Plate Tectonics

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Week - 03
Lecture - 15
Constructive/ Creative Plate Margin

Ok friends, welcome to this class of Plate Tectonics. So, if you remember up to the last class, we have discussed about what is lithosphere? and what is the different compositional stratigraphy of this earth? and how the plates are moving with respect to each other following the Euler's rotational pole or Euler's theorem. And how this heat variation is there along and across this continent as well as the ocean floor. So, today we are going to integrate all those knowledge and we will apply it to understand what is a creative plate margin. And there are three types of plate margin generally existing on this earth's crust. One is the creative plate margin where the term itself says the creation is there, the lithosphere is created here.

And another is the destructive plate margin where the lithosphere which is created at this plate margin is destroyed. And another is the conservative plate margin where neither creation nor destruction is there of this lithospheric plate. So in today, we will confine ourselves in creative plate margin where it creates and how it creates, what is its lithology and what is its rate of creation and what is its geology, geomorphology, geophysics and mineralogy all those things that we will discuss in this class. So, if you see here, this otherwise this creative plate margin is called constructive plate margin also or constructive plate boundary.

So the constructive or it is other word another term is used here that is called accretive plate margin, accretion that means addition. So this plate material or the lithospheric material is being added here the surface that is why it is called also accretive plate margin. So this accretive plate margins are marked by ocean ridges where new oceanic lithosphere is created. New oceanic lithosphere is created lithosphere. Lithosphere as we have discussed earlier it is the crust, the Moho and the upper part of the upper mantle. So this sandwiched layer that is called lithosphere.

So here if you see this animated figure, so this is a magma chamber this is the asthenospheric material is there and this magma it is coming and it is generating here and the rocks are formed mostly the rocks here that is of basalt. So here this is the ocean surface or the oceanic lithospheric surface and you see the basaltic magma which is erupting here and this erupted magma becomes solidified and added to this end of this already formed lithosphere. So that is why it is the accretive plate margin, constructive plate margin. So that is why this plate margin where the new lithosphere is created and they represent the longest underwater linear uplifted features on the earth's surface and can be traced by a belt of shallow focus earthquake that follows the crustal region and the transform fault which offsets this ridges at different place at certain distance. So what does it mean? It is representing the longest underwater mountain chain system.

So here if you see this topography if you are coming from this way gradually you are moving up topographically. Similarly you are going down so you are moving towards lower topographic region. So this region it is representing this mountain system. So this is underwater mountain chain and it is represented by shallow focus earthquake. So shallow focus earthquake along the crestal region this is called the crestal region this is crust and this crestal region if you see here there are number of faults are there.

There is normal faults and about this normal fault in detail we will talk in later time. So here you just remember that these crestal region or the mid-oceanic ridge they are represented by shallow focus earthquakes. So shallow focus earthquakes they are arranged around this mid-oceanic ridge system. Apart from this shallow focus earthquake along this crestal region there are certain fracture zones or transform fault which cross-cut the ridge for example this is the ridge and this is the fracture zone which is cross cutting. So these region they are also represented by shallow focus earthquake but relatively may be deeper than this crestal region.

So whatever this earthquakes they are happening along this crestal region and these may be somehow sometimes it is deeper than this. However the basic difference between these earthquake properties from here and here is that here along this crestal region the earthquakes are of normal faulting nature but this region or this transform fault or this fracture zone region the earthquakes are of strike-slip fault nature. So though shallow focus earthquakes are distributed all along the mid-oceanic ridge and this transform fault however the origin or this region for this earthquake are different and that is for normal fault along this crustal region and this strike slip faulting along this fracture zone.

And shallow focus earthquake once I say this based on this distance this focal depth distance so the earthquake has been subdivided if it is less than 70 kilometer that is called shallow focus earthquake 70 to 300 kilometer that is called intermediate and greater than 300 kilometer that is called deep focus earthquakes. And the deep focus earthquakes when we will talk about the destructive plate margin we will deal with and only the shallow focus earthquake here that is less than 70 kilometers they are confined in the crestal region as well as the fracture zones.

Now you see some of these figures of this mid-oceanic ridge system here this is mid Atlantic ridge and this is east Pacific rise and this is the global distribution of this plate boundary this is the mid-oceanic ridge systems this is the mid-oceanic ridge system and this is the subduction zone. So if you see this mid-oceanic ridge systems they are represented by depth of this earthquake is representing here. So that means this is the shallow focus earthquake that is zero to maximum 70 kilometer depth all these earthquakes they are representing the mid-oceanic ridge system. However if you are going to this subduction zone system gradually the color code is coming to this region that means these are the deep-focus earthquakes they are representing the subduction zone. Now the question arises what is mid Atlantic ridge and what is east Pacific rise ? and why these two terminologies are different ones why I am saying it is ridge and another I am saying it is a rise.

