Plate Tectonics

Prof. Pitambar Pati
Department of Earth Sciences
Indian Institute of Technology, Roorkee

Week - 04
Lecture - 19
Along Axis Segmentation of the Mid-Oceanic Ridge

Okay friends, good morning and welcome to this class of plate tectonics. So, if you remember our earlier class, we are talking about this mid-oceanic ridge system and we found there are two types of ridge, one is slow-spreading ridge another is fast spreading ridge. And irrespective of its rate of spreading, the mid-oceanic ridge is segmented along its strike and the segmentation is due to normal faulting. And this normal faults at the fast-spreading ridges, they are nearly vertical or around high angle. However, at the slow-spreading ridge, there are low angle inward facing normal faults. As a result, there is stretching of this crust and that's why the mantle inside it is swelling up and that's why this exhumation of this mantle occurs and that contributes a larger metamorphic domain at the slow-spreading ridge.

Today, we will talk about along axis segmentation of the mid-oceanic ridge. Along axis segmentation means along this ridge axis, there are different degree of segmentation, different order of segmentation and each order signifies different depth and length and that defines the magmatic composition, the magma chamber properties and this magma supply. And finally, it defines the directional movement of this spreading ridge system. So, how it could identified? It was identified from the swath mapping.

So, the swath mapping has been used to reveal the variation in the structure of the ocean ridge along the strike. So, if you see this diagrams, you have this vessel and it is radiating the waves and this is the sound waves mostly the sonar system and this is coming back and finally, it is processed and this mid-oceanic ridge picture it is built up. So, studies of this east Pacific rise have shown that it is segmented along its strike and this segmentation is by non-transform ridge axis discontinuities such as propagating rift and overlapping spreading center. So, these two terms one is propagating rift another is overlapping spreading center that has to be understood properly and these features may migrate up or down along the ridge axis with time. So, if you see this figure, this is the picture or the digital elevation model of this east Pacific rise.

Here you can say this is the direction of ridge and one segment is here another segment of the ridge is here and in between there is a gap and this portion it is the overlapping portion. So, this is the overlapping spreading centers that means we have this spreading from here we have this spreading from here and this part it is overlapping this is called overlapping spreading center and another is called propagating rift. The rift is propagating, so that is the ridge and it is propagating in this direction similarly, it is propagating in the direction. So, this geology in this segment that is defining how the ridge will behave, which part will be abandoned and which part will be active in geological future. So, now these are the two diagrams one is representing the east Pacific rise and another is the mid-Atlantic ridge.

So, now you see this ridge is not a straight, so here one segment and this is offset and that is another segment and then there is an offset this is another segment, then there is an offset, then another segment. So, like this the ridge is continuing. Similarly if you see the mid-Atlantic ridge here there are different small segments and each segment there it is divided and it is offset by this transform fault. So, here we have a transform fault, we have a transform fault similarly here we have number of transform fault that is segmenting this mid-oceanic ridge systems into small segments and that is why these magmatic properties and the rate of spreading at different segments varies and this dividing transform faults they also define which part this magma will generate and which part it will be more generate and which are less. Now you see the overlapping spreading centers they are non-rigid discontinuities and where this spreading center of a ridge is offset by a distance about 0.

5 to 10 kilometer and with the two ridge portions overlapping each other by about three times of this offset so, now if you see here we have this is the spreading center, this is the spreading center and if you see the distance and you see this overlapping distance. So, if the offset this is called offset that means, from this orientation it is taking some offset some distance and it is deviating from this orientation. Similarly this offset it varies from 0.5 to 10 kilometer and this overlapping is about three times of the offset. So, now if this is the offset amount, so this overlapping will be around or up to three times of that and that's why this is called the overlapping spreading center.

