Plate Tectonics

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Week - 04
Lecture - 18
Age-Depth Relationship around the Mid-Oceanic Ridge

Okay friends, welcome to this class of plate tectonics. And in today's class we will talk about this age-depth relationship around the mid-oceanic ridge ridge or MOR. So, as we know this mid-oceanic ridge is where these two plates diverges and mostly it is in the ocean floor. Here the new material being added at this plate boundary. So, once it is added here, this is solidified and welded at this part of this boundary zone and becomes solidified. So, it is the boundary where the oceanic plates separate from one another and thus it lie above the upwelling region of mantle circulation.

So, here we are the upwelling region that means this asthenospheric material the mantle material that upwells. So, upwell means we are moving up and mostly at the mantle system it is representing high heat zone. Similarly, downwell where this plate is subducting and in the mantle system it is represented by relatively cool zone as compared to this mid-oceanic ridge system. So, the upwelling mantle undergoes decompressional partial melting that we have already discussed in the last class.

This depressurizes the system and that's why the partial melting takes place and it is the magma which is generated they are less viscous and less dense than the surrounding solid and it is segregated and this form the solid mantle and it is buoyantly rise to the surface where it forms new principally basaltic layer So, we know this is the basaltic layer and these are the pillow basalt they are formed and mostly at the slow-spreading ridges the dikes or the plumbing system that is lying below this oceanic crust and at the fast-spreading ridges this dikes are exposed to the surface and this magmatic supply is very high. So, that's why we are getting the pillow basalt very high density or you can say highly disturbed pillow basalt here as compared to the slow-spreading ridges because there the magmatic supply is very less and one pulse of magmatic supply is there the pillow basalt are formed they are solidified. Then the next set of magmatic supply once it is coming. So, it is not able to disturb the earlier one because they are already solidified. However in the fast-spreading ridges as the magmatic supply frequency is very fast.

So, the first phase of magmatic supply this pillow basalt is formed they may not be solidified and then the next part of this oceanic system or this magmatic supply occurs so, it disturbs the earlier formed pillow basalt and some of them are totally disturbed and destroyed and remains as that is the fragments within the newer one. So, here if we are concentrating our self at the mid-oceanic ridge system and the surrounding so, what we are getting that the near to this ocean ridge as the rock contraction takes place. So, cracks are developed and due to this development of crack if you see this water is percolating down and this cool water which is percolating down at the depth they are heat up and finally they are coming to the surface as hot water as hydrothermal fluid. And this hydrothermal fluid it is releasing heat from the sub-surface to the surface. So, that's why if you take a temperature profile here you will get a high temperature in this zone and gradually if you are going away from this mid-oceanic ridge where the circulating system is seized.

So, here the temperature will be different. So, that means, at the mid-oceanic ridge system where this temperature release by this conduction as well as this hydrothermal circulation is there we are experiencing high heat-flow. So, that's why the cracks are predicted to advance rapidly and cool a large volume of rock in relatively shorter time. So, that intense localized source of heat are produced at the surface. So, like we are working in the air conditioner.

So, it is collecting heat from this room and it is releasing to the air. So, that's why we are getting high-heat here and once we are moving away from the system the heat is decreasing and the crust and the mantle cool at the surface by thermal conduction as well as hydrothermal circulation which generate a strong thermal boundary which is called the lithosphere. So, this asthenosphere and the lithosphere they are differentiated by this heat flow. In the asthenosphere we have high-heat flow and the lithosphere we have low-heat flow. So, that's why the asthenosphere and this lithospheric boundary that can be defined based on the heat flow system.

But at this place the heat flow or the heat loss it is by the conduction process and the hydrothermal circulation process. And once we are moving away from this mid-oceanic system this conduction process alone works in cooling this lithosphere. This hydrothermal circulation gradually reduces. So, that's why it is a short lived system. So, it is just active near to the ridge or just few kilometer away from the ridge, but once you are moving away from this active heat source.

