transform fault. Leaky transform fault means it is not pure transform origin. So, there is something which is representing the extension. For example, if you see we have a transform fault here and with time it is separating into different segments and this inter-segment area it is representing the extension, the mid-oceanic ridge development.

And this type of transform fault where the extension component is there that is called the leaky transform fault. So, a fault system in which new crust originates a disturbance leaky transform fault and these are the regions where the new crust is developed due to mid-oceanic ridge development. When the direction of a fault plane does not correspond exactly to the direction of spreading on the either side of that there is a component of extension across the fault. So now, here had it been like this that it means this spreading is perpendicular to this transform fault. So, probably this leaky transform fault would not have been happened.

But if here if you see this is spreading and but it is oblique to that so that means here we are introducing one component which is extensional component and due to this extensional component we are creating segments of mid-oceanic ridge here that's why this transform fault is called leaky transform fault. So, here the fault may adjust its trajectory so as to become approximately parallel to the spreading direction by developing into a series of fault segments joined by small length of spreading ridges already we have discussed here. Now another way how this leaky transform fault is developed so this is called when there is a small shift in the position of Euler's pole of rotation. So now imagine this is the transform fault earlier it was here and that's why the Euler's pole was somewhere here for example. Now suppose the Euler's pole shifts its position so that means here this transform fault or the Euler's small circle they have to adjust.

So that means earlier it was here if I am extending it, it will meet here but now you see this orientation has changed and due to this orientation change so the leaky transform fault is developed that means the new Euler's small circle has to adjust itself with the new Euler's pole. So that's why if you see the east Pacific rise this is the model that is the digital elevation model. If you see we have different abandoned transform faults they are lying. So this abandonment of transform fault it is nothing it is due to this change its orientation of this Euler's small circle or the transform fault due to the change of Euler's pole of rotation. So that's why by dating those the abandoned segments we can say when the Euler's pole changed its position with respect to these plates.

So the fault would then adjust with a new small circle direction and becomes leaky. So that's why when this system is changing so finally one component we are introducing that is the extensional component there so that's why it becomes a leaky transform fault. So there are two ways one is due to change in the Euler's pole and another way once there is a extensional component introduced there due to oblique spreading. If the relative motion between the two plates is not exactly parallel to the fault there is a small component of convergence or divergence. A transform fault with a small component of divergence is called a leaky transform fault.

So earthquake fault plane solution for this boundary near these Azores illustrate that small amount of extension occurring there and oblique spreading is more likely to occur on this low spreading ridges than the fast spreading ridges. So these are the key features how this leaky transform faults are developed and what are these features that can identify this leaky transform fault in the field. So here an example of this leaky transform fault the plate boundary between the Eurasia and Africa if you see here we have Eurasian plate we have African plate and the Azores junction at the mid-Atlantic ridge eastward towards Gibraltar. So this is the live example of leaky transform fault where this transform fault along this transform fault this extension is introduced and this mid-oceanic ridge signatures are found. As the ridge-ridge transform fault implies that the offset on them do not change with time.

here if you see we have different ridge they are separated by this mid-oceanic ridge sorry separated by this transform fault and finally we are getting this offset and due to the offset but still it is not changing. The reason behind whatever the offset is created by this transform fault or this strike-slip fault it is compensated by this spreading. So that is the mid-oceanic ridge system that is the ridge-ridge transform fault if this offset it is compensated by the rate of spreading then there will be hardly any offset it is a noticed around this system. So thus the geometry or the locus of this step-like ridge crest transform fault sequence in the equatorial Atlantic has remained essential unchanged due to this type of movement and from this development of this South Atlantic system. So that's why this rate of motion here it is compensated by the rate of spreading here.

As a result the locus parallels the continental shelf edge of the South America and Africa and reflects the geometry of this original shifting of the Gondwana supercontinent in this area. So, if you see here this is the Gondwana separation if you remove this Atlantic this where earlier coalescence together and due to this transform motion. So, now this Atlantic Ocean has been developed and due to this development of the Atlantic Ocean. So, this Gondwana separated into different segments. However, if you see this separation this transform motion is still it is remaining which is started or which was started during this Gondwana time.

Now if it is a transform fault or it is a strike-slip fault and it is offsetting the ridge offsetting this system that is called the subducting system then how this seismicity along this transform fault varies. So, this gentleman Skeys 1967 determined the focal mechanism solution for the earthquakes occurring in the vicinity of this fracture zone of the offset mid-Atlantic ridge system. So, this earthquake it says this mid-Atlantic ridge system or this mid-ocean ridge system if you see this beach ball diagram it is of normal nature. If you remember we had normal faults different normal faults are occurring here.

So, this is normal fault nature. Similarly, here this is normal fault nature, here this is normal fault nature because this is the mid-ocean ridges. However, this separated by this transform fault, this transform fault region that is representing the strike-slip motion. So, this beach ball diagram it is representing the transform fault motion. So, what is the beach ball diagram? We will take separate class for this same. So, events along the ridge axis are consistent with normal faulting along the north-south plains and most events occur in the active segment of this transform and have strike-slip mechanisms consistent with the transform faulting.

So, events along the fracture zones are much more common and this energy released is about 100 times greater than along the ridge crest. So that means here it says whatever the energy is released by the earthquakes occurring from this region that is much-much more in energy terms as compared to this energy which is released from this mid-ocean ridge segment. However, very few events occur in inactive fracture zones. If you are going here, you are going here, if you see it is a no seismicity. So that means only the seismic signatures they are restricted and the transform fault that is the active zone as well as the mid-ocean ridge segment and beyond that there will be no seismicity. So, thank you very much We will meet in the next class. Thank you.