And if you see this diagrammatic representation of the here we have a ridge axis and it is spreading in both ways, here it is spreading in both ways here it is spreading in both ways. So, now if you are concentrating yourself here what you are getting that here we have a spreading in this direction, here it in this direction similarly here it is opposite direction so that's means This region which is confined in between it is experiencing two opposite directional extension. So, that's why in this region there will be a shearing moment that is a rotational moment of this block. So, that is the second part of the story we will talk later. Now at this stage you believe that this is the spreading ridge and this segment is the spreading ridge and this part is called the offset and this part it is called the overlapping spreading center and mostly the overlapping is three times around from the offset amount.

Now the overlapping spreading centers that originate on fast-spreading ridges where the lateral offsets are less than 15 kilometer and the OCS geometry is unstable for a longer duration. So, that means I can say these are geologically not durable, geologically time wise that is not durable for particular or for some million years they are existing and with time they shift their position. So, for example, if you see here, tensional orthogonal spreading centers cause their lateral propagation until they overlap and they enclose the zone subjected to the shear and the rotational deformation. As we have discussed few minutes back you see we have a spreading center here that is the part of the mid-oceanic ridge we have here and where non-rigid transform faults are deployed. So, there we are getting this overlapping spreading centers.

So, now if you see this is spreading in this way, this is spreading in this way and similarly these are the spreading direction to opposite directions. Now this area which is enclosed here that is experiencing shear moment and rotational moment. So, block which is enclosed in between it rotates. So, due to rotation its orientation changes. So, that's why this magmatic centers that is this spreading centers they overlap and migrate further and this migration belongs to this way and if it is migrating it will migrate in this way.

Finally, this either this one will join become the full-fledged spreading center or this one will join becomes a full-fledged spreading center this one will be abandoned. So, this is the region. This is the region. So, due to this process if you can see these are the diagrammatic representation of this earlier ridges. So, due to this joining of this two, so this will be abandoned or either joining of this two this will be abandoned.

So, this way if you see this digital elevation model of this region you will find number of abandoned ridges are lying. So, that is the nothing these are the abandoned part where this overlapping spreading centers were earlier existing. Overlapping spreading centers are broad areas of interaction between overlapping ridges with classic hook-shaped geometries and predominantly extensional motions. Now, if you see here this is the spreading center and it is spreading. So, gradually this spreading it is moving in this way and gradually this spreading is moving in this way.

So, here it is extending. So, gradually this tip will move like this, the tip will move like this and it is the extensional part. Once this extension is going on with time this will join here or this will join here. So, whichever joins first for example, suppose this one is joining first so that means this ridge orientation will be like this and this part will be abandoned or otherwise if this joins this part will be the full-fledged and this part will be abandoned. So, OCS occur where true transform fault failed to develop because the lithosphere is thin and weak that we have already discussed where there true rigid transform fault is not able to be developed.

So, that's why this type of overlapping spreading centers they form and that's why here this lithosphere is very thin and it is weak that's why this type of arrangement is done, in addition to their size other factors control the development of transform fault or OCS are the cooling, strength of the oceanic lithosphere, the maturity of this interaction and the spreading rate. So, these are the influencing factor. So, not only their size so, the other factors these are the factors that is the cooling and the strength of the oceanic lithosphere, the maturity of the interaction and the spreading rate. So, these influence whether and what is the nature of this OCS if it occurs at all. Now if you see the initial configuration that is distance plus size of the interacting ridges rather than their separation alone controls the type of interaction.

So, that means the initial configuration that is how much distance is there of the segment and what is the size of the segment, what is the thickness of the segment that is the interacting ridges and their separation not only alone it interacts. So, these are also affecting the development of the OCS. So, measurement of several terms of transform and OCS reveal that a simple ratio between the total length of this interacting ridge segment that is L and their oversteps that is S that distinguishes transform from OCS. So, if you see here that is L by S if it is less than 6 then we are getting a transform fault and if it is greater than 11 then we are getting a OCS overlapping spreading center and this graph says this frequency and this is the L by S ratio. So, if you see this L by S ratio that is from transform to OCS you are getting here this if it is less than this and it is greater than this.

