Plate Tectonics

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Week - 04
Lecture - 16
Slow and Fast Spreading Ridges

Okay friends, let us talk about this plate tectonics. and the spreading ridge system If you remember in the earlier class we are talking about this oceanic ridge system, the accretionary plate margin where the magma is generated which is theolitic basalt or it is olivine theolite and depending upon this eruption level, depending upon the degree of partial melting and depending upon this magma mixing and mingling within that magma chamber with the adjacent magma chamber, the resultant magmatic eruption is defined. And that's why there is a variation of magmatic composition among different ridges and within a ridge at different parts. And today we will talk about the slow- and fast-spreading ridges. Though if you remember we were talking about this slow- and fast-spreading ridges, some of the ridges are slow-spreading and some of the ridges are fast-spreading and among one ridges there are different segments they are showing different rate of spreading. And the rate of spreading is defining the geology, geomorphology, geochemistry, geophysics, anything which is related to this earth sciences that is defined by this rate of spreading.

So now the question arises how to define that which mid-oceanic ridge is fast-spreading and which one is slowly spreading, what is the cut off? So is there any numerical value which define this fast to slow spreading ridges? So here if you see the mid-oceanic ridge system, this is the map given worldwide and that map we have already discussed and if you see this color representation of different rate of spreading at different parts and here some numerical values are given. The ultrafast ridge which is more than 12 centimeter per annum, if you see here this 12 centimeter per annum it is lying somewhere here and this region it is representing the ultrafast spreading ridges. That is part of the East-pacific rise is representing the ultrafast spreading ridge system. Then comes to fast-spreading ridge that is 12 to 8 centimeter per annum, 12 to 8 centimeter per annum that means it is like rising or it is lying here.

So if you see this color code it is yellow and some part of here some part here so they are representing the fast-spreading ridges. Then intermediate spreading ridges that is 5 to 8 centimeter per annum, 5 to 8 centimeter that means here it is intermediate spreading ridges and the color code is here these are the intermediate spreading ridges. Then slow-spreading ridges less than 5 or 2 to 5 centimeter per annum so they are representing here and ultra-slow spreading ridges that is less than 2 centimeter per year. So you can say here it is ultra-slow spreading ridges somewhere here and some of them are here. So that's why this cutoff for slow to fast, fast to intermediate, intermediate to slow and ultra-slow it is lies based on this value a numerical value given.

Fast-spreading ridge the example is the east Pacific rise and slow spreading ridge, Mid-Atlantic ridge and ultra-slow spreading ridge that is the southwest Indian Ocean ridge. Now the difference in the spreading rate give rise to distinct mid-oceanic ridge morphologies. So here we have a comparison of different morphologies of different mid-oceanic ridge system. So the faulting it is more relevant on fast-spreading ridge than the slow-spreading ridge and accounts for the vast majority of its relief. So the relief along this mid-oceanic ridge system it is mostly defined by the faulting.

The fault throws the difference between this upthrown and downthrown blocks and the width of this upthrown and downthrown blocks that means you can say the separation of faults. The all together defining the topography of this mid-oceanic ridge system. Both inward and outward facing faults they are found at the fast-spreading ridges. However at the slow-spreading ridges only we have listric normal faults we have back tilted blocks they are found. If you see here we have slow-spreading ridges that is the mid-Atlantic ridge we are getting the listric normal faults that is back tilted block.

And back tilted block has its own importance when we will talk about relative velocity measurement this back-tilted blocks as well as this inward and outward-facing faults they have major role. Because some of this relative velocity along this plate boundary it is compensated by the faulting. For example, suppose this mid-oceanic ridge is moving this way, but we have a fault it is back-tilted. So suppose this fault is like this so that means this block is coming back. Similarly this block this whole total system is moving back moving in this way but due to faulting again part of this block is coming back.