What is the difference between this or what is the geomorphological difference or topographic difference between the ridge and rise. For say you might have heard about this term quartz reef and that is coral reef. So there are geomorphological difference between reef, ridge and rise. Here you see this topography is mostly it is rugged topography very rough topography but here you see relatively smooth topography it is representing. So the ridge and rise it says once you are coming here and suddenly you are increasing in height and again falling down.

So this is a ridge. So but if you are coming here and gradually your height is increasing and gradually it is falling down so this type of topography it is called rise. So that is why this east Pacific rise is represent this type of topography that is why it is called rise and mid ocean ridge or this mid Atlantic ridge it is showing this type of topography and that is why it is called ridge. So now you see this is the global distribution of this mid Atlantic or sorry this mid-oceanic ridge system. Here this mid-oceanic ridge they are very rough as compared to this mid that is the east Pacific rise.

This one it is the mid Atlantic ridge and this is east Pacific rise and this is the transform fault if you see this is the ridge and this is the ridge segment so this is the separation and this is called the transform fault. So this ridge crest and this transform fault both are representing the shallow focus earthquakes and the total length of this spreading margin on the mid-oceanic ridge system is approximately 75000 kilometer. So all total global distribution of this mid-oceanic ridge system if you add it so you are getting 75000 kilometer. So that 75000 kilometer underwater mountain chain system that are lying just within that ocean floor. So this mid-ocean ridge are the Earth's largest volcanic system and accounting about 75 percent or more to all volcanic activities on this planet.

We have different volcanic activity source, we have deccans, we have hotspots we have subduction zone volcanism, we have deccan like volcanism but this mid-oceanic ridge volcanic system that is the volcanoes that are distributed in the mid-oceanic ridge that is representing more than 75 percent of all volcanic activities on this planet and it is the longest mountain range underwater. So if you move through this color code around the depth of this ocean so you are seeing see this is mostly it is light color that is representing shallow depth from this water level. So that means it is indicating these are the mountain chains or the uplifted area as compared to the adjacent ocean floor. So within that oceanic basaltic carpet you will find these ridge systems they are representing the accretionary or the creative plate margin which is lying in the ocean floor. The crests are commonly 2 to 3 kilometer higher than the neighboring ocean basin and it is locally showing this topography that can quite rugged and runs parallel to the crests and dominated by listric normal faults.

If you see this image here and from this ocean basin if you are moving towards this mid-oceanic ridge system gradually what you are getting a rugged topography and this rugged topography it is due to this magmatic eruption and magmatic solidification and it is the you can say the sudden solidification because the magma is erupting in a subaqueous environment getting cooled getting chilled at a quicker time and that is why you are getting this type of haphazard type of arrangement that means there is no specific way of arrangement of this magmatic system or the magmatic rock. So you are getting a very rough topography here and along this ridge crest if you see these lines they are nothing they are the representing the normal faults and in the cross-section this normal faults you will find they are the listric if you see this image these are the ridge crest and this is the central graben here and this magmatic eruption is occurring here in this zone and finally, you see these fault planes they are curved. So this curved fault plane they are called listric fault. So this mid-oceanic ridge system they are representing listric normal faults and they are accommodating this magmatic system from both sides and it is representing a central graben on this graben the magmatic activities going on. And the gross morphology of the ridges appears to be controlled by this spreading rate.

So if you see here we have three mid-oceanic ridge system representing first is the east Pacific rise then the mid Atlantic ridge then the southwest Indian ridge. So here if you see this rate of spreading here it is the most one. So this is the fastest rate of spreading is recorded here then intermediate rate of spreading then it is the slowest rate of spreading. So now you see depending upon the rate of spreading how the topography is changing here we are getting relatively smooth topography then here we are getting relatively rough topography and here we are getting most rough topography. So that means the morphology and this geomorphology the topographic expression of this mid-oceanic ridge system they are totally and totally controlled by the rate of spreading.