So, less than 6 we are getting the transform fault and it is greater than 6 or greater than 11 we are getting the overlapping spreading centers. So, this ratio it defines whether this transform fault will develop or the overlapping spreading center will be developed. This possibility is confirmed by the evidence that ridge segments with a similar overstep develop different type of interaction depending upon their total length and this Icelandic ridge that is East Iceland Ridge interacts with the Kolbeinsey or to this north and it is

Reykjanes to the south ridge both at a similar distance. So, now, you see we have a similar distance at the north and south. However, one way it is creating this transform fault and another way it is the overlapping spreading center.

So, this interaction with the longer Reykjanes ridge segment develops the OCS while the shorter Kolbeinsey ridge develop a transform zone. So, that's why it is same this length also measures or length also defines whether there will be OCS or there will be transform fault developed. In fracture mechanics when two cracks propagate towards each other they tend to deflect away from each other and propagate past each other and then stall out and the ratio is 3 is to 1 because at that point the cracks propagation force drops to 0. So, now, we have two cracks one is in this way another is moving this way. So, this it is ratio when it is 3 is to 1.

So, this is bending this way and this is in bending this way. So, this OCS continue to advance until one tip link with the other OCS. So, this will move and this tip will join here and this tip will join here. So, at that is the result a single spreading center will develop and one OCS becomes inactive and move away as spreading continues. So, if this is so, if it is continuing and is become the one.

So, this part become abundant. Now you see from the digital elevation models how this abundance OCS are lying here at the east Pacific rise. Now the whole system or whole mechanism has been developed here represented in diagrammatic manner if you see here this is two knife cuts in frozen wax film that is spreading initiates here. Now propagation of the spreading centers along this strike it is propagating now you see the distance earlier was this much now the distance is decreased. In fact, there this much overlapping is there.

So, spreading centers develop and curves towards each other encircling a zone of shear and rotational deformation OCS geometry established. Now see here this part it is overlapping and this block it is experiencing shear motion or rotational motion. So, progressive shear and rotational deformation continues until one OCS linked to the other. So, now, you see this OCS is joining here and a continuous spreading center is established and abandoned OCS and overlap zone are rafted away. So, now, you see we have the full-fledge ridge developed and this part that means, this segment and this overlapping regions that is the rotational block or rotated block these two together they are abandoned.

So, we have a full-fledged that is the oceanic ridge developed here. So, this is the all total mechanism how the OCS is developed and how different segments of the OCS they join and rejoin and how this rest part is abandoned. So, here two spreading centers overlapping apparently pushing against each other which would violate one of the rules of the plate tectonics that plates are rigid. So, now, you can see here already we have discussed. So, these are the abandoned parts and these are these overlapping parts here and in the digital elevation model in the east Pacific rise you can see how this abandoned segments are lying here and there.

So, this paradox is solved by the fact that the overlapping spreading center are non-steady state and propagate along the ridge as one segment lengthens the neighboring segment shortens. So, this segment once it is lengthening so that means magmatic supply is more and there is a extension here. So, once more extension is here and more magmatic supply is here so obviously, this magma deficient happens in this segment. So, that's why this part will not migrate as frequently as compared to this part. So, discovery of the overlapping spreading centers revealed that time-varying behavior of mid-oceanic ridge systems with implications of magmatism, volcanism and this pattern of hydrothermal activities.

So, these magmatic behavior, the volcanic behavior and the hydrothermal activity along the mid-oceanic ridge system they are also controlled by the overlapping spreading centers. So, for example, suppose we have been overlapping segment here we have magmatic activity here we have magmatic activity here, but relatively less. However, you cannot stop the hydrothermal activities. So, we have hydrothermal activity here we have hydrothermal activity here. So, that's why we are creating a zone of hydrothermal activity which is much more wider as compared to here and compared to here.