So that calculating this relative velocity along this plate boundary the role of these faults are immense. And this due to this inward and outward facing fault development we will able to find the horsts and the grabens along these fast-spreading ridges. However contrast to that we have a central graben at the slow-spreading ridges and we have the faults having high throw and the distance is also more because the frequency of faulting here it is more as compared to here. So that's why closely placed fault showing inward and outward facing surface you are confined here and here this region is defined by slow faulting and wider fault blocks and high fault throws. At fast-spreading ridges the bathymetry it is greatly increases from the abyssal plane to the ridge and rises up to around 500 meter.

If you see this figure representing the bathymetry of this East-Pacific rise. So gradually you are moving up and this is the mean sea level and gradually you are coming here and this bathymetry is gradually increasing from the surrounding ocean floor and it is rising around 0.5 kilometer. So that is around 500 meter it is moving up and the bathymetry and of these subdued by this volume of this lava flow erupted along the ridge axis. So how much this bathymetry will be controlled that depends upon the how much magma flow and in the fast-spreading ridges we have magma flow which is continuous and heavy magma flow is there.

So once the magma flow is continuous and heavily magmatic flow is there that's why we are getting a relatively smooth topography because it is basaltic magma. Basaltic magma it is less viscous so it is flowing continuously and this flow is very smooth that's why we are getting very smooth topography as compared to these slow-spreading ridges. And at fast-spreading ridges the high may rise due to the buoyancy of the hot rock at the shallow depth. So this topographic high it is may be due to the presence of a magma chamber and due to the high-temperature buoyancy. Once we are providing the temperature, high-temperature around this rock of this surrounding area will expand and this expansion will increase the buoyancy of these rocks that's why we are getting a topography which is relatively higher than the surrounding.

Then the classic example of the fast-spreading ridge is the east Pacific rise around 9 degree north latitude where the spreading rate is about 10 centimeter per annum. And conducted study around this or across this East Pacific rise mostly the seismic studies, seismic refraction studies it says that this crust is slightly thinner than it is encountered in the main ocean basin and that's why the upper mantle velocity beneath the crustal region is anomalously low and this low velocity zone extend to a depth of around 100 of kilometer. If you see this figure which is representing this study you see here we have seismic profiles and these are the velocity contours. Now you see along this axis this velocity is less and this low velocity zone around this axis it is going around a depth of around 100 of kilometer. So, here just only x y is given so, if this is the z scale.

So, this low velocity zone it is extending up to 100 of kilometer along this mid-ocean ridge system. Hotspot or this possible up source for this low velocity or low density region may be due to this three regions. What is the three regions? One is the thermal expansion of this upper mantle material beneath the ridge crest. So, now you see we have this upper mantle material and we have a magma chamber which is continuously supplying heat. So, rocks are expanded.

So, that's why due to this thermal expansion of this mantle material. So, this type of low velocity zone is expected and it is followed by contraction of the sea-floor spreading which is carried away this mid-oceanic system away from this heat source. Once it is moving away from the heat source now it is getting contracted. So, that's why this expansion and contraction away from this magma source. So, this may be the one of the reason for which we are getting a higher topography here and we are getting lower velocity zone here.

Second thing that the second possibility says the presence of molten material within the anomalous mantle. See molten material, so it will be magma chamber, melt is there, melt lens is there. So, that's why it can give you the low-velocity system. Then a temperature related phase change. So, if you see this mantle peridotite which was earlier lying at certain depth it was maintained in a particular temperature and pressure regime.

Once it is coming to this environment which is low pressure and high-temperature environment. So, at high temperature environment probably it is changing a phase which is of lower density minerals are representing there. So, these are the three possible solutions to describe how this low-velocity zone along this mid-oceanic ridge along this specific rise can be explained. So, the region is bounded by several hundreds of meter wide zone of fissuring and up to 10 kilometer of active normal faulting. So, this fast-spreading ridge I am talking about it is 10 kilometer wide around this is fissuring and active normal faulting and this new volcanic zone or the region of the active crustal accretion zone is confined to the trough which is roughly 100 meter wide zone and it is 10 meter deep axial depression.