So, this hydrothermal circulation the effect of this hydrothermal circulation is reduced. So, why it is reduced? Because if you see if you remember our earlier class we are talking about the mid-oceanic system at the layer 1 that is the sediment if it is see here this layer 1 gradually the thickness is increasing towards the subduction zone or towards this continent at the mid-oceanic ridge the layer 1 or the sediment that is very negligible or it is may not be there. So, that's why once we are developing cracks are here the cracks are open. So, they are allowing this water to percolate down, but once you are moving from this mid-oceanic system and this sedimentation becomes active or it is more pronounced these cracks are closed. So, the cracks earlier it was here this is filled with sediments.

Apart from that once you are coming from this mid-oceanic system these hydrothermal fluids they cool down and finally, some minerals they precipitate within that cracks so, in both way due to sedimentation effect and due to this mineralization we are clogging we are closing this cracks So, that's why once we are coming away from this mid-oceanic ridge the effect of cracks that is the hydrothermal circulation reduces. And this process by which this hydrothermal system is reduces and the other process that is the conduction process become dominant. So, here we have both conduction process as well as hydrothermal circulation process for cooling this lower part of this mantle or the lithosphere but once this cracks are clogged and closed only the conduction process is there. So, that's why the heat production here will be high as you come down the heat production will be less. And this clogging of this cracks that is the sealing of the cracks that is called sealing age.

So, the time taken for this closing of this cracks that is called sealing age that means, this cracks are sealed. So, this sealing age that depends upon the sedimentation rate. So, if you remember we are talking about the rate of sedimentation in the Pacific it is less as compared to the Atlantic. So, this sealing age therefore, in the Atlantic it is much less as compared to this sealing age of this Pacific. So, this average age of sealing of cracks it is 60 ma 60 million years but that depends upon the rate of sedimentation that depends upon the rate of spreading at high rate of spreading it may be less and is less rate of spreading may be high so, that's why the sealing age depends upon the rate of spreading as well as the rate of sedimentation.

Here if you see the rate of sedimentation in the global oceans they are presented and the scale is given here and the high rate of sedimentation if you see we are finding here and here and here. And along this mid-ocean ridge for example, if you see the south-west of this sorry! the south east of the Indian ocean ridge here the rate of sedimentation is high as compared to the other part. Similarly at this part of the Pacific here this rate of sedimentation is high as compared to other part. So, that's why sealing age will be different in this region as compared to this part. Similarly here if you see this rate of sedimentation is high as compared to other part of this Atlantic ridge.

So, that's why the rate of sedimentation and the rate of spreading that defining the sealing age and on average it is 60 Ma, but it is not same throughout the globe. So, ultimately once this conduction system is dominating by the close of this cracks. So, the heat production or this heat distribution from this mid-ocean ridge system to away from the mid-ocean ridge system is reducing. So, if you see it here the long-term average sedimentation rate in the world's ocean it is given here and that it defining the sealing age what would be the sealing age at different part of this ocean. Now if this conduction cooling is there and finally, what is the effect of this cooling? Gradually the density of this lithosphere is increasing and it is contracting so, that the density is increasing and the sedimentation is just above it.

So, it is thickness is increasing. So, as the oceanic crust move away from ridge axis is cooled by the conduction cooling alone and the oceanic lithosphere formed by cooling and the crust and the upper mantle and the thickness is between 50 to 140 kilometer. And this is represented by a simplified equation

$$h \cong 2\sqrt{kt}$$

h which is the thickness of the lithosphere equal to 2 root over k and t. This t is the time the age of the lithosphere in million years and k is the thermal diffusibility. So, this age t can be approximated by this two factors one is the distance from the mid-oceanic ridge and this relative rate of plate motion.

So, by these two factors we can calculate the t. So, this cooling has two effect what is the first one is the lithosphere contracts and increases its density away from the ridge So, once we are here near to the heat source these rocks are in the buoyant condition and the rock are in the expanded condition. So, once you are coming from this heat source the rocks are contracting. So, the density is increasing and second thing that because the lithosphere-asthenosphere boundary is controlled by temperature the cooling causes the lithosphere to increase the thickness away from this mid-oceanic ridge. So, two effect first is the density increases second thing is that the thickness is increasing.