Similarly if you see this cross-section this is diagrammatic representation it is the fast spreading ridge. Now you see this topography is smooth it is moving up and moving down here we have a just positive area which is representing the volcanic eruption area. But now you are coming to this medium rate of spreading ridges here you see this due to normal faulting this topography is not smooth as it was here. Here we are getting a topography which is like this is faulted or something like that. So this smoothness is decreasing and once you are coming to the slow spreading ridge again this topography becomes more rough and this through of this fault becomes more so that this topography it is representing here it is showing more rugged as compared to this fast spreading ridges.

So the rate of spreading it is defining what type of topography it should appear along this mid-oceanic ridge system. Spreading rates at different point around this mid-oceanic ridge system vary widely. So if you say about one mid-oceanic ridge suppose say this Indian Ocean ridge or it is the mid Atlantic ridge or the East Pacific ridge the rate of spreading throughout this ridge is not same it is not constant. Similarly along different ridge it is also different. For example if you see here this type of diagram representation this color is indicating this is 152 millimeter per annum.

So this region it is representing the fastest rate of spreading. Similarly the same East Pacific rise is here however you see it is decreasing this color code is yellow and similarly here this is again decreasing here it is again decreasing. So that means along this mid-oceanic ridge even one ridge is there but the rate of spreading at different parts of the ridge is different. Similarly if you compare this different ridges for example this is Southwest Indian Ocean ridge and this is East Pacific rise and this is the mid Atlantic ridge you will find a drastic variation in the rate of spreading. So the rate of spreading which is defining all types of geology and geophysics, geochemistry of this mid-oceanic ridge system and here this is the diagrammatic representation of this fast spreading and slow spreading ridge you see the fast spreading ridge it is showing a relatively positive area or positive topography.

However if you see the slow spreading ridge it is showing a negative topography that means we have a central graben here and around this graben the normal faults they are showing high throw as compared to this normal faults which are presenting here. So due to this high throw and having a central graben this slow spreading ridges they are showing more rugged topography as compared to the fast spreading ridges And the axis of spreading is marked by a narrow zone of volcanic activity that is flanked by the zones of fissuring. If you see here we have a narrow zone of volcanic activity and this volcanic activities that is flanked by these features they are fractures this volcanic activities here and these fractures are in magma filled and they are representing the dikes. So that in the future classes we will talk about sheeted dyke complex and these sheeted dykes are nothing these are the fractures which are filled by magma and solidified. So this central eruption zone it is flanked both side by normal faulting and near to this mid-oceanic ridge system this normal faults or through this normal faults magma is coming out and erupted at the central ridge system.

So this is a zone rather a plane and away from this volcanic zone the topography is controlled by vertical tectonics of normal faults. So what exactly it means? So now you see here we have high temperature we have a magma chamber it is supplying magma and the rock are buoyant and the rocks they are in the shallow side. So now you see we have a shallowing up the system but once this system it is going away from this heat source gradually decreases its height because it is buoyancy decreasing. So that is why the rigidity is increasing it becomes more tight and more rigid and that is why it shrinks down and due to this shrinkage there are normal faults developed, fractures are developed and this shrinking is vertically. So that is why away from this mid-oceanic ridge system this oceanic lithosphere it shrinks vertically and that is why vertical tectonics become more dominant and that is why it develops normal faults. But beyond distance of around 10 to 25 kilometer from the axis the lithosphere becomes stable and rigid and this 10 to 25 kilometer from either side of this ridge system that is called plate boundary zone or it is called crestal accretion zone.

If you see in this figure here this 10 to 25 kilometer either side of the ridge axis here the magmatic activities are confined and away from this 10 to 25 kilometer both side that means you can say around 50 kilometers zone apart from this 50 kilometer zone this system is cooled and it shrinks down and this 50 kilometer system or this 50 kilometer width where this plate material or this magmatic material is being added to this older lithospheric system that is called crestal accretion zone or it is called plate boundary zone. Crestal accretion zone that means it is accretion is taking place at the crest so that is why it is called crestal accretion zone that means addition of material it is happening at the crestal region. So that is why it is called crestal accretion zone or it is called a plate boundary zone. So these 50 kilometer it represents the plate boundary zone that means this boundary of this plate and this side is the boundary of this plate. So these two plates suppose for example A and B they are being separated here or that you can say that is they are joining here.