So, here if I drawing this topography, so though we are getting this type of rise at the central part we are getting around a trough which is 100 meter wide and around 10 meter deep. That means, it is a very shallow and very you can say very narrow zone of a depression which is filled with magma and that the rate of spreading along this entire length of this EPR is varying from 7 to 17 centimeter per annum and this variation is also due to different rate of spreading and rate of different rate of magmatic eruption. So, all through this East pacific rise or any mid-oceanic system the rate of spreading is different and the rate of magmatic eruption is also different. Along this east specific rise there is a shallow axial truss where lava are erupted and the topography is subdued due to the larger volume of magma injected as dikes and lavas erupted along the ridge axis. So, finally, if you see this image we are getting this East Pacific rise at the fast-spreading ridge it is smooth topography smooth positive topography around 500 meter up from the surrounding ocean floor and here we have a small depression which is filled with magma and the magma erupting continuously and flowing in both way and finally, giving a smooth topography and the morphology of the intermediate and slow-spreading ridge is dramatically different that the fast-spreading ridge system.

So, here if you see the new volcanic zone is defined by 10 kilometer wide and 0.5 to 2.5 kilometer deep axial graben bounded by inward dipping normal fault that is very drastically different from the fast-spreading ridge. If you remember the fast-spreading ridges that is only 100 meter wide zone is was there and 10 meter deep zone was there, but contrast to that we have 10 kilometer wide zone and around 0.

5 to 2.5 kilometer deep zone of graben which is magma eruption is representing. The region of active faulting up to 50 kilometer wide. So, this 50 kilometer wide you can say if you compare earlier it was 10 kilometer wide and now I am getting it is 50 kilometer wide and we have different eruptive centers. If you see this magma is coming it is erupting here, it is erupting here, it is erupting here. So, we have number of eruptive centers also increasing and most of these eruptive centers if you see they are away from this ridge axis.

So, that means it is a wider zone around 50 kilometer where this magma eruption is taking place. And the mid-atlantic ridge this classic example is a slow-spreading ridge where the rate of this North Atlantic spreading is around 2 centimeter per annum and the lavas are erupted within the new volcanic zone and some cases erupted outside of this axial trough so, that we have discussed that due to this fault this magma can pass through this fault and can erupt here. So, within that 50 kilometer anywhere there is a chance of magmatic eruption. Now the slowly spreading ridges are formed by coalescence of a small volcanoes that is 1 to 2 kilometer wide and hence it is known as axial volcanic zone. Now if you see this comparison between the fast-spreading system and the slow-spreading ridge system.

Now the fast-spreading ridge system we have a crystal we have a magma chamber below and is continuously magma is being supplied and it is erupting here and we have a slow-spreading ridge system where magma is supplied and there are number of normal faults and this magmatic eruption may takes place in a wide zone rather it is confined in a narrow zone in the fast-spreading ridges. Now imagine we have a normal fault which is shallow depth and stretching to large distance and in the crustal level below this crust the asthenospheric material it is under tremendous stress. So, now once we are stretching it we are thinning the crustal material. So, once we thin this crustal material so, the metal which is lying at the asthenosphere it will try to move up. So, that's why if you see here once we have normal fault shallow depth normal faults this mantle material which are coming and erupting and near to this ridge system.

Similarly, here the mantle material is coming and erupting or it is emplacing itself along this mid-oceanic ridge system. So, at MAR or the mid-atlantic ridge development of style of median valley which is cyclic process between the phases of tectonic extension and volcanic. What is the cyclic process and this tectonic extension and volcanic construction? If you want to understand here just if you see we have this slow-spreading ridge here the magmatic supply is not frequent. Now for example, we supplied a magma for a particular time and this magma erupted and this total system is cooled down and it is solidified. Now we are stretching it because it is a rift system with the mid-oceanic system we are stretching it continuously and once we are stretching the system and another phase of magma is coming out.