So, as the lithosphere thickens by additional cooling it becomes denser and this denser has this effect on this lower lying asthenosphere. So, it subsides deeper to the underlying ductile asthenosphere. So, if you see here we have lithosphere and somewhere if you see it is just going like this which is it is subsiding below the asthenosphere. So, this aging process causes the oceans to double the depth towards the continental margin and towards the subduction zone. If you see here once we are suppose this is the water level and gradually we are at the mid-oceanic ridge.

So, we have to go to less depth to reach the oceanic lithosphere and here we have to move this much distance to move the oceanic lithosphere. That's why the water depth it is increasing towards the continent and towards the subduction zone. However, at the mid-oceanic ridge the water depth is less. So, the thickness of the oceanic lithosphere is a function of its age. At the ridge axis lithosphere thickens it approximately 2 kilometer.

However, if you are moving away from it, its thickness is increasing and it may reach about to 40 to 100 kilometer. And here this is the diagrammatic representation how this lithosphere is more dense than the asthenosphere. So, if it is happening then it is how behaving within this asthenospheric system. You see this is the asthenosphere and the lithosphere once it is thickens its density increases and due to this high density. So, it is just pushing inside the asthenospheric system.

So, similar effect you can see here in the sedimentary sequence where we have this mud and we have the sand. So, sands they are just going down in the syn-sedimentary deformation structures. So, this is the boundary that can be seen. So, this is analogous to that due to high density it part of this lithosphere it is pushing inside this asthenosphere. So, this is important factor for this global tectonics because after 10 million years the oceanic lithosphere is denser than the asthenospheric mantle and can therefore, subduct into this mantle.

So, here we have three different models this is proposed by this Richards 2020. So, the first one if you see this is called half half-space cooling model. See half-space cooling model says this ZC is the crustal thickness. So, we have this crustal thickness this was the crustal thickness of this much. Then Z are the zero ridge depth here this is the zero ridge depth.

So, that means, the mid-oceanic ridge we are at the mid-oceanic ridge and Wp is the subsidence at a function of age. So, this was the system this much is subsiding. So, had it been not subsided. So, probably this would be the thickness, but once we are moving away from this mid-oceanic system with age this is the age is increasing. So, how this lithospheric system is subsiding from this top and Ta (zp) this it is called half plate model and the Zp is the plate thickness Ta(zp) it is the adiabatic temperature and C is the boundary layer model.

So, these are the different models that is proposed for understanding this lithosphere-asthenosphere boundary condition with temperature and pressure and how this lithosphere it is behaving above the asthenosphere at a high temperature and at high pressure. So, this cooling and contraction of this lithosphere cause a progressive increase in a depth to the top of this lithosphere away from the ridge accompanied by a decrease in the heat flow. So, we have three ridge systems the southwest Indian ocean ridge, the Atlantic ridge and the Pacific rise and we have depth in meter it is increasing and this is the 0 that is the ridge crest and both way we are moving away from the ridge crest now if you imagine suppose we are at the 1000 kilometer away from all the ridges from the ridge crest. So, within that 1000 kilometer so, if you see this southwest Indian ocean ridge it is the age it is 60 Ma and here it is 10 a. So, in between it will be somewhat different.

Similarly if you see here this water depth at the 1000 meter away from this mid-oceanic ridge. So, we are at this depth and at the same time at the Atlantic ridge we are at this depth and at the east Pacific rise we are at this depth. So, that means, this rate of spreading and the rate of cooling that decides this how much depth it would be from this mid-oceanic ridge with time. So, the main constraints of these models are the observed depth that is correct for sediment loading and the heat flux at the ocean floor as a function of age. Here this corrected for ocean sediment loading because once we are moving away from the mid-ocean ridge the sedimentation rate is increasing and the sedimentation rate once it is increasing so, it is putting downward pressure.

So, it is bending the system it is suppressing the system to downward. So, we have to reduce this sedimentation effect to calculate here directly that how much actually the heat related contraction is taking place rather the sediment related. So, this gentleman Parsons and Sclater in 1977 they determined the nature of this age-depth relationship of the oceanic lithosphere and suggested that the depth d in meter is related to age t in million years by this formula and this is called the half-space model. So, this model suggests the lithosphere cools indefinitely, but it is not possible because once this lithosphere is cooling indefinitely.