So, that's why there is an unevenness of the hydrothermal activities and where there is overlapping spreading center there is a more region affected by hydrothermal activities. Similarly, volcanic activities also we have volcanic activity here we have here though it is less, but still we have a wider zone of volcanic activities as compared to the single segment of this ridge. Now, the fastspreading ridges are segmented at several different scales. So, they are divided into different orders. The first one is the fast order segmentation.

The first order segmentation for example, if you see here it is called D1 or the transform fault. And this first order segmentation is defined by the fracture zone and the propagating rift that is called transform fault which divide the ridges at the interval of

300 to 500 kilometer and the axial depth anomalies, the large axial depth anomaly that means, if you take a cross-section here. So, we have a ridge here and we have a transform fault here this is the first order discontinuity and this is the ridge segment again. So, here its length is about 300 to 500 kilometer and this axial depth anomaly that is high axial depth anomalies like this we have axial depth that means, in the z direction or the z dimension it is high. However, subsequent order of discontinuities gradually the depth anomaly decreases and finally, at the largest one this is the fourth order that is only the surficial conditions it remains.

So, that's why once the order increases that means, the length decreases as well as the third dimension that is the depth anomalies also decreases. So, here if you see this is the first order discontinuity or S1 and this is represented by transform fault. Now suppose another transform fault is there. So, that means, we have a first discontinuity here another first discontinuity here in between this ridge this is one segment, but further if you zoom it we will get another discontinuity here that is called second order discontinuity. So, the second order discontinuity again if you zoom that is you will get the third discontinuities.

So, again you would zoom you will get it fourth order discontinuity. So, that means, the scale you look at the more and more segments you will get. So, that's why the first order discontinuity its length is about 300 to 500 kilometer and it is representing larger depth anomalies. So, now, if you coming to the second order discontinuity second order segmentation it is an interval of 50 to 300 kilometer and it is caused by non-rigid transform fault which affect crust that is still thin and hot and is large offset around 3 to 10 kilometer OCS that cause axial depth anomalies of hundreds of meters earlier it was large axial depth anomalies, but here it is axial depth about hundreds of meters. Similarly kilometer wise that is length wise it is 50 to 300 kilometer earlier it was larger that is 300 to 500 kilometer, but now we have a small segment.

So, like this we have small earlier we have a segment like this now we have a segment like this is the second order discontinuity this segment of like this then depth wise also it is less. So, earlier this was the depth now this is the depth and the third order discontinuity or the third order segmentation it is at interval of 30 to 100 kilometer and is defined by small offset that is 0.5 to 3 kilometer of OCS where depth anomalies are very few tens of meter. So, that means, I want to see the order is increasing. So, the depth anomalies also decreasing and this length is also decreasing.

And the fourth order discontinuities that is the segmentation at a interval of 10 to 50 kilometer it caused by very small lateral offset less than 0.5 kilometer and of this axial rift and small deviation from the axial linearity to the ridge axis. So, now, you see this starting from the second order we zooming it to the third order again we are zooming it to the fourth order. So, gradually the length is decreasing and it is depth is also decreasing and more minutely we are looking the ridge. So, these are rarely associated with depth anomalies and may be represented by gaps in the volcanic activity or the geochemical variation within the central rift.

So, if you remember earlier class we are talking about this magmatic variation or magmatic compositional variation or these volcanoes they are associated along this mid-oceanic system. So, the fourth order discontinuities are nothing they are not the real discontinuities but you can say this is the deviation or this is the separation of these volcanoes. So, here within that magma chamber or within that axis so there are pockets of magma they are aligned along this mid-oceanic system. So, this deviation from this alignment from the central axis this is represented by this fourth order discontinuity. So, that's why it is the gaps in the volcanic activity and it is the gaps in the chemical variation within the central rift.