So, now up to or during this last phase of magmatic supply this becomes solidified and becomes rigid. Now the next phase of magmatic eruption that has to break this solidified and rigid system and have to erupt. So, that's why this volcanoes which are erupting by breaking this solidified or the rigid system they are erupting violently compared to this fast-spreading ridges. So, that's why one phase of tectonic extension is there then magmatic supply is there.

So, now the system is solidified. Then another phase of tectonic extension so magmatic supply is there. So, then the system is cooled and solidified. Then third phase of magmatic supply is there so, it is a cyclic process. So, the tectonic extension and this volcanic reconstruction along these slow-spreading ridges they are in cyclic process occurring. However, at the fast-spreading ridges the magmatic supply is continuous.

Magma is continuously being poured out. So, there is no such phenomena of cyclicity is there. Now the normal faulting along the ridge is important for the several reasons. What are the reasons? One is the normal faulting accommodates the fraction of relative plate motion. So, this relative plate motion as we have discussed suppose for example this plate is moving from this center point in this way and now we have a normal fault. So, due to this normal faulting now you see how much distance this block is going back.

Similarly, from here this much distance is going back. So, that's why the relative plate velocity along this plate margin it is somehow it is accommodated by this normal faults. And the relative plate motion along the ridge axis however mostly accommodated by the intrusion of this sheeted dikes. Sheeted dikes layer when we will talk about this lithospheric layers if you remember we have talked we have a pillow basaltic layer and below this pillow basaltic layer we have sheeted dikes. Sheeted dikes are nothing they are the fractures which are filled with magma and this through this sheeted dikes this magma is supplied to the surface.

So, most of this relative velocity it is accommodated by this intrusion of sheeted dikes because once the sheeted dikes are intruded. So, they are expanding the system. The number of sheeted dikes we are emplacing. So, more and more we are expanding the system. So, the relative velocity once we are measuring it is adding to the system due to expansion and similarly at the normal fault we are expanding but the same time part of the block is rotating back and that's why during the calculation of this relative plate motion it normal faulting is playing major role.

And normal faulting provides pathway for the ocean water to penetrate the crust where it is heated by this hydrothermal gradient and it is comes along this ridge and forming this VHMS or the volcanogenic massive sulphide deposit. Now you see this normal faults they are providing the pathway this water is going down and after certain depth it is getting heated up and this heated water it is coming up to the surface as hydrothermal solution. And during going to this rock material and coming away from this rock material it leaches out this minerals from the system. And once this water is coming out and is interacting with the surrounding water ocean water this Eh-pH condition changes. So, it is giving rise the mineralization like that Fe, Mn, H_2S, H_2, CH_2, CO_2.

So, like this gases and some minerals are there. So, mostly the volcanogenic massive sulphide we will discuss in detail during mineralization plate tectonics this is the mostly it is found at the mid-oceanic ridge system due to this process. In addition to this steeply dipping normal faults found along this ridge axis low-angle normal faults and oceanic core complexes are also found along this ultra-slow and slow-spreading ridges. So, what does it mean? So, now you see we are stretching the system. Once we are stretching system with a low-angle normal fault as we have discussed this material which was the asthenospheric material is coming to the surface or near to the surface and exposed along the mid-oceanic ridge. So, this exposure along this mid-oceanic ridge are nothing these are called the A-magnetic accretion not the magmatic accretion.

So, that means not due to this magmatic process this material which was lying below it is coming as melt. But it is coming as a solid material which is due to depressurization this part of this material is coming to this system. So, that's why the ocean core complexes these are called the ocean core complexes they are found along the slow and ultra-slow spreading ridge and this reason being they are emplaced along or due to stretch by the shallow depth normal fault, low-angle normal fault and the segments and at segment that ends adjacent to the oceanic transform faults and that is non-transform accommodation zones. So, we have transform fault we have non-transform accommodation zone that is called fracture zones along those zones also these materials are coming out. What is this mechanism? We will talk about when we will talk about this transform plate boundary.