So this is the plate boundary zone and this is the plate boundary zone for A and B respectively. So now you see this diagrammatic representation of the topography, the structure if you see this is the east Pacific rise and this is intermediate one this is also east Pacific rise around a different position you see it is third degree or three degree south and this is 21 degree north and this is mid Atlantic ridge 37 degree north. So these two images they are representing the first one and the intermediate spreading rate one and this is the slow spreading rate one. So now if you compare this topographic profile this topographic profile around this plate boundary zone it is smooth and here it is relatively roughness is added to that and at the slow spreading rate you see how roughness is added here and here it is representing a positive structure here near about flat without positive or negative but here we are getting a negative structure that means we have a central graben through which this magma is being erupted. Now if you remember our last few minutes back we were talking about this plate boundary zone it is represented by listric normal faulting.

So we have listric normal faults here and due to this listric normal faults the magma eruption is there and around this central axis and finally once this plate is moving away from this magmatic system or the ridge boundaries so it is shrinking down this is also it is shrinking down and once it shrinks down we are creating vertically developed normal faults or vertical normal faults due to shrinkage. So vertical fractures are developed. Now imagine we have normal faults developed here which were listric in nature and gradually once we are moving away from it we are adding normal faults or these cracks like this. So finally the two sets or different sets of fractures or different sets of faults they are cross-cutting each other and that is why making these rocks into different blocks due to fracturing. So due to this blockage or due to this block like appearance it allows this seawater to go inside and that plays a major role while we are talking about this Volcanogenic Massive Sulphide deposit mineralization along this mid-oceanic ridge.

This knowledge will help you to understand how this mid-oceanic ridge system is allowing water to pass inside and how it is coming to this magmatic level or around the high heat zone again it is coming back to the surface and it is responsible for the mineralization around this mid-oceanic ridge system. Magma eruption along the mid-oceanic ridge system occurs in a zone rather than a particular plane already we have discussed this is a zone which zones of fissuring and that zone is crestal accretion zone or it is called the plate boundary zone and many of the essential characteristics of the ridge such as rock types, topography, structure, geomorphology, metamorphism so geophysics, geochemistry everything it is controlled by one factor that is called the spreading rate and the spreading rate is the most influencing factor which is influencing all types of geology and geophysics of this mid-oceanic ridge. Now if this is so the magma is erupting and finally it becomes a part of this earlier formed crust so what is the rock type it is forming and how it is happening so. Now how to generate a magma at the mid-oceanic ridge system? In normal conditions the peridotite of mantle is not in a condition to melt.

So now the peridotite it is a high temperature rock so it will stable at the high temperature and pressure environment. In normal condition it does not melt however we have to create magma to feed along this mid-oceanic ridge. So that we have to do some permutation combination in the pressure temperature regime along this mid-oceanic ridge so that we have to melt this mantle peridotite and we have to create this magma due to this partial melting. So for that what is exactly happening here that is called decompressional melting. Decompressional melting means we are releasing the pressure we are reducing the pressure so once we are reducing the pressure what is happening the geotherm and the melting point they are cross-cutting each other.

So that is why this mantle peridotite is melting. So due to high heat flow at the ocean ridges and the oceanic islands the geothermal gradient crosses the peridotitic solidus at a depth of about 50 kilometer giving rise to this parental magma of this ocean crust. If you see here what is shown in this diagram we have a geotherm we have solidus. So here now you see at the mid-oceanic ridge system what is happening this solidus and this geotherm they are cross-cutting that means the temperature is more than the solidus. So that means this rock is forced to melt so that is why this melting occurs here.

Once melt occurs that melt will try to rise up and this we have a fracture zone that is through this fractures this melt which was generated due to the decompression it is coming out as basaltic magma and erupting at the mid-oceanic ridge system. However if you see the hotspot the hotspot it is coming from the D- double prime layer if you remember correctly it is coming from D- double prime layer it is the higher depth. So now if you see here this geotherm and the solidus so they are cross cutting at a depth of this much. So that is why this hotspot magma if you see this magma is generating from this level however at this mid-oceanic ridge the magma is generating from the shallower level. So that is why we have a carpet of basalt that is the oceanic lithosphere and this oceanic lithosphere at which is magma is derived from this level and it is continuously being derived from here.

So its composition more or less remains same. However as the magma is derived from this level definitely it is of different composition than the magma which is derived from relatively shallower level. So that is why within that carpet of basalt we are getting at hotspot whatever this rock type is different composition chemically than the surrounding basaltic system. So that is why though we have a carpet of basalt here but still the rock types we are getting from this hotspot magma or hotspot islands they are of different composition as compared to the surrounding basaltic system. Mid-oceanic ridge basalt have this composition of olivine tholeiite and it exhibit only minor variation in major element composition caused by variation of alumina and this iron content. Now if you see this tholeiitic basalt what is its characteristics you can say we are getting the ground mass usually fine-grained it is inter-granular no olivine and clinopyroxene whatever which is get it is called augite then orthopyroxene it is hypersthene and may rim of this olivine and no alkali feldspar is found and interstitial glass and quartz is common. And this phenocryst that is the olivine is rare written on zone and may be partially reserved and show reaction rims of orthopyroxene and orthopyroxene is uncommon and early plagioclase is common, clinopyroxene is pale brown augite.