So, there would be no plate tectonics. So, somewhere we have to heat it up. So, that the convection current should start it is that should be subduction. So, that's why the plate tectonics will continue. So, that means, though this model was proposed in the first model but it had some error so, this relationship only holds for the oceanic lithosphere younger than 70 million years. So, this is called the space model that we have discussed earlier this one.

Then this work in 1978 that is suggested a model in which this cooling layer comprises 2 units rather than 1 unit where it was explained in the half-space model. So, the 2 units says the upper unit is rigid and the lower unit that is in the contact with the asthenosphere. So, in this model the upper unit which heat moves by conduction process because it is a rigid system and this heat flow is due to the conduction process and it is mechanically rigid system and the lower unit which is a viscous thermal boundary layer with the asthenosphere. So, that means, it is directly contact with the asthenosphere and as the lithosphere moves away from this spreading center depth of the both unit they are increasing. So, once they are increasing so, part of this asthenosphere.

So, it interact with the lower part of the lithosphere or the lower unit and it convection starts. And once the convection starts so, it is providing heat to the upper layer to the rigid layer so, that its thickness can no more be increased. So, here the lower unit eventually thickens to a point where it becomes unstable and start to convect this brings extra heat to the base of the upper layer and it is prevents its further thickening. So, this model suggest the age-depth relationship for the oceanic lithosphere older than 70 Ma is given by this formula.

$$d = 6400 - 3200 \exp^{(-t/62.8)}$$

So, this is called plate model. So, earlier it was called space model and it is called plate model. So, this model suggest the lithosphere ultimately attains an equilibrium situation determined by the temperature at the lithosphere-asthenosphere boundary where the convection starts so, this convection starting it is resulting the plate to alive the plate motion is there. So, this half-space model and the half-plate model and apart from that there was another model which was proposed. So, this model it is can called this GDH 1 model or it is called the depth heat flow measurement based on that is called global depth and heat flow model. So, global depth and heat flow model so, this was proposed in 1992.

So, a large global data set was used to calculate or to reach this equation. What is that? So, here the depth and heat flow measurement derived model that is called global depth and heat flow model that gave the best fit to the observation. What is the best fit for observation? So, these two models or these two equations is one is valid for this less than 20 Ma lithosphere and another is valid for the larger than 20 Ma lithosphere.

$d = 2600 - 365t^{1/2}$

$d = 5650 - 2473 \exp^{(-t/36)}$

So, d or depth equal to this one it is valid for less than 20 Ma and depth is this one it is for greater than 20 Ma. So, that means, here if you see this is the plate model and this is the space model here we are concentrating the lithosphere as a one unit.

However, here we are considering the lithosphere as two different unit. So, here we have a mantle that is the convection is going on and this convection it is providing heat to the system and due to this heat supply this start convecting and once convection starts at the lower level it provides heat to the upper part. So, once the heat is produced or heat is supplied from the lower boundary it will not able to thicken further, so that's why it will start behaving as a plastic material and that's why this lower part and partly it is going inside into the mantle system or the asthenospheric system so, that is why here this convection starts again. So, the crustal parameters in determining the best fit to the data is limiting plate thickness and the temperature at the base of the lithospheric plate. So, in the GDH1 model these have value of 95 kilometer and 1450 degree Celsius respectively.

So, this is the plate thickness it is around 95 kilometer and this temperature it is around 1450 degree Celsius. Now if you see this observed and this calculated value here there are three one is GDH1 that is the solid line then PSM model this is the dotted line and HS model this is it right so, the observed and the calculated one if you see these are fitting best with the GDH model. Similarly, in this graph also that means, it is the thickness versus this observation and this is the heat flow versus the observation so, with the age. So, now if you see the age and heat flow it is best fitting with the GDH model. Similarly, the age versus thickness it is best fitting with the GDH model.

So, though different models have been proposed so far, but this GDH model is the best one and here it is 95 kilometer the crustal thickness of the lithospheric thickness is taken and 1450 degree Celsius the temperature is taken. So, this model it best fit to the global observation and the present day this is the different ocean basins. So, thank you very much and we will meet in the next class.