So, this fourth order discontinuity have no depth anomalies it is a near surface phenomena. However, other three discontinuities that is the third order, second order and first order they have both length-wise and depth wise they are influencing the mid-oceanic system Fourth order segmentation is on the same along axis length scale as the interval between pure melt pocket in the melt lens. So, if you see here we have melt lenses suppose this is the mid-oceanic ridge system and we have melt lenses different melt lenses are arranged. So, any deviation among this melt lenses they are considered at the fourth order discontinuities. So, now if you see it is a cross-section we have this magma chamber and different pockets of magma are here and here and here.

So, you are looking a cross-section. So, different pockets of magma and along these pockets of magma there will be definitely the chemical variation there will be definitely the amount of magma accumulation. So, these deviation these different that is representing the fourth order discontinuity along this mid-oceanic ridge system. Third and fourth order segments appears to be short lived as their effect can only be traced for a few kilometers in the spreading direction. Second order segmentation however create off axis scars and the spreading crust consisting of cuspate ridges and elongated basin that cause differential relief of several hundreds of meter.

If you see here we have second order discontinuities. So, if you take a cross-section from here to here you will find finally this type of ridge and depression ridge and depression. So, the ridge and depression are nothing these are the abandoned overlapping spreading centers and these representing the geomorphological variation along this or across the mid-oceanic ridge system. However, this third order and fourth order segmentation they are short lived. So, their existence is for a small time then they mix with this mid-oceanic ridge system. However the second order one so, that is long time duration it lives and that's why it is representing the geographical changes or geomorphological changes and the topographic changes along the mid-oceanic ridge system.

Segmentation of the ocean ridge appears to be controlled by the distribution of partial melt beneath the ridge system. So, it is the distribution of a partial melt. So, we know the different depth, different partial melting and the magma which is generating from different depth have different composition and different degree of partial melting is there. So, that's why the segmentation of the ocean ridge it is appears to be controlled by the distribution of the partial melts. Now, transform faults are the first order discontinuity and they are long lived identified by large depth anomalies and by magnetic anomalies and offset ridge axis by the over 30 kilometers.

Second order discontinuity offset around 2 to 30 kilometer. So, on intermediate and fast-spreading ridges, second order discontinuities are overlapping spreading centers. While at slow-spreading ridges, they slow oblique offsets and ridge axis or ridge axis and the deep depressions in the seabed. So, this that means I want to say these are representing the different degree of discontinuities and they are representing the geomorphological changes, the magma pockets that means this compositional variations along this ridge axis. So, at intermediate and fast-spreading ridges, the third order discontinuities are also overlapping spreading centers, but with much reduced offset and at depth anomalies. While the fourth order discontinuities show a very small offset in the summit grabens and deviation of the axial linearity of the axis.

So, these rarely have a depth anomaly, but can be petrological segmentation that means I want to say we have different segments and different segments that behave differently depending upon the rate of spreading. Somewhere it is permanent, somewhere it is temporary and this represent the geomorphological changes, the geography, the topography and this magmatic composition along this mid-oceanic ridge. So, by and large we can say this mid-oceanic ridge system though it is a 1000s of kilometer length, but it is not a single bar shaped body and it is segmented into different parts and the segmentation not only on the surficial expression but depth wise also depending upon the order of segmentation the depth influence is also there. The first order it is high depth then gradually if you are coming to the fourth order as well the depth anomaly decreases and it is representing the magmatic composition, the along axis magmatic variation, compositional variation, the along axis topographic variation, along axis geomorphological variation. Somewhere it is representing rough topography by basins and the spurs and somewhere it is smooth topography.

On slow-spreading ridge the third and fourth order discontinuities are short-lived features marked respectively by gaps between and within the individual volcanoes. So, if you see this table here their first order, second order, third order and fourth order and total system is summarized what should be their segment length, what should be its depth and what should be its magmatic composition like that. So, within that you can compare how these different orders they are differentiated from each other. So, thank you very much. We will meet in next class. Thank you.