So they may contain phenocryst of olivine or plagioclase or rarely of clinopyroxene. So this is the characteristics of the olivine tholeiite which is erupted at the mid-oceanic ridge system and we are getting this basalt olivine tholeiite and it is falling in this field. So this is the characteristics or this magmatic characteristics of this mid-oceanic ridge system. Now the analysis of the trace element reveals that much of this compositional variation in the basalt is explicable in the terms of high level of fractionation. So it is the high level of fractionation which is occurring here in the mid-oceanic ridge basalt and the frequent presence of a xenocryst of deeper level origin indicate that rocks only spent very short time at a high level magma chamber. So we have frequent presence of a deeper level xenocryst that means this deeper level material are coming out as xenocryst and that is why whenever this magma is erupting from the shallower level but it is believed that magma is spending less time at the shallower level and most part it spend at the deeper level that is why we have deeper level xenocryst they are common in the tholeiitic basalts And sampling of the east pacific rise revealed a series of basalt that are diverse in the major and trace element chemistry.

And this compositional variation has been interpreted in terms of a series of magmatic injection centers along the crest as if you remember we have magma chambers we have different magma chambers at a different depth along the mid-oceanic ridge and the magma is spending different time at different magma chambers and once they are coming to the surface there may be a chance of repeated intermingling, intermixing of this magma and finally they are erupting together. So that is why this type of compositional variation mineralogical variation is found along this mid-oceanic ridge basalt. And differences in the depth and extent of partial melting and the degree of fractionation show a regular pattern of chemical variations and the ridge crest. So that is why this difference in the depth and extent of a partial melting how much partial melting is taking place of the mantle peridotite and the degree of fractionation how much fractionated the magma is that also defining what type of chemical composition the magma should have. As the primary melt appears to be identical the differences are not related to the process in the upper mantle but believed to reflect the fractionation environment that is after the partial melting.

So these are these changes, these chemical changes what this tholeiitic basalt or this mid-oceanic ridge basalt of different ridges and within a ridges at different segment how they are varying with different regions which are sited here. Now the lithology and chemistry of basalt generated mid oceanic ridge show a simple correlation with the spreading rate.

Again here this spreading rate is playing the role as few minutes back we were talking this spreading rate which is the most you can say the culprit which is controlling all this geology and geochemistry geomorphology geophysics of this mid-oceanic ridge system. Slow-spreading systems are characterized by complex magma chamber with widespread accumulation of a calcic plagioclase and the presence of phenocryst-liquid reactions morphologies and pyroxene dominated fractionation extract. So this slow spreading ridge systems they are showing these characteristics.

Similarly fast spreading ridge they are showing different characteristics compared to that and even if the fast spreading ridge among different segments they are showing different characteristics. And fast spreading ridges however suggest low pressure basalt fractionation tend to iron-rich composition with little plagioclase accumulation or crystal liquid reactions. And basalt from very slow and ultra-slow spreading ridges have lower sodium and high iron content than typical mid-oceanic ridge basalt reflecting similar degree of mantel melting and melting at greater depth. So that means I want to say we have fast spreading ridge we have different magmatic composition we have slow spreading ridge we have different magmatic composition and we have ultra-slow spreading ridge we have different magmatic composition. And this variation in the magmatic composition is nothing due to the degree of fractionation degree of intermixing how much time it is spending at the shallow level magma chamber how much time it is spending at the deeper level and interacting with the surrounding.

All those that defining the magmatic properties erupted at the mid-oceanic ridge system. Different thermal regimes or varying mantle compositions along the length of these ridge or lateral migration of melts in the upper mantle are some of these possibilities so that the difference in the mid-oceanic ridge petrology is here. So, this difference in the mid-oceanic ridge basalt petrology is nothing if the differential thermal regimes and this varying mental composition. And varying length of time that is spent along these different levels of the magma chamber melting and different degree of partial melting of this material at the surrounding. All those that defining what should be the magmatic composition arriving here at the mid-oceanic ridge. So, thank you very much we will meet in the next class.