So, oceanic core complexes or the megamullions are formed by low-angle detachment faulting and the expose of peridotite upper mantle serpentinized shear zone and this crust. So, this type of stretching on this upper mantle this type of stretching of the lithosphere this mantle material that is coming out and they are emplaced along this mid-oceanic ridge. So, this type of low-angle detachment faulting around this ultra-slow and slow-spreading ridge they are playing major role for such amagnetic emplacement. Now, you see the diagrammatically it is represented here we have this low-angle normal faults and once we are stretching the system this mantle material they are coming out.

So, they are exposed here. So, once we are stretching the system this mantle material they are coming out because we are thinning this lithospheric system and there is magmatic emplacement and there is amagnetic emplacement. So, both magmatic and a-magmatic emplacement that is responsible for taking this material which was lying below along this mid-oceanic ridge system. An ultra-slow mid-oceanic ridge accommodates relatively plate motion by magmatic and amagmatic accretion process that we have already discussed what is magmatic? and what is amagmatic accommodation place? and due to this magmatic eruption and amagmatic emplacement both it adds or it influence the relative plate motion because finally, the system is stretching. So, once you stretching and expanding so that means, is allowing or it is adding a component in the relative plate motion. The mode of accommodation is different from the fast and the slow-spreading ridge at fast-spreading ridge the magmatic supply is more and this relative velocity of the plate is more contributed by this magmatic emplacement or this seated die emplacement.

However, at the slow and ultra-slow spreading ridge this relative velocity along this plate boundary it is contributed significantly by this amagmatic emplacement that is the emplacement of this material or the asthenospheric material due to stretching along this low dipping normal faults. Magmatic centers occur along the spreading axis punctuated by regions of magmatic accretion where this mantle peridotites are emplaced directly to the ridge axis through low-angle normal faulting and exhumation. So, this process of coming the low-lying material near to the surface that is called exhumation process. So, exhumation process is one of this important process for crustal evolution. So, this exhumation process in continent it is happening and from this beginning of this earth up to now and in this oceanic system exhumation process mostly occurring at the slow and ultra-slow spreading ridges due to the stretching by the low-angle normal faults.

Amagmatic accretion is specially prevent among the high oblique ultra-slow spreading ridge system. If you see here we have oblique spreading and ultra-slow spreading. So, these type of environment are more suitable for this amagmatic accretion and this fast-spreading ridges they are responsible for magmatic accretions. The Gakkel ridge is one of these slowest spreading ridges at this mid-oceanic ridge on this earth that is 1.

1 centimeter per annum. So, in that cases or in that places you can notice the amagmatic emplacement is more dominant. However, if you go to the east Pacific rise you will get the magmatic emplacement is more dominant. And the southwest Indian ocean ridge and the Gakkel ridge are the type localities for ultra-slow spreading ridge and which is also type areas to study the amagmatic emplacement of this mantle material. So, now the spreading rate across the western volcanic zone Iceland which is a dying ridge segment is propagating ridge system is around 0.8 centimeter per annum and the spreading rate across the Red Sea is low as 0.

7 centimeter per annum. So, these type of slow-spreading ridges systems where this amagmatic emplacement can be studied. And either it is slow-spreading ridge or fast-spreading ridge, but the common feature of this fast and ultra-fast spreading ridge are there it is the overlapping spreading center and the propagating ridge system. What is this overlapping spreading center that is called OCS and the propagating ridge that it will take another class for that but overlapping ridges occur at a number of scales, but could eventually lead to the formation of microplates and this microplates for example, like the eastern plate and Juan Fernandez plate these are the microplates and with time they are accommodated with the larger plate which is near to it. So, if you see here this is the eastern plate and this is Juan Fernandez plate it once upon a time it was a part of this plate and now it will become this plate and this become independent probably in geological future they may be accommodated by some plate either here and here depending upon the rate of spreading and the propagation of the ridge surrounding to it.

This was for this today's class. Thank you very much. We will meet in the next class.